East Greenland 72-74° N Inland to Coast Thermo-tectonic Evolution

Jensen, Peter K.; Hansen, Kirsten

1. Igneous rocks and processes

1.1 Hotspots and intraplate magmas: mantle sources, magmatic processes and metasomatism.

ORAL

The role of sublithospheric mantle sources in continental flood basalt magmatism: lessons learned from the Karoo LIP

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The role of sublithospheric mantle sources is elusive in continental flood basalt (CFB) provinces. This is because on their way to the surface of the Earth, the parental magmas of CFBs interact with thick continental lithosphere and may lose their primary geochemical characteristics. Several studies have also suggested that the predominant mantle sources of continental flood basalts are within the continental lithosphere. Our studies in the Antarctic and, more recently, African parts of the Early Jurassic Karoo LIP over the past 25 years have revealed the existence of several sublithospheric mantle-derived magma types. Their sources range from depleted upper mantle (DM) to different kinds of enriched mantle (EM), and possibly even to ancient primordial plume sources originating from the core-mantle boundary. Whereas the recognized EM sources seem to be anomalous and had minor contributions to Karoo magmatism, the DM and primordial-like sources may have been very important in the generation of voluminous Karoo magmas. Energy-constrained assimilation–fractional crystallization modeling has revealed that only a few percent of assimilation can shift the CFB trace element and radiogenic isotope signatures close to those of lithospheric wallrock materials. We suggest that, with the possible exception of very strongly enriched magma types, the continental lithosphere has in many cases acted as a 'pepper mill', only spicing up CFB magmas otherwise predominantly generated in the sublithospheric mantle.

ORAL

Magmatism associated with Gondwanaland rifting: Evidence from Iraq Zagros Suture Zone

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The opening of the southern basin of the Neo-Tethys as a result of the breakup of Gondwana during Late Triassic was accompanied by the eruption of flood basalts. This process led to the fragmentation of continental lithosphere and rifting of these fragments from the northern margin of Gondwana and created deep trench grabens which were subsequently filled by radiolarite deposits. Such events are well documented in southern Turkey, northwestern Syria and southwestern Cyprus. Fragments related to these activities also exist as thrust nappes in the Iraqi Zagros Suture Zone(Avroman platform limestone and Qulqula radiolarite)Such nappes also occur systematically beneath the obducted ophiolites from Greece to Oman. In the Iraqi Zagros Suture Zone the Late Triassic Avroman nappe was thrusted over the Early Cretaceous Qulqula radiolarite and both were thrusted over the Late Cretaceous ophiolites. The Avroman volcanics are lava flows consisting of olivine-basalts, diabases, trachytes and tuffs. Previous K-Ar dating of a diabase rock gave an age of 220 Ma ± 20. Geochemical analysis of these rocks indicates that the alkali olivine basalts are strongly enriched in light rare earth elements without Eu anomalies. Trace element data for the

most primitive mafic igneous rock samples suggest that the tholeiitic basalts are derived from an enriched mantle source with OIB signature formed within plate activity. This alkaline magmatism may have taken place as continental flood basalts erupted during rifting of Gondwana at Norian with evidences of mantle plume interaction in the early rifting phase related to the opening of the Neo-Tethys.

ORAL

Tracing of mantle heterogeneity in Karoo flood basalts using Nb-Zr-Ti-Y ratios

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The study of mantle sources of continental flood basalt provinces is often compromised by crustal contamination overprinting of the incompatible element and isotopic ratios of the predominant rock types. Geochemical tracers which are unaffected by contamination help to: (1) identify co-genetic types of flood basalts, (2) establish parent-daughter relationships between flood basalt types and rare uncontaminated picrites, and (3) constrain mantle source heterogeneity even when picrite types are unknown. Identification of such tracers has turned out to be difficult, however.

We have examined variations of Nb/Y, Nb/Zr, and Nb/Ti at given Zr/Y (quantified using ΔNb_Y, ΔNb_{Zr} and ΔNb_{Ti}) in geochemically diverse Karoo flood basalts. Importantly, the delta-Nb values are only mildly affected by melting, crystallisation, and contamination processes and can be used as tracers of mantle source heterogeneity.

In the Karoo province, the variations in ΔNb_Y, ΔNb_{Zr}, and ΔNb_{Ti} and initial Nd and Sr isotopic ratios call for at least three mantle source end-members: Two have Nb-depleted compositions relative to primitive mantle, but markedly different depleted and enriched isotopic compositions. The third end-member is Nb-undepleted and shows isotopic affinity to bulk silicate Earth. Three Karoo picrite suites can be associated with these end-members, whereas other picrites probably represent subordinate mantle components.

In the Karoo province, the delta-Nb tracers pave the way for: (1) provincial scale mapping of mantle heterogeneity using variably contaminated flood basalts and (2) identification of picrites best suited for geochemical characterisation of the major mantle components.

ORAL

Assessing primary vs. secondary geochemical fingerprints of Icelandic basalts using high-Fo# olivine crystals

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Oxygen isotope ratios ($d^{18}O$) of Icelandic basalts are notably distinct from MORB-sourced basalts. Two prevailing hypotheses have been put forward to account for this: interaction with low-$d^{18}O$ crust or mantle heterogeneity [1]. High-Fo# olivine crystals are widely used as a proxy for primary melt composition prior to crustal modification [2]. Therefore, their geochemical characteristics can be useful to determine the source of low-$d^{18}O$ in Icelandic basalts. We couple in-situ $d^{18}O$ of high-Fo# (>80) olivine crystals from the neovolcanic rift- and flank zones as well as older Tertiary units with major and trace elements using SIMS, EMPA and LA ICPMS as tools to identify primary vs. secondary controls

on some notable geochemical characteristics of Icelandic basalts.

The olivine crystals show limited intra-grain variability but, collectively, they display a variation in $d^{18}O_{(Ol)}$ of >3 ‰ across Iceland, with most values falling below the expected depleted mantle-value (~5.1 ±0.2‰ [3]). The lowest $d^{18}O_{(Ol)}$ (+2.77 ‰), is measured in crystals from central Iceland, close to the inferred plume head [4]. Trace element ratios of these olivine crystals (e.g., Mn/Fe) suggest a peridotitic mantle source, implying a shallow (likely crustal) origin of the low $d^{18}O_{(Ol)}$. In contrast, crystals from the South Iceland Volcanic Zone display trace element ratios indicative of greater amount of pyroxenite in their source region while their $d^{18}O_{(Ol)}$ vary significantly (from +3.45 to +4.98 ‰). These results, together with previously published $^{3}He/^{4}He$ values for these same samples [4], imply a regional shift in the dominating mantle lithology and plumbing conditions beneath Iceland.

ORAL

Luenha picrites reveal a primitive mantle type plume source in the Karoo large igneous province?

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Two distinctive picrite suites have been previously considered to represent important parental magma types in the Karoo large igneous province: (1) the Mwenezi picrites indicate an enriched mantle source (initial εNd ca. -10) of lithospheric origin for enriched high-Ti basalts, whereas (2) the Vestfjella ferropicrites reveal a depleted convective upper mantle source (εNd +8) for low-Ti basalts. Both picrite suites are characterised by negative ΔNb values (-0.9 to -0.1) indicative of relative Nb-depletion. Our geochemical data on recently discovered picritic lavas in the Luenha river area, Central Mozambique, reveal a third significant mantle source for Karoo basalts.

The Luenha picrites differ from other Karoo picrites based on their high positive ΔNb values (+0.5 to +0.6), low Ti contents, and low Zr/Y. Variable initial $^{87}Sr/^{86}Sr$ and incompatible trace element ratios likely result from mild crustal contamination. A single picrite sample lacks indications of contamination and indicates a mantle source with $^{87}Sr/^{86}Sr$ of 0.7041 and εNd of +2 and an overall geochemical affinity to a primitive or mildly depleted mantle. We maintain that this magma source may represent the previously unknown mantle component which is required to explain the high abundance of Karoo low-Ti basalts with positive ΔNb. Bearing in mind that several large igneous provinces (e.g. Ontong Java) have been recently associated with melting of geochemically primitive mantle type plume heads, the Luenha picrites may provide a unique geochemical insight into a major plume source previously inferred from geophysical studies of the Karoo province.

ORAL

The important distinction between ancient HIMU and young HIMU-like sources in intraplate magmatism

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Continental intraplate magmas with isotopic affinities similar to HIMU are identified worldwide. Involvement of an asthenospheric HIMU or HIMU-like source is contested because the characteristic radiogenic Pb compositions at unradiogenic Sr and moderate Nd and Hf compositions can also result from in-situ ingrowth in metasomatised lithospheric mantle. Sr-Nd-Pb-Hf isotopic composition of late

Cretaceous lamprophyre dikes from Westland, New Zealand provide new insight into the formation of a HIMU-like alkaline intraplate magmatic province under the Zealandia microcontinent and former contiguous regions of Gondwana. The oldest (102-100 Ma) calc-alkaline lamprophyres are compositionally similar to the preceding arc-magmatism and represent melts originating from subduction-modified lithosphere. From ~98 Ma, alkaline intraplate magmatism emerged throughout Zealandia that would remain active up to the present day. We break with the classical grouping of this magmatism into a single suite and show that distinct ancient and young enriched sources controlled melt isotopic compositions. The distribution of these sources in the Cretaceous was strongly coupled to lithosphere terrane structure and emphasizes the influence of enriched metasomes in the lithospheric mantle as a melt source.

POSTER

Tracing pyroxenite in the mantle source at Heard Island in the Indian Ocean

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Heard Island hosts the largest active volcano of the Kerguelen Oceanic Plateau, where whole rock geochemistry suggests an important contribution from recycled ocean crust. We present minor element compositions for olivine from Heard Island, as a tracer of the initial magma, in order to investigate the connection between source lithology and mantle source components.

Olivine crystals in the lavas from Heard Island have 72.5 to 87.5 Fo mol% and form two groups distinguished by Ni and Mn compositions. The main group of olivine crystals contain Ni* of 540 to 870 (Ni*=Ni x FeO/MgO; n = 14 of 17 samples) and Mn* of 90 to 110 (Mn* = Mn/FeO), which are similar to the global array. The second group has high Ni* of 1060 to 1820 and high Mn* of 150 to 175(n=3 of 17 samples), elevated in Ni* and Mn*with respect to the global array. The olivine mineral chemistry is independent of whole rock trace element and isotope geochemistry that reflects mixing between the mantle source components.

Olivine crystals from Heard Island that plot along the global array are consistent with derivation from a pyroxenite rich source (60 to 90%). Furthermore, a pyroxenite rich source lithology is attributed to all geochemical end members. However, the wide range implies incomplete hybridisation or heterogeneous supply of eclogite in the mantle below Heard Island.

The olivine crystals that display elevated Ni* and Mn* potentially reflect melting of the oceanic lithospheric mantle, which has previously been metasomatised by melts generated by the mantle plume.

POSTER

Hydrothermal alteration of the ultramafic rocks at the Kemi intrusion

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The Kemi chromite deposit is located close to the town of Tornio (northern Finland). The mineralization is hosted within the mafic-ultramafic Kemi intrusion that is part of the Tornio – Näränkäväärä belt. This belt consist of about 20 individual intrusive igneous complexes within the Fennoscandian Shield that have been emplaced at 2.4 to 2.5 Ga. The Kemi intrusion has a lenticular shape and is about 15 km long and 2 km wide in the middle section (Alapieti et al., 1989). The main chromite units are located in the basal part of the intrusion and have an average thickness of 40 m, but vary from a few meters to

160m. The chromitite units are enveloped and intercalated with variably altered peridotite and bronzites.

Hydrothermal alteration has pervasively affected the ultramafic sequence mainly in the lower and upper segments, leaving the middle partly unaltered (Alapieti et al., 1989). These lithologies can still be identified due to the preservation of their primary textures. Bronzites and peridotites surrounding the chromitite layers have been altered to serpentine, talc, tremolite, chlorite and carbonates (Gronhölm, 1994). Alteration has also affected chromite grain composition and texture, finding some grains with inclusions of altered silicate minerals. The occurrence of the mentioned alteration assemblages requires the influx of fluids rich in SiO_{2aq} (Paulick et al., 2006). The study of the hydrothermal alteration permits interpretation of its origin and makes it possible to establish spatial distribution of the altered assemblage as well as associations with the ore and possible exploration vectors.

POSTER

Birthing an ocean island rift: mantle fingers or lateral flow?

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Rift zones play a key role in modulating the growth and destruction of ocean islands. However, it is not always clear whether magma feeds into rifts from the mantle or from beneath the island's central complex before being diverted into rift zones. Seismic monitoring of the 2011- 2012 eruption on El Hierro showed that it was fed by magma that underwent lateral transport at the base of the ocean crust before final ascent. If this is generally true for Canary Island rifts, then there may be large implications for rift zone magma evolution and the preservation (or crustal modification) of mantle isotope signatures. To test this concept, we carried out mineral-melt thermobarometric modelling on dykes of the Miocene-Pliocene Northeast Rift Zone (NERZ) on Tenerife, which is a superbly exposed example of a feeder system to a major ocean island volcanic rift. Our initial results point to sub-MOHO level crystallization of feldspar and pyroxene, in stark contrast to the latest rift eruption on El Hierro. Our preliminary data thus support a model of rift growth on Tenerife through injection of mantle-derived hot fingers. This conclusion is in line with anisotropy of magnetic susceptibility (AMS) data, which indicate non-unidirectional emplacement of magma along the rift. Moreover, the mantle finger model is consistent with plume-like (HIMU) radiogenic isotope ratios preserved in many of the NERZ dykes. Ocean island rift formation thus appears to differ between islands in the Canary archipelago, which must be taken into consideration when assessing mantle versus crustal geochemical indices.

POSTER

Geochemical characteristics of an enriched Icelandic tholeiitic magma suite: the case of the Kverkfjöll volcanic system

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The active Kverkfjöll central volcano and its associated fissure swarm are situated at the northern margin of the Vatnajökull glacier, Iceland. The volcanic system is characterized by subglacial pillow basalt ridges and post-glacial lava flows, erupted on c. 35 km thick crust at the flank of the Northern Rift Zone (NRZ). Published petrochemical data from Kverkfjöll are very limited, in contrast to its neighboring volcanoes Bárdarbunga, Grímsvötn and Askja. We present preliminary geochemical and Hf-Pb isotope data

largely acquired from subglacial pillow rim glasses, focusing further on their dissolved volatile contents (EPMA, FTIR) as well as trace elements (LA-ICP-MS).

The Kverkfjöll basalts are noticeably enriched in FeO (12-16 wt.%), with relatively uniform compositions (MgO = 4-8 wt.%) compared to other tholeiitic magma suites in Iceland. They are anomalously enriched in incompatible elements, closely resembling transitional and alkali basalts from flank zone areas in Iceland. Such enrichments are also evident in the dissolved volatile contents of the Kverkfjöll glasses, which are some of the highest in Icelandic basalts (e.g. Cl = 350 ppm, H2O = 0.9 wt.%). Moreover, the Pb-Pb and Pb-Hf isotopic signatures of Kverkfjöll falls in between the well-defined trend of the NRZ basalts and the EM1-like compositions of the flank volcano Öræfajökull, unique among Icelandic basalts [1].

The aim of this in-progress study is to address if the Kverkfjöll basalts sample a distinct, previously unrecognized component of the Iceland mantle, or if their volatile enrichment and atypical isotopic signatures can be explained by other means.

POSTER

Alkaline OIBs derived by pyroxenite-melting of low-T mantle

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High precision microprobe and laser ablation analyses of forsteritic olivine phenocrysts from the alkaline EM1-type ocean islands of Gough and Tristan have high ratios of Fe/Mn, Zn/Fe, Ga/Sc and Ni*FeO/MgO suggesting a large pyroxenite melt component in the magmas. Crystallization temperatures calculated for the magmas range between 1140 and 1227°C and overlap the temperatures of MORBs confirming that the melts are derived from the asthenosphere. Applying correction along the olivine-liquidus slope to sub-lithospheric pressures suggests a mantle segregation temperature of max. ~1300-1350°C which overlaps the range estimated for MORB. Therefore the high Fe/Mn and Ni*FeO/MgO cannot have been caused by melting of very high temperature peridotitic mantle at large depths as has been suggested for some plume basalts by various authors. Results for trace element modeling in the OBS1 pyroxenite melting simulator (Kimura & Kawabata, 2015) on primitive samples from Gough Island reproduce expected pressures and temperatures of melting and suggest 8-13% pyroxenite in the mantle source and ~80% pyroxenite melt in the magmas in agreement with the olivine compositions. For comparison, olivine compositions from two Cape Verde Islands indicate a plume melt end-member derived by peridotite melting at temperatures comparable to those for Gough Island despite very similar pressures and extents of melting as indicated by the La/Sm and Dy/Yb of the basalts. This shows that the Sobolev et al. (2007) olivine model is still viable for moderate temperature OIBs.

1.2. Volcanism in the North Atlantic, from breakup to current time

ORAL

Anatomy of the Sørvágsfjörd volcanic complex: Late Palaeocene explosive basaltic volcanism on the Faroe Islands

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We report on the basaltic Sørvágsfjörd volcanic complex (SVC) at the base of the Malinstindur Fm in the Faroe Islands Basalt Group. This ~1.5 km wide and ~90 m high structure is exposed in a sea cliff on Vágar Island. The structure rests on fluvio-lacustrine sediments of the Prestfjall Fm and it represents a positive paleo-relief onlapped by flood basalts. The SVC composite stratigraphic sequence includes from base to top: i) volcaniclastic sandstone grading into bedded tuffs, ii) agglomerates, iii) two ignimbrite units, iv) erosion surface, v) paleosol bed, in places replaced by lahar/debris flow, vi) ignimbrite unit, vii) agglomerate, viii) two ignimbrite units, ix) erosion surface. The complex is faulted and intruded by stacked sills, dykes and irregular plugs. On nearby Tindhólmur islet (1.5 km SSW) a paleo-valley incises the Prestfjall Fm, is filled with lava flows and overlain by lahars and ignimbrites. Another younger and deeper paleo-valley incises the lahar/ignimbrite sequence and is subsequently filled by lavas, mega-breccia, and lahars (and re-incised). Both valleys are buried by the Malinstindur Fm. The SVC records a significant explosive volcanic period characterized by two phases that both include near-vent agglomerates and pyroclastic density currents. The explosive volcanism was preceded by regional uplift, faulting, erosion and valley incision, followed by construction of positive volcanic relief, erosion and continued uplift due to intrusion activity, erosion and valley incision prior to burial. The SVC is unique within the NAIP and important to the tectono-volcanic evolution during the transition from pre- to syn-breakup magmatism.

ORAL

Structural links between the Jan Mayen Microcontinent and the central East Greenland coast prior to, during, and after breakup.

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A detailed tectonostratigraphic framework model of the Jan Mayen microcontinent area has been correlated with its western conjugate margin of central East Greenland, spanning from the primary North Atlantic breakup (~56-55 Ma) to secondary local breakup processes (~49-21 Ma). The reconstructions of the Jan Mayen microcontinent and surrounding oceanic crustal evolution demonstrate a clear correlation to central East Greenland, with respect to major structural boundaries and unconformities within the stratigraphic record. Igneous stratigraphy was compared specifically for the plateau basalts, the alignment to the Iceland Plateau rift segments, and to the Igtertivâ Formation of Kap Dalton within the Blosseville Kyst area.

The Jan Mayen microcontinent represents the next adjacent graben system besides the Liverpool Land high domain and appears to follow the northeast-southwest trending half-graben symmetry of the Mesozoic period of the Jameson Land Basin. These observations are based on structural segmentation and trends visible in Paleozoic-Mesozoic stratigraphic

thickness map series for both conjugate areas. The Blosseville Kyst adjacent area of the southern extension of the microcontinent indicate a rapid thinning of the pre-break-up section but increase in break-up and post break-up volcanic strata.

For the first time we demonstrate that the western flank of the Jan Mayen microcontinent was also a volcanic margin, and we reconstruct the newly mapped Late Eocene to Early Oligocene sub-crop and volcano-facies maps of the Jan Mayen microcontinent aligned to a newly mapped volcano-facies and structural elements map of the Blosseville Kyst – Scoresby Sund – Liverpool Land basin margin.

ORAL

From Iceland to the Bight Transform Fault. Evolution of 1000 km of Volcanic Rifting Plate Boundary

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Iceland is a part of the NAIP and as such forms a large island in the middle of the north Atlantic. With its continental shelf, Iceland covers about 780 kkm3. The MAR plate boundary crosses through Iceland from south to north. In this presentation, we present results from two missions that cover the southern and northern part of the Reykjanes ridge. We shall show how the Reykjanes ridge plunges into the abyss from Iceland and follow its extent some 1000 km to the south, until it hits the Bight Transform fault. This part of the MAR system is slow spreading with an average separation of 2 cm per year. Due to unprecedented detailed multibeam mapping in the area finest details in volcanic structures can be observed. However, the active plate boundary shows remarkable diversity in overall forms and individual landforms as we extend away from Iceland. Close to Iceland shallow magma storage in the crust is evident, with calderas and evolved magma composition. At the termination of the Reykjanes ridge AVR are observed at regular interval. These ridges are formed in multiple eruptions and occupy the rift valley. However, towards the north rift valleys are absent ore shallow. In between the rift valleys we observe monogenetic eruptive vents. Reorganization of the plate boundary is observed in magnetic fabric of the seafloor and numerous oceanic core complexes seem to be related to such reorganization. Off rift monogenetic eruptive vents are also more frequent as we go further away from Iceland.

ORAL

Coast-parallel dolerite dykes along SE Greenland: Southernmost onshore evidence of the Tertiary North Atlantic Igneous Province?

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Pristine dolerite dykes of presumed Tertiary age have previously been mapped on the SE coast of Greenland, south of where the coast-parallel Tertiary East Greenland dyke swarm (EGDS) extends into the Atlantic Ocean (Klausen & Larsen, 2002). Between 64˚15' and 65˚45'N, a total of six dykes constituting a more northerly located and E-W trending segment are all compositionally similar to the older tholeiites of EGDS (Hanghøj et al., 2003); whereas, twelve dykes constituting a more curved SW-NE trending southern segment resemble younger transitional-alkaline EGDS dolerites. Together with their distinct OIB-like bulk rock geochemical signatures, these two southerly located swarm segments most likely formed at the same time as the main EGDS and were primarily sourced from a ~600 km southward displaced proto-Icelandic hot spot enriched mantle source. Compared to

the Icelandic Mantle array by Fitton et al. (1997) and a petrogenetic REE-grid by Tegner et al. (1998), relatively high Zr/Y, Nb/Y and $(La/Sm)_N$ suggest that the southern segment's transitional-alkaline primary melts formed through ~ 5% partial mantle melting and segregated at ~30 km depth. Based on these results – albeit without supporting absolute ages or cross cutting relationships – we tentatively propose that (1) early tholeiitic melts formed through decompression melting along a proto-Atlantic rift that lines up with the EGDS, but injected obliquely into the E-W trending northern dyke swarm segment; and (2) a dextrally offset off-axis rift system allowed for the generation of more alkaline melts to feed more westerly located coast-parallel dykes within the southern swarm segment.

ORAL

NE Atlantic break-up and magmatism

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Northeast Atlantic (NEA) break-up in the Early Eocene has generally been viewed as the culmination of a series of episodic rifts events, spanning from Carboniferous through Paleocene. However, Paleocene rifting is conspicuously minor or absent. We propose development of a dextral Paleocene proto-NEA Transform system that allowed opening without further rifting. Several observations support this proposal: the linear, although segmented, line of break-up cutting obliquely across the Cretaceous hyperextended basin; a steeply terminated outer margin; shallowing basement and thickening continental crust toward the margin; coeval compression at Greenland's northern leading edge, and sinistral motion along its western side.

The proto-NEA Transform linked with the De Geer Transform and further with a transform along the northern Barents and Kara Sea, effectively yielding a broken plate between Greenland's southern tip and the Laptev Sea. Opening of this c. 6000 km long segment occurred around a pole in the Laptev Sea, with higher extension rates at the southern distal end. SDRs of the magma-rich NEA margins diminish northward and are absent in the Eurasia Basin. This architecture is well known and has typically been attributed to the radius of a plume. However, given that plates are approximately rigid, there is another option – that magmatism reflects the rate of extension (and associated decompressional melting). The NEA break-up magmatism may therefore be rooted in plate tectonics.

A relationship between extension rate and melt generation is further supported by evidence from the margins along the Aegir-Kolbeinsey Ridge pair, located on either side of Jan Mayen.

ORAL

The evolution of Hekla volcano in the 20th century: Integrating remote sensing data from the past 70 years

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Hekla volcano is one of the most active volcanic systems in Iceland and has erupted ~23 times since the settlement of Iceland in AD 874. The historical Hekla eruptions have been studied from written records and tephra chronology. These eruption records indicate a very constant magma production, which over the last millennium have produced a total of at least 7 km^3 (DRE) of eruptive material.

In the 20th century Hekla mountain erupted five times (1947-1948; 1970, 1980-1981, 1991, 2000). These eruptions were well documented

and it has been estimated that ~80% of the total erupted volume was lava. However, the lava flow thicknesses used in the volume calculations are uncertain due to coarse sampling at selected lava thickness profiles or at flow fronts. Accurate lava volume estimates are therefore crucial in order to asses the volume of eruptive material in the 20th century.

In the Hekla area, repeated aerial stereo-photography surveys have been conducted since 1945 allowing creation of Digital Elevation Models (DEMs) and ortho-photographs using digital photogrammetric techniques. We selected seven photogrammetric surveys (1945, 1946, 1960, 1979, 1984, 1987, 1992) to construct historical DEMs (5m/pixel) and ortho-photos (0.5-1m/pixel). Together with modern radar-based DEMs (1998 and 2012-2013) and a lidar-based DEM (2015) these data sets provide pre- and post-eruption topography of Hekla for each of the five eruptions in the 20th century. These DEMs allow creation of thickness maps and thereby unprecedented estimation of lava flow thickness and lava flow volume.

ORAL

A hot, top-down model for the formation of the North Atlantic Igneous Province and the Iceland hot spot

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The Greenland-Iceland-Faroe Ridge (GIFR) is an area that has been magmatically hyperactive since the formation of the North Atlantic Igneous Province at ~55 Ma. The magmatic crustal thickness and its compositions is different from the average oceanic crust in a way that possibly requires elevated temperature and enriched composition of the mantle melt source. A popular explanation for this involves the convective rise of hot plumes, often postulated to originate at the lower mantle with a different temperature and composition than the upper mantle. However, since the GIFR initiated just where the embryonic North Atlantic rift crossed older Caledonian sutures, alternative "top-down" models have been proposed, opposing a "bottom-up" model in which an emerging deep mantle plume would exactly coincide with the location of lithospheric weaknesses. Here, we present a new top-down physical model where lithospheric extension led to delamination of a dense quasi-stable mantle lithosphere and lower crust. The delaminated material sank into the lower mantle and caused a plume-like return flow of hot and primordial material that reached the North Atlantic rift system and caused enhanced melt productivity. Our model predicts melt volumes that are of similar magnitude as those observed in the North Atlantic, and explains why Iceland remains magmatically active at present.

ORAL

Geometry and temporal development of the Faroe Islands Basalt Group in the Faroe-Shetland Basin: Seismic mapping and well correlations by chemo/lithostratigraphy

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The offshore distribution of the Faroe Islands Basalt Group (FIBG) has received much debate since the early 1980's. We present new observations and interpretations on the late Palaeocene-early Eocene volcanic history of the Faroe-Shetland Basin (FSB). These efforts are based on novel integration of i) seismic mapping of the geometry of the pre- and syn-breakup volcanic piles and volcanic facies with ii) chemo/litho-stratigraphy of the volcanic sequences in the nine exploration wells in Faroese sector of FSB and iii) the known onshore petro-chemistry of the FIBG. Contour maps of the depth to i) the base of the volcanic pile, ii) the A'-horizon, and iii) the top of the Palaeogene volcanics are presented along with isopach maps

of the thickness distribution of the respective pre- and syn-breakup volcanics and associated volcanic foresets. We illustrate the offshore geometry of the FIBG with generalized geoseismic sections and its temporal development with sequence stratigraphic charts. Comparative analysis of volcanic thickness distributions and kinematic indicators reveal a number of aspects concerning the emplacement of flood volcanism into FSB; including seemingly persistent lava transport systems, south- and eastward progradational lava deltas, sub-basins at times acting as depocentres for volcanics while volcanically starved at other times. A greater volume of volcanics was delivered to FSB during the pre-breakup volcanism in comparison to the syn-breakup phase. The syn-breakup volcanic deposits are predominantly present in the northern part of FSB and along Fugloy ridge, likely reflecting eastward migration of volcanic systems and proximity of the emerging Aegir ridge.

ORAL

Interaction between volcanic and sedimentary transport systems in the greater Judd Basin on the North East Atlantic Margin

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Understanding the transition from the volcanic units of the North Atlantic Igneous Province to the non-volcanic units in the Faroe Shetland Basin, has proven to be a challenge, partly due to inability of seismic data to resolve the difference in seismic response between volcanic and non-volcanic units, and partly due to lack of well control.

Published interpretation of well 6005/15-1 on Sjúrður High suggested a thin extrusive basalt section in the early Eocene and intrusive units in the mid-Palaeocene section. A new integrated interpretation of reprocessed seismic data and re-evaluation of well-cuttings demonstrates that the intrusive units originally classified as basaltic sills are predominantly pre-breakup extrusive basalts and hyaloclastites. This enabled mapping of discrete volcanic packages within the dominantly non-volcanic sedimentary section in the greater Judd Basin area.

Mapping of pre- and syn-breakup volcanic units around the greater Judd Basin area, demonstrates a large variation in the interaction between the volcanic and non-volcanic systems. Towards the south volcanics were fed into the Judd basin during mid-Palaeocene. Following a volcanic regression, basinal accommodation space was filled by siliciclastic sediments primarily sourced from the southeast. In the early Eocene volcanics again transgressed far into the Judd basin before volcanism eventually was restricted to the location of the incipient Northeast Atlantic further north-northwest.

One implication of mapping the event horizon of an igneous province using seismic data is that we can now achieve a more detailed understanding of the temporal and spatial evolution of volcanic and sedimentary depositional processes in basin-hosted volcanic provinces.

1.3. Understanding Large Igneous Provinces and associated rapid environmental changes: from the North Atlantic Igneous Province and beyond.

ORAL

The Pre-Caledonian Margin of Baltica: overview and research in progress

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The Caledonian margin of Baltica formed by continental break-up of Rodinia in the Late Proterozoic to Ediacaran. With exception of the dike-swarm near Egersund in SW Norway, the Fennoscandian basement including the autochthonous basement windows along the axis of the mountain belt were little affected by the magmatism associated with the break-up. The distal parts, however, were strongly attenuated, hyper-extended and a 1000 km long segment, intensively intruded by a Large Igneous Province (LIP), the Pre-Caledonian LIP (PC-LIP). Here, we provide glimpses of our work in progress from the vestiges of the margin. More details on several aspects of the margin evolution are presented by co-authors. Here we present a regional model for the pre-Caledonian margin suggesting it was highly complex and included micro-continental sliver(s) and both a hyperextended, magma-poor domain with transition(s) to attenuated embryonic oceanic and magma-rich margin domains. The break-up related PC-LIP magmatism lasted from approximately 615 to 570 Ma, but the most intense activity appears to have been at ~600 Ma. Our ongoing work suggests that the impingement of a mantle plume on the Ediacaran continental lithosphere was associated with a temperature anomaly of ~100°C, causing widespread melting of the asthenosphere and dyke-intusion of the continental crust and sediments of the margin. We suggest that the pre-Caledonian margin of the Iapetus preserved in the Scandes comprise most of the elements of passive continental margins, and that it probably represents one of the best exposed field analogue for the deeper and least known parts of passive margins.

ORAL

Comparing the geophysical expression of the Seiland Igneous Province with the SW Barents Sea crust – indications for a LIP during opening of the Iapetus ocean?

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The Seiland Igneous Province (SIP) in northern Norway is expressed by large outcrops of mafic and ultramafic rocks of Neo-Proterozoic (Ediacaran) age and is hosted by the Caledonian Kalak nappe. The SIP has been suggested to be the plumbing system of a large igneous province. Unaltered ultramafic rocks in crustal settings are characterized by low magnetization and exceptional high crustal densities, the latter forming a contrast to common crustal rocks. Such rock attributes have also been detected by integrated interpretation of gravity, magnetic and seismic data on the continental shelf in the southwestern (SW) Barents Sea at Senja Ridge and Veslemøy High. Furthermore, a highly dense rock unit of large lateral extension, has been found below large parts of the SW Barents Sea, either, at a lower crustal level, or in the uppermost mantle. We investigate a possible link between the rock units with high density in the SW Barents Sea and the SIP. If both belong to the same magmatic event, they may be characterized as relicts of a LIP which developed at the time of the opening of the Iapetus Ocean. An alternative scenario for the origin of the offshore ultramafic rocks at the Veslemøy High has been published suggesting exhumed mantle developed by

hyperextension during the ultraslow opening of the Cretaceous Bjørnøy Basin. Finally, obducted ophiolitic crust containing mantle rocks is another possibility which will be discussed.

ORAL

Karoo LIP thermogenic degassing less important than previously estimated — new evidence from thermo-hydro-mechanical numerical simulations

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Thermogenic discharge into the atmosphere associated with the Karoo LIP event (183 Ma) is currently estimated to as much as 12,600 Gt of methane. In order to precise the degassing rates at the basin floor, we investigate the influence of the Karoo Basin stratigraphic physical properties, including a realistic initial TOC profile. Using state-of-the-art numerical models of hydrothermal fluid flow through porous rocks we investigate the formation and evolution of hydrothermal systems powered by sill intrusions. We take into account the energy consumption of the dehydration reaction and the thermogenic cracking in the sediments as well as the increasing pore space upon sediment dehydration. Permeability depends on porosity and, in addition, a simple Mohr-Coulomb rheology is used to simulate hydrofracturing. Our results indicate that fluid flow caused by a single sill intrusion emplaced in the deep organic-rich formation is insufficient to rapidly transport thermogenic methane to the basin floor. Instead the mobilized methane accumulates in shallower parts of the basin, where it may be later remobilized by shallower intrusions. Our new estimates suggest a reduction of one to two orders of magnitude in the amount of thermogenic gas emitted during the Karoo LIP event.

ORAL

Large-scale sill emplacement in Brazil as a trigger for the end-Triassic crisis

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It has long been postulated that the Central Atlantic Magmatic Province (CAMP) was involved in the end-Triassic extinction (ETE), one of the largest mass extinctions of the Phanerozoic. Previous studies have mainly focused on the extrusive section of the province, however several lines of evidence point toward sill emplacement in Brazil being a key factor regarding the extinction. These sills have intruded the Amazonas and Solimões basins, which include major deposits of evaporite, carbonate and organic-rich shale, and it has been suspected that contact metamorphism of these lithologies generated thermogenic gases that were released to the end-Triassic atmosphere. Until now, detailed studies regarding the extent of the sill complex and estimates of sediment-derived volatiles have been absent, likely because outcrops and samples are extremely limited. Here we have access to samples and logs from seven deep boreholes drilled in the Amazonas and Solimões basins. The sills comprise up to 24% of the stratigraphy, and the majority have intruded evaporite-and carbonate dominated deposits. Thermal modeling demonstrates that large scale carbon generation followed sill emplacement, including as much as 116 000 Gt CO_2. We also provide new constraints on the timing of sill emplacement by high precision U-Pb zircon geochronology. Our findings demonstrate synchronicity between the sills and the ETE, and we suggest that venting of sediment-derived volatiles such as C, S and Cl played a major role in the end-Triassic crisis.

ORAL

Evidence from Denmark for NE Atlantic pre-PETM volcanism

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A new section on the Fur island in Denmark includes two quadruple volcanic ash layers which are older than the Paleocene-Eocene Thermal Maximum (PETM). The ash layers occur immediately below sediments dated to the PETM interval. The ash layers are of a normal basaltic type and older than hitherto recognized volcanic ash layers from the Paleocene-Eocene transition in Denmark (i.e., the negative and positive numbered ash series of Bøggild, 1918). Three other Danish PETM sections (Ny Klitgård, Ølst-Hinge, Harre-1) show 1-3 volcanic ash layers closely associated with the base of the PETM interval. The ash layers point to a significant volcanic episode and their stratigraphic position supports previous evidence for NE Atlantic volcanism as a trigger of the PETM (e.g. Svensen et al., 2004). All sections show a shift from oxic sea-floor conditions (indicated by bioturbation) below the PETM interval, to anoxic conditions (indicated by finely laminated sediment) within the PETM interval. The basal layer of the PETM interval at Fur is a 5 cm thick density flow deposit occurring immediately above the ash layers. The density flow deposit is not recognized in other Danish sections and points to local sea-floor instability.

ORAL

The lithostratigraphy of a hyperextended domain in the magma-rich to magma-poor transition zone in the southern Pre-Caledonian LIP, Scandinavian Caledonides, Norway

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Remnants of the ancient rifted margin of Baltica are preserved in the allochthons of the Scandinavian Caledonides. The Baltica margin nappes comprise a magma-rich segment, i.e. the pre-Caledonian LIP (Tegner et al. 2016), and a magma-poor. (Andersen et al. 2012; Jakob et al. 2017). The transition zone between the magma-rich and magma-poor domains corresponds approximately to the northern termination of the Jotun Nappe Complex. Metaperidotites and metamorphosed mafic rocks abound in the metasediments of this transition zone.

North of Lesja, an original lithostratigraphic succession of the ancient Baltica hyperextended margin may be preserved. At its base is a sheet of metaperidotite that is locally characterized by a pegmatitic texture, containing pseudomorphs after decimetre-sized, metamorphic olivine. Few mafic dykes cutting the metaperidotite are also observed.

The top of the metaperidotite sheet is in contact with metamorphosed mafic rocks or in a stratigraphic contact with a monomictic metaperidotite conglomerate. The latter grades upwards into a polymictic conglomerate. The metamorphic mafic rocks and the conglomerates above the metaperidotites, but locally also the ultramafic rocks, are overlain by a metasedimentary unit that comprises a large number of mafic intrusives (and volcanics?) and

locally contains ultramafic clasts. Similar successions have been described from fossil ocean-continent transition zones elsewhere (e.g. Manatschal and Müntener 2009).

We suggest that the lithostratigraphic succession north of Lesja represents a hyperextended domain in the magma-rich to magma-poor transition zone of the pre-Caledonian margin of Baltica that received abundant mafic magmas during and after the mantle was exhumed at the seafloor.

ORAL

Types and styles of volcanism in the North Atlantic Igneous Province: Implications towards understanding their potential climatic impact.

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The North Atlantic Igneous Province (NAIP) is arguably the best studied of the Large Igneous Provinces (LIPs), but it is somewhat unusual in that its volcanism is somewhat protracted and pulsed. Two main phases are recognised with one occurring some 5 million years before the Paleocene-Eocene thermal maximum (PETM) and another which occurs at the PETM. The different styles and types of volcanism that are found during the onset, main phases and the waning parts of the NAIP, as well as the intrusive plumbing systems that go to feed them, all play a potential role into how the LIP may have contributed to the changing climate at this time. Flood volcanism is rarely restricted to simple lava flows, and here we review the relative timings and locations of the key types of eruption that occurred in the NAIP. Lava flows, hyaloclastites, major volcanic centres, and thick ash accumulations bears testament to the volcanism as well as a full range from basic to silicic compositions. It can be shown that over the PETM times, the volcanism was particularly widespread, with significant ash beds as well as a plumbing system that significantly intruded into the surrounding sedimentary basins at this time causing a multitude of gas escaped venting structures. The changes in style from early eruptions to the second phase volcanism in the NAIP need to be considered to help our understanding of the PETM crisis.

ORAL

Fur Island in Denmark: A window into Paleocene-Eocene hyperthermals and North Atlantic volcanism

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The Paleocene and Eocene epochs were typified by ice-free greenhouse conditions, punctuated by even warmer hyperthermal events driven by rapid release of carbon to the atmosphere. The largest of these, the Paleocene-Eocene Thermal Maximum (PETM), was an extreme (5-6 °C) and rapid (<20 kyr) global warming event at ~56 Ma that persisted for ~170 kyr. The PETM coincided with a major pulse of magmatism from the North Atlantic Igneous Province (NAIP), suggesting that the emplacement of the NAIP could be responsible for the climate perturbations. An excellent locality to explore this relationship is the island of Fur in Denmark, where over 180 tephra layers originating from the NAIP are preserved in a diatomitic clay sequence. Here we present the initial results of the project "Ashlantic", which drilled a 73 m borehole through the Fur Formation in August 2017. We

use a variety of detailed geochemical and stratigraphic analyses to assess the extent and duration of volcanism across the PETM. In particular, we use volcanic proxies such as Hg deposition to assess the influence of volcanism and thermogenic degassing on the surface carbon cycle. We will combine this with high precision U-Pb dating of magmatic zircons found in tephra layers and high-resolution cyclostratigraphy to place the PETM and later hyperthermals within an improved absolute timeframe. Expanded shelf sections such as the Fur Formation are fundamentally important for understanding hyperthermal events and volcano-climate interactions due to the possibility of measuring variations on a sub-millennial timescale.

ORAL

A fossil magma-rich rifted margin revealed in the Scandinavian Caledonides

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The Iapetus opened ~610 Ma ago possibly due to the interaction with a mantle plume at the base of the lithosphere. Stretching of the conjoined crystalline crust started prior to break-up and provided accommodation for continental and shallow marine syn-rift sediments. An early non-magmatic phase with discrete and localized deformation was followed by pervasive mafic magmatism where dyke-emplacement accounted for the bulk of the stretching. During the Caledonian orogeny, the Iapetan margin was thrusted onto Baltica as the Iapetus closed. Now, vestiges of the magma-rich margin reside within nappes from central Sweden to northern Norway. Although overprinted by Caledonian fabrics, there are localities where pre-Caledonian structures are well-preserved, thereby allowing for detailed studies of deep to intermediate processes at magma-rich rifted margins. We propose that the architecture of the magma-rich margin of Iapetus and magma-rich rifted margins, in general, can be studied in the Caledonides. The well-preserved parts of the margin comprise: 1) Parts of a lower crustal magmatic complex w/gabbros and mafic dykes intruding stretched crystalline basement; 2) Strongly stretched and attenuated crystalline basement intruded by mafic dikes; 3) Highly intruded pre- to syn-rift sediments and 4) Extrusive mafic lavas, including pillow basalts, interlayered with metasediments. Together these levels represent a nearly continuous section through a magma-rich rifted margin, with some never-before described levels, such as the lower crustal magmatic complex.

ORAL

Environmental and ecosystem responses to massive volcanism during the end-Triassic mass extinction

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The end-Triassic mass extinction (201.56 Ma; Wotzlaw et al. 2014) is generally explained by massive input of CO_2 and/or methane to the atmosphere from the Central Atlantic magmatic province (CAMP). High precision U/Pb dating of CAMP intrusives and extrusives have shown that the magmatic activity commenced c. 100.000 years prior to the ETE (Davies et al. 2017), and occurred in at least four pulses over approximately 600.000 years (Blackburn et al. 2013). Indeed, both calcareous and organic $\delta^{13}C$-records across the Triassic-Jurassic boundary (TJB) show that large scale emissions of isotopically light carbon to the atmosphere took place at that time. Physiological responses in

terrestrial plant fossils indicate that this lead to intense global warming across the TJB (McElwain et al. 1999), while in the marine realm, ocean acidification from the increased pCO_2 is indicated by the loss of calcifying organisms (van de Schootbrugge et al. 2007). Recently, a new correlation of TJB successions, based on a combination of biotic (palynology and ammonites), geochemical ($\delta^{13}C_{org}$) and radio-isotopic (U/Pb ages of ash beds) constraints, was proposed (Lindström et al. 2017). This new correlation has an impact on the causality and temporal development during the end-Triassic event, as it indicates that the bulk of the hitherto dated CAMP rocks preceded or was contemporaneous to the onset of the mass extinction. Here, we investigate the temporal chain of events across the ETE as constrained by the new correlation in combination with new high-resolution CAMP ages extrusives (Blackburn et al. 2013; Davies et al. 2017).

ORAL

The Relationship Between Paleogene Hydrothermal Vent Complex Diameters and Conduit Heights in the Vøring and Møre Basins Offshore Mid-Norway

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Large Igneous Provinces (LIPs) emplaced within basins are frequently associated with many hydrothermal vent complexes sourced from thermal aureoles around sill intrusions. These piercement structures consist of cylindrical conduits that connect the sill aureoles with vents at the paleosurface. More energy is considered to be required to create both longer conduits, as they require higher fluid pressure to fracture long pathways, and larger vents, because more rock is mobilized near the seabed. Four datasets from the Vøring and Møre basins (Mid-Norway), consisting of 718, 213, 106 and 13 Paleogene hydrothermal vent complexes, are used to determine the relationship between vent diameters and conduit heights. The vent complexes and associated sills were mapped using regional 2D seismic data (first dataset) and 3D seismic data (three datasets). Generally sills have pipe-like vent complexes located above their margins or above sill steps or local highs, however, one shallow sill has >110 hydrothermal vent complexes distributed over its top surface. The upper part of the vent complexes display mound, crater, or eye-shaped geometries. Observed vent diameters range from ~100 m to ~11 km, with a sizable majority <2.5 km wide. The vertical conduit heights range from ~100 m to ~4 km with a sizable majority <2.5 km. There are weak positive correlations between the upper vent complex diameters and conduit heights in all four datasets. The weak correlations suggest the quantity of energy transferred from the sill aureoles, via fluid transport, to the hydrothermal vents is partially dependent on the heights of the conduits.

ORAL

Release of volatiles during North Atlantic flood basalt volcanism and correlation to the Paleocene-Eocene Thermal Maximum (PETM)

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Significant environmental changes and global warming during the PETM have been attributed to the release of CO_2 or methane gas due either to extensive melting of hydrates at the ocean floor or to interaction of mantle-derived magmas with carbon-rich sediments. Although it is well established that flood basalt volcanism

associated with the opening of the North Atlantic Ocean broadly coincides with the PETM, further detailed timing constraints from stratigraphic correlations, magnetostratigraphy, and the duration of flood basalt volcanism suggest that it is also possible that the main flood basalt sequence in East Greenland postdates PETM.

Estimates suggest that a minimum of $1.8x10^6 km^3$ of basaltic lava erupted during North Atlantic flood basalt volcanism. Based on measurements of melt inclusions from the East Greenland flood basalts our calculations show that approximately 2300Gt of SO_2 and 600Gt HCl were released into the atmosphere. Yearly fluxes are estimated to be 8-23 Mt/y SO_2 and 2-6 Mt/y HCl if all the North Atlantic flood basalts erupted in 100.000-300.000 years. This is equivalent to ≈18600 Laki-like events, one happening every 5-16 years. The SO_2 released into to the atmosphere during flood basalt volcanism can form acid aerosols that absorb and reflect solar radiation, causing an effective cooling effect.

The climatic changes due to the release of volatiles in these amounts, and for periods extending for hundred thousand of years are likely to be significant. One consequence of the North Atlantic flood basalt volcanism may therefore have been the initiation of global cooling to end the PETM.

ORAL

NE and NW Atlantic Paleogene Voluminous Magmatism and Global Crises: Seismic Observations and the Need for Future Scientific Drilling

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The NE and NW Atlantic continental margins are characterized by massive Paleogene igneous constructions, associated with continental breakup and early seafloor spreading. We have recently completed a comprehensive interpretation of the nature and distribution of the extrusive and intrusive mafic rocks on regional 2D and selected high-quality 3D seismic data in both regions. Interpretations have been augmented by scientific and industry borehole data and on-shore field work. On the Vøring Marginal High, 3D mapping reveals a highly variable crustal structure, with large-scale pre-breakup structural highs and sedimentary basins. These structures where infilled and covered by flood basalts and volcanogenic sediments during the early stages of continental breakup in the earliest Eocene. Subsequently, rift basins developed along the continent-ocean boundary and were infilled by up to 6 km thick basalt sequences, imaged as SDRs. Intrusive sill complexes and associated hydrothermal vent complexes in the Vøring Basin have dominantly a Paleocene-Eocene boundary age based on a few high-quality U/Pb ages and seismic mapping. Similar igneous complexes, including SDRs, lava deltas, lava fields, sills, and hydrothermal vent complexes, were also mapped in the NW Atlantic and on the NE Greenland margin. The dominant hypothesis is that the massive magmatism was caused by a mantle plume originating from the core-mantle boundary, and that intense and short-lived (<100,000 years) intrusive and extrusive magmatism triggered global warming during the Paleocene-Eocene thermal maximum (PETM). However, we argue that new scientific drilling in the NE and NW Atlantic is required to substantiate these hypotheses.

ORAL

Improving seismic interpretation of igneous sill complexes via seismic modelling

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Seismic interpretation has been playing a key role in establishing the role of igneous sill complexes emplaced in organic-rich sediments on global climate change throughout geological history (e.g., Svensen et al. 2004, Aarnes et al. 2015): the heat brought by the sills to their organic-rich host leads to massive thermogenic generation of greenhouse gases (e.g., CO2, CH4), eventually catastrophically released to the atmosphere. Robust volume estimates of these greenhouse gases rely on robust estimates of magma volumes of the sill complexes, which require confident mapping of subsurface sill intrusions.

Large sills are easy to map in seismic data, because they create strong property contrasts, which cause high amplitude reflections. However, igneous sills vary strongly in thickness and up to 88 percent of the sills may be missing in the interpretation, since their thickness is below the seismic resolution limit (Schofield et al. 2015).

In this presentation, we present seismic modelling study designed to characterize typical seismic signatures (splitting, stepping, braided reflections) of thin intrusions, and to indicate potential ways to infer the shapes of thin intrusions in the seismic interpretation. Due to their anomalously high vp/vs ratio, intrusions cause a characteristic amplitude-vs-offset (AVO) response with high AVO intercept and gradient. Thus, we will highlight the great potential of using seismic pre-stack and offset data for the interpretation of thin intrusions. Our results indicate how seismic interpretation and thereby volume estimates of sill complexes can be significantly improved using data of relevant quality.

ORAL

U-Pb baddeleyite dating of multiple mafic dyke swarms in the Dharwar craton, India – evidence for a 30° internal block rotation during the Paleoproterozoic

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A significant portion of large igneous provinces (LIPs), especially those thought to be associated with mantle plumes, have been linked with breakup of continents and, therefore, provide a critical source of information in reconstructions of ancient crustal blocks. First-order crustal connections to a plume include radiating mafic dyke patterns, inferred to reflect lateral magma transport away from a plume centre located at the focal point of the swarm[1,2]. The 2.37 Ga giant Bangalore-Karimnagar dyke swarm of the Dharwar craton, southern India, displays a distinct radial pattern (of at least 30º) from which a western source of magma has been inferred[3,4]. However, on the basis of paleomagnetic data and an arcuate trend to structures in the Archaean basement, an alternative interpretation of the fanning pattern of the Bangalore-Karimnagar swarm has been raised[5,6,7]. Here we present 17 U-Pb baddeleyite ages, which comprise seven generations of Paleoproterozoic dykes swarms within the 2.37-1.79 Ga age interval.

By restoring a 30° counter-clockwise rotation of the northern Dharwar block relative to the southern block, we show that pre-2.08 Ga arcuate and fanning dyke swarms consistently become approximately linear, as do ancient curvilinear trending geological features, such as regional Dharwar greenstone belts and the late Archean (ca. 2.5 Ga) Closepet batholith. This finding reinforces previous suggestions that the radial pattern is apparent, and not a primary feature[e.g. 7]. Our findings call for reassessment of previous paleoreconstructions involving the Dharwar craton based on tectonic/geologic piercing points, paleomagnetism and inferred plume centre locations.

ORAL

Volcanic causes for the PETM and other past hothouse climates

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Mass extinctions and transient climate events commonly coincide in time with the formation of Large igneous provinces (LIPs). Classic examples include the end-Permian event which coincides with the Siberian Traps, the end-Triassic with the Central Atlantic Magmatic Event (CAMP), the Toarcian with the Karoo LIP, and the Palaeocene-Eocene Thermal Maximum (PETM) with the North Atlantic Igneous Province. The emplacement of igneous sills into sedimentary basins, and the associated contact metamorphism of the host sedimentary rocks, has emerged as a major player in the understanding of the link between LIPs and past climatic change. We stress that for these processes to have an environment impact, the gases need to be transferred to the surface and atmosphere on a very short timescale, which is borne out by dating of the sill complexes in question. We have identified a range of different pipe structures that acted as gas transport channels during the end-Permian, the Toarcian, and the PETM, and present a classification and detailed overview of the key parameters governing their formation. We show that the potential for degassing of greenhouse gases, aerosols, and ozone destructive gases in sedimentary basins affected by volcanism is substantial, and can explain the triggering of both transient climatic events and mass extinctions.

ORAL

The pre-Caledonian Scandinavian Dyke Complex and 600 Ma plate reconstructions of Baltica

Christian Tegner[1], Torgeir B. Andersen[2], Hans Jørgen Kjøll[2], Eric L. Brown[1], Graham Hagen-Peter[1], Fernando Corfu[2], Sverre Planke[2] and Trond H. Torsvik[2]
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A spectacular dyke complex is surprisingly well preserved along c. 1000 km in the Caledonian nappes of central and northern Scandinavia. This dyke complex was originally emplaced into continental sedimentary basins along the rifted margin of Baltica, it is part of the Central Iapetus Magmatic Province (CIMP), and it has U-Pb ages of 615-590 Ma.

To constrain its origin and to potentially guide plate reconstructions of Baltica we: (1) re-visited the dyke complexes of the Ottfjället, Sarek, Kebnekaise, Tornetrask and Indre Troms mountains of Sweden and Norway; (2) produced new and compiled published geochemical data; (3) modeled mantle sources and melting dynamics; and (4) extended reconstructions of the paleo-position of Baltica back to 600 Ma. The compiled dataset includes c. 600 analyses that forms a coherent suite dominated by tholeiitic ferrobasalt, but including alkali basalts in the central portion.

The tholeiitic dykes display lateral variations in geochemical enrichment (e.g. delta-Nb, La/Sm(N) and Sr isotopes) in the southern and central portions, grading to more depleted compositions in the north. Our petrological modeling suggests melting of asthenospheric mantle involving at least two source compositions at temperatures elevated about 100 °C above ambient mantle, consistent with melting of a zoned mantle plume originating from a plume generation zone at the core-mantle boundary. If the position of the present plume generation zone in the Pacific can be viewed as stationary back to 600 Ma, we entertain the idea that the Scandinavian Dyke Complex may be used to guide plate reconstructions.

POSTER

Pyroxenes used as probes for assessing gas loads from LIP magmas: a crystal/melt partitioning study for sulfur and halogens

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Magmatism from Large Igneous Provinces (LIPs) has in several cases been causally linked to mass extinctions, with at least five conspicuous examples in the Phanerozoic. LIPs likely generated changes on the global environment by degassing of volatile species such as S, C and halogen compounds, from both melts and thermal metamorphism of volatile-rich intruded sediments. However, quantitative estimates of the degassed volatiles are hard to obtain for ancient magmatic systems, particularly in the absence of melt inclusions. We propose to fill the gap of knowledge on sulfur partitioning between minerals and melts, at the aim of using phenocrysts as probes of volatile contents in the melts from which they crystallized. Measuring a volatile concentration in natural minerals (chiefly clinopyroxene) and combining it with an experimentally determined partition coefficient (KD), the volatile load of basaltic equilibrium melts can be calculated. We measured a clinopyroxene/melt sulfur KD of 0.001±0.0003 for basaltic experiments performed at conditions typical of LIP basalts (FMQ-2; 800-1000 MPa; 1000°-1350°C), through ion microprobe (Nordsim). Experiments were also simultaneously analyzed for Cl and F. For these elements the measured KDs were 0.0106±0.0089 and 0.1837±0.0795, respectively. Compatibility of sulfur, chlorine and fluorine in clinopyroxene from basaltic systems is markedly different (F>Cl>S), in agreement with what observed by previous studies. Application of the newly measured sulfur KD to samples from thoroughly-dated lava piles from the Deccan Traps and from the Siberian Traps sills reveal that most of the basalts were at or near sulfide saturation (ca. 2000 ppm for low fO_2 melts).

POSTER

Glendonite in an early Eocene Konservat-Lagerstätte (Fur Formation of Northern Denmark) and Palaeocene / Eocene formations on Svalbard are good climate and biosphere interpretive indicators.

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Mors

The early Eocene Fur Formation of Denmark comprises a 60 meters thick diatomite holding over 200 volcanic ash layers related to the North Atlantic Igneous Province (NAIP) (Larsen 2003). The Fur Formation overlays the Ølst Formation (Stolleklint Clay) which includes both the Palaeocene-Eocene boundary and Palaeocene-Eocene Thermal Maximum (Schoon 2013, 2015). Intriguing is therefor outcrops in parts of the Fur Formation of ikaite pseudomorph termed glendonite, $CaCO_3$. Sediment legit shows that the cold environment mineral ikaite, CaCO3 • 6H2O, formed shortly after deposition in relation to thick volcanic ash layers. (Hugget et al. 2005; Schultz 2009, 2014). The occurrence of glendonites indicates a period of cooling after the Palaeocene-Eocene Thermal Maximum possibly due to heavy volcanism (Brooks 2006). In the NAIP Palaeocene/Eocene Glendonites are also seen on Svalbard (Spielhagen 2009). The interpretive powers are immense as Mo clay area Fossil Lagerstätte is unparalleled worldwide in terms of representing the initial diversification of the modern fish in the marine, offshore realm (Pedersen et al. 2011). It contains the first major post-K/T boundary diversification of marine fish in association with terrestrial organisms such as birds, insects and plants, all of which are extremely well-preserved, as has been demonstrated in pioneering works in the field of molecular palaeontology (Vinter 2008; Lindgren et al. 2012, 2014, 2017). The rich and diverse fossil content comprising both marine and terrestrial organisms makes the Mo clay area an outstanding window into the early Eocene biosphere, where fossil indicate high latitude migrations of particular faunal elements.

POSTER

Lithological and geochemical variations during the PETM and later Eocene hyperthermals: details from a new drill core from Fur, Denmark.

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One of the most extreme episodes of global warming in Earth's history is the Paleocene-Eocene thermal maximum (PETM), which lasted ~170 000 years from ~55.8 Ma, and was followed by several smaller hyperthermal events during the Eocene. The period was initiated by substantial carbon release to the ocean-atmosphere system, causing a global temperature increase of ~5-8°C. This global warming event coincided with the second pulse from the North Atlantic Igneous Province (NAIP), suggesting a possibly causal relationship. One of the best exposures covering the PETM interval is the Fur Formation and Stolleklint Clay, found on the island of Fur in northwest Denmark. Over 180 interbedded tephra layers of NAIP origin are found within this diatomite and clay rich sequence. The diatomite clays were deposited during the late Paleocene and early Eocene in a restricted, shallow marine basin with interchanging well laminated and structureless (strongly bioturbated) subsections reflecting alternating redox bottom conditions. During a recent fieldtrip as part of the Ashlantic project, a ~70m long core was drilled through this sedimentary succession in order to investigate the role of volcanism in the prolonged global warming and observed climatic changes during the PETM. In this contribution, we will present a new and detailed overview of the lithological and chemical variations through the Fur Formation, including data from high-resolution XRF-core logging. Our data give an improved insight to the PETM and post-PETM climatic perturbations, and help us understand the climatic response to ash deposition.

1.4. Tephra markers in the circum North Atlantic area

ORAL

Explosive volcanic activity in Iceland during the Weichelian – Different from the Holocene?

Esther Ruth Guðmundsdóttir[1], Guðrún Larsen[2], Jón Eiríksson[3] and Ólafur Ingólfsson[4]
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Eruption frequency is high in Iceland and has been estimated to exceed 20 eruptions per century on average during the Holocene. The majority of the eruptions are mafic (~ 90%) and predominantly explosive (~70%).

For the past 10.000 years the explosive activity in Iceland is relatively well known based on numerous soil profiles and lake sediment archives across the country. What about during the Weichselian? How was the explosive volcanic activity in Iceland during this last glaciation? Was it similar to the Holocene? Which volcanoes were active and what was the level of their tephra producing activity?

To answer these questions, tephra in high-resolution lake sediments spanning 10.000 years and marine sediments extending 50.000 years have been investigated. Lake sediments in East Iceland (Lake Lögurinn), records 170 explosive eruptions during the Holocene. The marine sediments (core MD99 2272) from the North Icelandic shelf records about 200 tephra layers back to the middle Weichelian.

There are strong indications that volcanism in Iceland during the Holocene has been periodic at several timescales with apparent periods of 140, 500, and 4-5000 years. Preliminary results from this study reveal that the 4-5000 year periodicity extends as far back as 50.000 years, with eruption frequency peaks between 1-2000, 5-7000, 9-10.000, 12-14.000, ~16-18.000, ~22-23.000, ~32-33.000, 36-~37.000, ~45-46.000 and ~49-50.000 years.

ORAL

Proximal tephras from São Miguel, Azores Islands, and their links with distal sites in Europe

Hans Johansson[1] and Stefan Wastegård[1]
[1]Stockholm University

The Azores archipelago is one of the most active volcanic areas in the North Atlantic region, with approximately 30 eruptions during the last 600 years. The geochemical composition of associated tephra-derived glass is, however, not well characterized. It has recently been suggested that trachytic tephras found in distal areas such as North Africa, the British Isles and Greenland may derive from eruptions on the Azores, but proximal data from the Azores are scarce and the correlations have been tentative at best. These tephras lie clearly outside the geochemical Icelandic province and have a potential to improve the European tephro-stratigraphy/tephrochronology framework, especially in sites in south and central Europe where tephras from more than one European volcanic system have been found (e.g. Lane et al., 2015). Analyses of tephra glass from five mid and late Holocene eruptions on the Azores Islands were presented by Johansson et al. (2017) and there is a striking geochemical similarity between trachytic tephras from volcanoes on the São Miguel island and cryptotephras found on Ireland (e.g. Chambers et al., 2004). The dominant wind direction over the Azores is favourable for tephra dispersal to western Europe and we suggest that at least three tephras found in Ireland were erupted from the Furnas volcano, and that trachytic tephras erupted from São Miguel have a potential to contribute to the construction of a European-wide tephrostratigraphic framework.

ORAL

Linking late Quaternary palaeoclimate records in the North Atlantic area: cryptotephras at Körslättamossen, S Sweden

Simon Larsson[1] and Stefan Wastegård[1]
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The spatial and temporal development of rapid climate shifts during the last deglaciation in the North Atlantic area is still uncertain (e.g. Davies et al. 2012). The method of tephrochronology has the potential to precisely link different palaeoclimate archives from sites separated by vast distances (e.g. Lane et al. 2017), which is particularly useful to assess the issue of the timing and spatial development of these climate events (e.g. Lowe 2001, Lane et al. 2011, Davies et al. 2012).

The Körslättamossen fen in Scania, southern Sweden—previously studied by Hammarlund & Lemdahl (1994)—was analysed for cryptotephras. Preliminary results indicate the presence of at least five separate cryptotephra layers (concentrations >500 shards/cm^3), two of which have been geochemically analysed and identified as the Hässeldalen Tephra (HDT) and the Laacher See Tephra (LST). This is the first geochemically confirmed find of the LST on Swedish mainland, extending its dispersal area further northwest than in previous reconstructions and providing new insights to the dispersals of its several eruptive stages. The Körslättamossen fen appears to be a promising site for the usage of tephrochronology to link palaeoclimate archives in the circum North Atlantic area.

ORAL

Tephra stratigraphy in Iceland during the Holocene

Thor Thordarson[1] and Áslaug Geirsdóttir[1]
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Tephrochronology plays a conspicuous role in paleoclimate studies across the North Atlantic because tephra horizons are excellent stratigraphic markers and correlation tools in Holocene sedimentary archives. Comprehensive knowledge of the tephra stratigraphy in Iceland is essential for understanding of the far-field chronologies and for tephra detection and discrimination. Over the last two decades we have seen momentous improvements in the Holocene tephra record in Iceland, especially because of the expansion of the traditional soil-based tephra studies to include glacial, lacustrine and marine sediment archives along with heightened awareness of the importance of tephra studies for volcanological and petrological research. This has been achieved via collective, inter-disciplinary effort involving several dedicated research groups and the key outcomes include: (a) a near complete high-resolution Holocene tephra stratigraphy, dating back to 8-12 ka for West, Central, South and Southeast Iceland, including the circumference of the Vatnajökull glacier, (b) a near-complete Holocene record of magma compositions produced by individual volcanoes, including detailed geochemical characterization of all major silicic tephra deposits, (c) a much improved, high precision analytical procedure for major and volatile element concentrations in volcanic glass, suitable for grains down to the size range of 3-10 mm, (d) a comprehensive geochemical procedure for tephra identification, (e) that some of the key far-field tephra marker horizons previously conceived to be the product of one eruption, are in fact comprised of several tephra layers produced over periods of few hundred year. I intend to present a comprehensive review these research endeavors and their outcomes.

ORAL

Tephrochronology of North Europe: A look back and prospects for the future

Stefan Wastegård[1]
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Chronological control and the resultant ability to examine the degree of synchrony among records of different origin are critical for the understanding of climate and environmental variability. There is an increasing demand for exact time markers in the palaeoclimate

community as more investigations now aim at high temporal resolutions. Tephrochronology, which is an age-equivalent dating method, exploits these time-synchronous markers and offers a unique possibility to test hypotheses regarding synchronous or non-synchronous responses to climate forcing. Few, if any geochronological methods can match the precision it offers both temporally and spatially. A new generation of tephrochronologists has been undertaking novel research into cryptotephras (layers of nonvisible volcanic ash encompassed within sediments) in ice-cores, the North Atlantic, the Mediterranean and several adjacent areas. The range of tephrochronology has radically been extended into geographic areas not previously considered suitable for this approach and many more records can now be integrated in a 'tephra lattice' for precise linking of sequence. In this talk, I will give a comprehensive overview of the state-of-art of tephrochronology of North Europe and also present some prospects for the future.

POSTER

Holocene tephra stratigraphy in the Vestfirðir peninsula, NW Iceland

Esther Ruth Guðmundsdóttir[1], Anders Schomacker[2], Skafti Brynjólfsson[3], Ólafur Ingólfsson[4] and Nicolaj K Larsen[5]
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In recent years the terrestrial tephra stratigraphy in Iceland has been vastly improved through detailed investigations of soil and lake sediment archives revealing hundreds of tephra layers. These studies have focused on areas in south, north, east and central parts of Iceland. Fewer studies have been carried out in west Iceland. The aim of this study was to significantly improve the knowledge of tephra stratigraphy and tephrochronology in western Iceland by investigating the sedimentary records from eight lakes in the northernmost part of the Vestfirðir peninsula. In these eight lake sediment records spanning the Holocene, 39 tephra layers have been identified, thought to represent 34 eruptive events originating from five volcanic systems; Hekla, Katla, Snæfellsjökull, Grímsvötn and Veiðivötn-Bárðarbunga. Of these 39 tephra layers, 34 have not been reported before in the Vestfirðir peninsula. Six have recently been reported in the area; the Hekla 1693 tephra (Brynjólfsson et al., 2015) Snæfellsjökull Sn-1 tephra, Hekla 3 tephra, Hekla 4 tephra, Brattihjalli tephra (Schomacker et al., 2016) and Saksunarvatn tephra (Schomacker et al., 2016; Harning et al., 2016). Here we propose that the Brattihjalli tephra is in fact the 6060 year old Hekla Ö tephra marker layer, demonstrating that the Hekla Ö tephra extended much further to the west than previously reported, covering about 2/3 of the country. Thus, the Hekla Ö tephra covers an as large area in Iceland as the Hekla 5, Hekla 4, Hekla 3 and Hekla 1104 tephras, emphasizing the importance of Hekla Ö as a chronological marker.

POSTER

Timing of early Holocene explosive eruptions in Iceland – improved tephrochronology

Maarit Kalliokoski[1], Esther Ruth Guðmundsdóttir[2], Bergrún Arna Óladóttir[1], Hreggviður Norðdahl[3] and Ívar Örn Benediktsson[3]
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The Icelandic tephrochronology is an important tool for dating and correlating sedimentary archives, landforms and archaeological sites both in Iceland and overseas. A robust tephrochronology is also essential for deriving information on eruption frequency patterns. However, the early Holocene part of the Icelandic tephrochronology lacks securely dated tephra marker horizons. Ages of the tephra layers between the Hekla 5 and Saksunarvatn tephras in soil profiles and peatlands have previously been dated only indirectly by interpolating soil or sediment accumulation rates between tephra layers of known age. As this period represents about one third of the Holocene, it is critically important to establish new tephra markers within this part of the tephrochronology. The detailed tephra stratigraphy from Lake Lögurinn, East Iceland (Gudmundsdóttir et al. 2016) was used as an aid in selecting potential tephra markers in soil sections, lake sediments and peatlands in East, Northeast and North Iceland. To qualify as a tephra marker, a tephra needs to have at least regionally significant dispersal area, it must be securely dated and harbour characteristics which distinguish it from other tephras close in age (Larsen and Eiríksson 2008). Thus, new marker tephras for the early Holocene are established by electron probe microanalysis of tephra geochemistry, careful comparison of tephra stratigraphy between sites and radiocarbon dating of selected tephra layers.

1.5. New trends in the study of the crystallisation and evolution of layered mafic complexes

ORAL

Strontium isotopes in plagioclase record magma chamber dynamics of the Skaergaard intrusion

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We report Sr isotope data obtained by laser-ablation multi-collector ICPMS for individual plagioclase crystals from the Skaergaard intrusion. Guided by micro-XRF petrography, we targeted cores and rims of primocrysts, as well as interstitial plagioclase from all major zones and subzones of the Layered Series (LS), Upper Border Series (UBS), and from the Sandwich Horizon (SH) and transgressive granophyre. Current analytical protocol enables $^{87}Sr/^{86}Sr$ determination with precision of 1 part in 10^4 using a Nu Plasma II mass spectrometer and RESOultion 193 nm excimer laser with a ~150-um-diameter beam. Initial $^{87}Sr/^{86}Sr$ ratios (weighted means for individual samples) range from ~0.7041 to 0.7045 for plagioclase ranging from 25–70 An%. There are correlations between $^{87}Sr/^{86}Sr$ and An%, with the largest variation in $^{87}Sr/^{86}Sr$ among An-rich plagioclase. Stratigraphic relations show a progressive increase in $^{87}Sr/^{86}Sr$ from ~0.7041 at the base of Lower Zone A to ~0.7044 at the top of Lower Zone B, a value that is essentially uniform up stratigraphy through the SH. The UBS mirrors the LS, but also contains radiogenic An-rich plagioclase ($^{87}Sr/^{86}Sr$ up to ~0.7045) near the roof of the intrusion in contact with Tertiary volcanic rocks. In the field these samples are associated with rafts of partially assimilated Precambrian gneiss. The plagioclase Sr isotopic record suggests an important role for in situ AFC processes during early stages of Skaergaard evolution that diminished with inward solidification and insulation of the magma

reservoir from country rocks and, in particular, the roof zone of the UBS containing rafts of basement material.

ORAL

Magmatic fractionation by cumulate rock formation with expulsion of residual melts: a case from the Tertiary Kærven Syenite Complex, East Greenland

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The evolution of silicate melts by crystal fractionation processes in magma chambers is relatively well understood from experimental petrology, thermodynamic modelling, and suites of volcanic rock. However, from studies of plutonic complexes it is evident that our understanding of the physical processes acting in magma chambers during the crystallisation of magmas, and which are believed responsible for the evolution of silicate melts, needs further clarification, even with respect to quite fundamental issues. We present new major and trace element data from an intrusive unit of the Tertiary Kærven Syenite Complex, East Greenland. The geochemistry of the syenitic rocks of the WK-2 unit displays ambiguous indications for their formation. On one hand accumulation of a gabbroic mineral assemblage is indicated from linear correlation of several elements, and on the other hand an alkali feldspar dominated assemblage significantly affects the rock compositions as shown by high Eu/Eu*, Ba and K/Rb. A simple liquid line of descent by fractional crystallisation executed by crystal settling or open system wall rock crystallisation cannot explain the geochemical variation. Instead, we present a crystallisation model for the WK-2 unit consisting of a) partial crystallisation of an isolated mush during which the liquidus assemblage changes from gabbroic to alkali feldspar syenitic, b) expulsion of a fraction of the residual liquid, and c) final crystallisation of the remaining liquid fraction. The model is in line with the in the situ crystallisation of Langmuir (1989), and also, with variations, apply to some other KSC intrusive units.

ORAL

Differential migration of interstitial immiscible liquids in the Skaergaard Layered Series

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The liquid line of descent of the Skaergaard magma intersects a binodal creating an immiscible conjugate pair comprising a dense Fe-rich liquid and a buoyant Si-rich liquid. These two liquids have different wetting properties: the Si-rich liquid wets plagioclase, whereas the Fe-rich liquid wets oxides, pyroxene and olivine. The two liquids may therefore undergo differential migration within a gabbroic crystal mush: the Fe-rich liquid sinks and accumulates in mafic layers, while the Si-rich liquid rises and accumulates in plagioclase-rich regions. Microstructural evidence demonstrates that differential migration occurred in rapidly deposited modally graded layers from LZc upwards in the Layered Series. The melanocratic bases of modally graded layers in UZa develop finely-spaced internal layering, consistent with patterning driven by different wetting properties of the immiscible interstitial liquid.

Evidence for differential migration is also recorded by mafic and felsic rims developed on the top and bottom margins of anorthositic roof blocks in LZc. Highly tabular blocks have an upper mm-thick mafic rim and a lower leucocratic rim. As the block aspect ratio decreases, the rims disappear, with the mafic rim retained at lower aspect ratios than the leucocratic rim. These rims are formed as the Fe-rich interstitial liquid sinks through the mush until it reaches the relatively impermeable blocks, whereas the Si-rich liquid

rises and ponds beneath them. Tabular blocks are most effective at trapping these liquids.

These observations demonstrate the complexity of behaviour in a crystal mush containing two-phase interstitial liquid. Simple cumulate paradigms do not apply in such a system.

ORAL

Sedimentary layering in mafic intrusions: the Skaergaard trough bands

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The trough bands of UZa of the Skaergaard Intrusion comprise individual stacks of upwardly concave, crescentic, modally graded layers, forming elongate structures pointing towards the intrusion centre from the nearby vertical wall on the western part of the chamber floor. Their origin is contentious, with some advocating a sedimentary origin while others argue for post-accumulation formation via recrystallization and metasomatism primarily triggered by localised gravitationally-driven compaction.

Crescentic modally graded layers are present throughout the Layered Series below UZa. Although they do not commonly form extensive stacks, their bases are clearly erosional surfaces, attesting to their sedimentary origin. Similar erosional surfaces are commonly preserved in the UZa trough bands, associated with changes in axial positon or width of the trough. The UZa trough bands occur within a ~300m thick stratigraphic interval containing abundant highly elongate prismatic plagioclase grains that we argue were derived from collapse of the wall mushy layer. Detailed microstructural analysis of the modally graded layers in the trough bands demonstrates a locally developed strong mineral lineation parallel to the trough axis, together with morphological evidence for deposition of individual euhedral grains. Evidence from consideration of dihedral angle variation and the morphology of late-stage gabbroic pegmatites suggests that the floor mush near the wall at UZa times was anomalously thick. We argue that trough bands are a normal component of sedimentation on the floor of the chamber, and that the unusually extensive stacks of trough bands in UZa are a consequence of temporary overthickening and steepening of the floor.

ORAL

Late-stage melt migration in the Skaergaard Intrusion

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The Skaergaard Intrusion preserves a variety of late-stage melt structures such as gabbroic pegmatites, paired felsic and mafic lenses (interpreted to be solidified coarsened immiscible emulsions), dendritic anorthosites, and melanogranophyres. Previous work on such structures has focused on particular localities in the intrusion, treating each structure in isolation.

We have established relationships between the different melt migration structures, linking morphological and compositional variation to the physical properties of the crystal mush and the progressive evolution of the bulk magma. Gabbroic pegmatite morphology varies through the floor cumulates due to changes in mush rheology (Larsen & Brooks, 1994), consistent with newly developed constraints on mush thickness. Pegmatites are podiform in thick mush but planar in thin mush. They are spatially associated with paired felsic and mafic lenses, which occur 5-10 metres stratigraphically above pegmatites in LZ, but at the same stratigraphic horizon in UZ. The paired lenses form irregular, approximately layer-parallel clusters in thick

mush, but thin concordant dendritic structures within strongly foliated modally graded layers. The modal mineralogy of the paired lenses evolves upward consistent with evolution down the binodal: below LZc the mafic component comprises olivine pyroxenite, but is dominated by oxides above LZb. In UZb pegmatites are melanogranophyric, and paired lenses are confined to localised horizons recording significant syn-magmatic disruption, consistent with the inferred evolution of the bulk magma towards the Si-rich side of the binodal.

Our observations demonstrate that mush physical properties control the movement of interstitial liquids, with wide-ranging implications for our understanding of sub-volcanic processes.

ORAL

Skaergaard gabbros: Fractionation and dissolution in crystal mush

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Recent work on the macro-rhythmic (MR) layered gabbros in the Skaergaard Intrusion that host the PGE-Au mineralisation shows that their evolution involved dissolution of early-formed liquidus phases and the convective loss of interstitial liquid (mush melt). An early formed liquidus paragenesis (P1) was replaced by a gabbroic paragenesis (P2) that crystallised from mush melt and was out of equilibrium with the contemporary bulk liquid. P2 constitutes up to 50 vol. % of the sampled gabbro and hosts droplets of immiscible sulphide melt.

Melts on the liquid line of descent reach the two-liquid field and unmixed in Fe- and Si-rich silicate melts when the intrusion was 90 % solidified. The mineralization formed after 75% crystallisation and MR layers of the mineralisation would retain ~25 wt. % dense and Fe-rich melt after crystallisation of 60% of its mass and a convective loss of ~15 wt % Si-rich melt.

In bulk MR rocks, FeO and P_2O_5 are negatively correlated. Gabbros rich in P2 are poor in P_2O_5, except for the main Au mineralisation and samples with granophyric veins. Using a SOM (self-organizing map) analysis, Au Ce, Y, Nb and Pb are shown to follow P_2O_5, and Au is added along grain boundaries to layers already enriched in precious metal bearing droplets of sulphide melt.

The present-day gabbros represent the sum of processes acting between the liquidus and subsolidus in semi-closed, proto-MR layers. Mush melts fractionated until their evolved residuals were re-mixed into and drove the evolution ofremaining bulk liquid.

ORAL

Untangling the formation of adcumulate rocks in layered intrusions: a microstructural study of the Skaergaard and Bushveld intrusions

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Despite decades of study, the formation of adcumulates remains a topic of discussion in the layered intrusion community. Models for the formation of adcumulates broadly fall into two groups: 1) those based on a primary origin by the growth of primocrysts in chemical communication with the overlying bulk magma (Wager et al., 1960); and 2) those based on two-phase flow, whereby the evolved melt is expelled from the crystal mush by gravitationally-driven compaction (McKenzie, 2011, Meurer & Meurer, 2006; Sparks et al., 1985; Tegner et al., 2009).

To resolve this issue, we performed a detailed microstructural examination of two different examples: the Layered Series of the Skaergaard Intrusion, and anorthosites from Upper Zone of the Bushveld intrusion. We analysed grain

orientation by electron backscatter diffraction, and compared this with mineral chemistry. Plagioclase in the Skaergaard shows almost no evidence for crystal plasticity, and no evidence for dissolution-reprecipitation. We argue that Skaergaard gabbros underwent negligible compaction and therefore that the adcumulates are primary. In contrast, Bushveld anorthosites show ample evidence for dislocation creep such as low angle boundaries, and neoblasts formed during dynamic recrystallisation. However, the extent of deformation is the same for anorthosites both immediately below and above metre-scale magnetitite layers, suggesting that the deformation is likely to be due to regional slumping, rather than internally-generated buoyancy forces.

Our results suggest that compaction is not the main mechanism that drives the formation of adcumulates but, when present, can result in a minor medication of the primary igneous fabric.

ORAL

Combined 'sedimentary' and in-situ origin for magmatic Fe-Ti-V deposits: new insights from the Skaergaard intrusion, East Greenland

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New field observations from Skaergaard, East Greenland reveal five 0.5–2m thick, oxide-rich intervals within a ~30 m thick sequence near the top of LZc. Individual intervals are continuous along strike from the centre of the intrusion to the margin. This sequence exhibits density-sorted modal layering defined by basal concentrations of Fe-Mg rich phases (including magnetite and ilmenite) and top-of-interval concentrations of plagioclase. The layering style develops from being wispy and laterally discontinuous close to the margin, to strongly defined and laterally continuous at the centre. On-lapping, layer-truncation and channel-like features are commonly observed. The oxide-rich horizons are commonly associated with stoped wall and roof blocks, up to 400 m long, which are oriented with long-axes parallel to the floor. In the size range 10^{-1}–10^{1} m, the tops of high aspect ratio blocks exhibit cm-thick oxide rims; the undersides exhibit cm-thick rims of leucocratic (felsic) material. These paired rims are absent from low-aspect ratio blocks. Oxide-rich seeps, discordant to layering, are also commonly observed.

On the basis of these observations we propose a combined 'sedimentary' and in-situ magmatic origin for Fe-Ti-V deposits whereby (1) newly-crystallised, gravitationally unstable material, was removed from the wall and deposited on the floor; the deposition process resulted in density-sorted modal layers, and (2) liquid immiscibility in the mush produced conjugate Fe-rich silicate and felsic liquids that enhanced the primary modal layering, and led to the oxide-rich seeps and paired rims on blocks. This model is compatible with the absence of LZc on Skaergaard's western margin.

1.6. Alkaline magmatism, carbonatites and associated mineral resources.

ORAL

Clinopyroxene as a petrogenetic indicator: using integrated trace element and zoning profiles to reveal magma chamber processes in the Ditrău alkaline magmatic system

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Clinopyroxene is considered as a significant petrogenetic indicator that can be used to unravel the evolution of magmatic systems. EMPA and LA-ICP-MS have been used to analyse major and trace element compositions of diverse clinopyroxene crystals in seven related rock types of the alkaline igneous suite of the Ditrău Alkaline Massif, Romania.

Phenocryst and antecryst populations from high-Cr Fe-diopside to high-Zr aegirine-augite have been distinguished based on mineral zoning patterns and geochemical characteristics. Clinopyroxenes record two major magma sources as well as distinct magma evolution trends. The diopside population is derived from an early camptonitic magma related to basanitic parental melts, whilst a group of diopside-hedenbergite crystals represents a newly identified Na-, Nb- and Zr-rich magma source for the the Ditrău magmatic system. This magma fractionated towards ijolitic and later phonolitic compositions with pronounced HREE, Nb, Zr and Hf enrichment along with increasing Na/Ca ratio. Field observations, petrography and clinopyroxene-melt equilibrium calculations reveal open- and closed-system magma chamber processes that played a role in the magmatic evolution: magma recharge and mingling, pyroxene recycling, fractional crystallisation and accumulation. Repeated recharge events of the two principal magmas resulted in multiple interactions between more primitive and more fractionated co-existing magma batches.

Investigation of complex zoning characteristics and equilibrium melt calculations show that antecryst recycling is a significant process during magma recharge and demonstrate that incorporated crystals can significantly affect the host magma composition and so whole-rock geochemical data should be interpreted with great care.

ORAL

Probing the structural state of Y and Nd in eudialyte using X-ray absorption spectroscopy

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Eudialyte group minerals (EGM) are important rare earth-bearing alkali-zirconosilicates in agpaitic syenites. Alongside c.12 wt.% ZrO_2 and 1-2 wt.% Nb_2O_5, EGM host c.1-10 wt.% total rare earth oxides with relatively high proportions of valuable heavy REE (c.35%). The EGM structure accommodates REE in various sites, mostly inferred to occupy the 6-fold coordinated Ca-dominated M1-site, or the low symmetry 8-9-10-

fold coordinated Na-site. However, XRD refinement is relatively insensitive to REE site allocation, and HREE and LREE may occupy different sites due to their varying ionic radii. How REE are distributed on the micro-/nanoscale, particularly following fluid interaction, is poorly known. We use synchrotron radiation X-ray absorption spectroscopy to study the structural state and distribution of LREE and HREE in EGM and their alteration products. We collected Y K-edge and Nd L_{III}-edge μ-XANES and μ-EXAFS to quantify coordination numbers and bond distances, with Y and Nd as proxies for HREE and LREE respectively. Micro-XRF element mapping combined with SEM and TEM provide insights in the micro-/nanoscale REE distribution in EGM and its alteration products. Crystalline (XRD-confirmed) EGM from Ilímaussaq, Narssârssuk, Norra Kärr, Kipawa and Lovozero yield near-identical μ-XANES for Nd and Y, indicating similar LREE/HREE site occupations in EGM of varying compositions. Preliminary Y EXAFS processing of the Narssârssuk EGM yield optimal fits in 6-fold coordination and Y-O bond distances of c. 2.26-2.32 Å, consistent with Y substitution for Ca on the octahedral M1-site. Cerium absorption in the Nd L_{III} pre-edge region demonstrates minor variations in Ce-oxidation state across the localities.

ORAL

The Spatio-Temporal Evolution of Hf isotopes in the Gardar: Evidence for Mid-Proterozoic Crustal Recycling?

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The Gardar Province of Greenland refers to alkaline magmatism from intraplate rifting in the Mesoproterozoic. To understand further the sources of heavy REE and HFSE in the Gardar, we analysed the Lu-Hf isotopes of several Gardar centres, representing early (Motzfeldt, North Motzfeldt, Ivigtut) and late (Ilímaussaq, Østfjordsdal, Narsarsuk, Nunarsuit, Paatusoq) Gardar magmatism and the geographical extent of the Province from Ivigtut in the West to Paatusoq in the East. Gardar magmas intruded Archaean crust (Ivigtut), Ketilidian metasediments (Paatusoq) and Ketilidian granitoids (the others).

Age-corrected Hf isotopes show low Hf values inconsistent with sourcing from depleted mantle in Gardar times. Early Gardar zircons have significantly lower age-corrected Hf than those of the Late Gardar. Hf signatures in Early Gardar zircons project back to Ketilidian or older mantle extraction ages (> 1.8 Ma). One might interpret such data to indicate that Hf in the Early Gardar zircons was scavenged from Ketilidian basement. However, primary Gardar melts are unlikely to have contained negligible Hf and an unrealistic proportion of assimilated Ketilidian Hf is required. However the data are consistent with a model whereby subduction of Archaean crust (i.e. very low $^{176}Hf/^{177}Hf$) during the Ketilidian enriched the subcontinental lithospheric mantle with Archaean Hf. In Gardar times, mantle melting preferentially accessed this subducted (Archaean) mantle component, providing magmas with anomalously low Hf isotopic ratios. As rifting continued, proportionately more contemporary Hf was present in the melts. The model suggests recycling of Archaean crust via the mantle in Gardar times.

ORAL

Geochemical constraints on the formation of the Archean Siilinjärvi carbonatite-glimmerite complex, Fennoscandian shield

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With an age of 2610 ± 4 Ma the Siilinjärvi carbonatite-glimmerite complex in Finland is one of the oldest known carbonatites and the oldest being currently mined for phosphorous. It was

emplaced in the Karelia Province following cratonic stabilization. The Siilinjärvi complex consists of carbonatite, calcio-carbonatite, carbonatite-glimmerite, and glimmerite surrounded by a fenite, forming a tabular body 16 km long and 1.5 km wide. The complex is affected by north-south Palaeoproterozoic steep shearing. Carbonatite occurs as thin (several cm) roughly vertical lenses in glimmerite that forms thicker (10 cms) vertical veins. Despite the large carbonate-phlogopite modal variablity, compositions of the phases calcite, dolomite, tetraferriphlogopite, apatite and richterite do not vary significantly across the complex. The distribution of apatite is rather uniform, with average glimmerite and carbonatite containing 10.4 and 9.9 modal % apatite, respectively. Compositionally the carbonatite veins are calcio-carbonatites, whereas the glimmerites are potassic ultramafic rocks with Mg# over 0.8. All are cumulates, but are geochemically linked, showing similar trace element trends. Average C-O isotopic compositions are $\delta^{13}C$=3.7‰ and $\delta^{13}O$=7.4‰. The geochemical data indicate that the carbonatite and glimmerite are cogenetic with fractionation processes possibly playing a significant role in their genesis. Isotopic compositions show relatively uniform patterns and, we propose that the carbonatite and related lithologies are evolved from primitive carbonatite liquids produced by low degree melting of a carbonated mantle source. We propose that the complex has represents a relatively deep well mixed magma chamber with consequent accumulation and crystallization, feeding magmatic activity at higher levels.

ORAL

Fluid-rock reactions in the carbonatites of the 1.3 Ga Grønnedal-Íka alkaline complex, Southwest Greenland

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Petrogenetic studies of carbonatites – carbonate-dominated igneous rocks – are challenging because carbonatite mineral assemblages and mineral chemistry typically reflect variable pressure-temperature conditions during crystallization, and fluid-rock interaction caused by magmatic-hydrothermal fluids. However, this complexity results in recognizable alteration textures and trace element signatures in the mineral archive that can be used to reconstruct the magmatic evolution and fluid-rock interaction history of carbonatites.

Our study focuses on the 1.3 Ga Grønnedal-Íka carbonatite-syenite complex in Southwest Greenland. The alkaline complex marks the onset of the Gardar continental rifting event, during which it was subsequently intruded by basaltic dikes and underwent extensive faulting. We present LA-ICP-MS trace element data for magnetite, calcite, siderite and ankerite-dolomite from the iron-rich carbonatites of Grønnedal-Íka, and use this data, in combination with detailed cathodoluminescence imaging, for identifying magmatic and secondary geochemical fingerprints preserved in these minerals.

The chemical and textural gradients point toward a 55 m wide basaltic dike as the focal point of a fossil hydrothermal fluid flow system, providing heat for F and CO_2 rich fluids that mobilized LREEs, Nb, Ta, Ba, Sr, Mn and P. These fluids reacted with and altered the composition of the surrounding carbonatites up to a distance of 40 m

from the dike contact, where a high-grade magnetite mineralization was formed through oxidation of siderite. Our results can be used for discriminating between primary magmatic minerals and later alteration related assemblages in carbonatites in general, which can lead to a better understanding of how these rare rocks are formed.

ORAL

A review of the Transitional Layered Kakortokite (TLK), IlÍmaussaq Complex, South Greenland

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Kakortokite represents the lowest member of the peralkaline magmatic stratigraphy of the Mesoproterozoic IlÍmaussaq Complex, South Greenland. Kakortokite is an agpaitic nepheline syenite of which the lowest part shows spectacular layering. Kakortokite is originally subdivided into three parts: (1) A lower layered kakortokite (LLK) about 200 m thick, (2) slightly layered kakortokite (SLK) about 35 thick, which is overlain by (3) transitional layered kakortokite(TLK) with a thickness of about 40 m. The LLK consists of three-layered units composed of black, red, and white layers formed by modal enrichment of arfvedsonite, eudialyte and feldspar-nepheline respectively. SLK is almost unlayered and appears as a grey kakortokite, locally with faint black layers. TLK represents a return to the black-red-white-layered units.

TLK is best exposed north-west of the proposed fault along Lakseelv where it gradually grades into the overlaying lujavrite. In this section, nine eudialyte-enriched layers occur named A to I in descending order from the contact to the lujavrite. The uppermost four layers (A-D) occur as a complex intergrowth of several rock types, which pinch and swell and include eudialyte-rich and naujaite-like rock. These layers are not a simple modal enrichment of eudialyte, but are interpreted by us as a reaction between naujaite slabs and kakortokite magma. The remaining layers (E-I) occur as faint layers in grey kakortokite and represent a local modal enrichment of eudialyte. Therefore, we suggest the kakortokite stratigraphy to be described as LLK (≥ 200 m) overlain by SLK (≈ 75 m).

ORAL

Alkaline pegmatites of the Larvik Plutonic Complex – what are they?

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The Larvik Plutonic Complex is a differentiated alkaline complex situated in the Permian Oslo Region and consists of a series of semi concentric ring intrusions of monzonitic rocks (Petersen 1978; Neumann 1980). The monzonitic rocks are collectively known as larvikite and extensively quarried as a dimension stone. Within the host plutons numerous nepheline syenite and syenite pegmatites, as well as minor nepheline syenite dykes occur with an ambiguous relationship and contrasting mode of emplacement. Although many of these pegmatites have been extensively studied for their mineral content and provided first descriptions of 30 mineral species, the petrological evolution of the pegmatites is still poorly understood. Different classification schemes have been devised to relate and compare contrasting pegmatite features such as morphology, mineralogical zonation, and rock textures (e.g., Brogger 1890; Piilonen et al. 2012). However, such differences are not directly related to petrogenetic similarities between these pegmatites. Wöhlerite, ideally $NaCa_2(Zr,Nb)(Si_2O_7)(O,OH,F)_2$, occurs abundantly among the early liquidus mineral assemblages of the nepheline syenite pegmatites. The flexible

crystal structure of wöhlerite is able to incorporate cations of different size and valence, and thus record contrasting pegmatite-forming magmas.

This contribution provides a regional comparison of wöhlerite major- and trace-element composition coupled with detailed field mapping of selected pegmatites to reveal a close petrogenetic relationship between pegmatites and heterogeneities of the host larvikite.

ORAL

Trace element and Nd-isotope data of eudialyte from the Kakortokite sequence of the Ilímaussaq complex suggest subsolidus remobilization of rare earth elements by magmatic fluids

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The kakortokites, agpaitic floor cumulates of the peralkaline Ilímaussaq Complex, South Greenland (1160 Ma[1]), constitute a world-class deposit of rare earth elements (REE), largely hosted in the alkali-zirconosilicate eudialyte. Autometasomatic and/or hydrothermal alteration of eudialyte has caused formation of pseudomorphs exhibiting a variety of secondary REE-/Zr-phases. Previous work[2] identified three alteration types, characterized by the secondary zirconosilicates catapleiite, gittinsite and zircon.

Here we present ICP-MS trace element and TIMS Sm/Nd isotope data of micro-drilled eudialyte-pseudomorph pairs from four samples spanning the kakortokite stratigraphy (three catapleiite-type, one gittinsite-type) and one zircon-type pseudomorph sample from the 'hybrid' units that cross-cut them, to study the nature of altering fluids and their high field strength element (HFSE-)mobilizing capacity.

Trace element data show catapleiite-alteration caused a 15-25% decrease in REE, Ta, Nb, Zr, Sr and Y (relative to precursor eudialyte) and up to four-fold increase in Rb and Th ($[Th]_{pmo}$ = 27-100 ppm), while gittinsite- and zircon-alteration caused stronger heavy REE (HREE) depletion (≤50%). REE fractionation is evidenced by lowered Sm/Nd ratios in all but one pseudomorph-sample, indicating that altering fluids were capable of remobilizing and fractionating HFSE and REE.

$^{143}Nd/^{144}Nd_{t=1160}$ ratios of fresh eudialyte (μ_{eud} = 0.511090, s.d. = 5) are indistinguishable from those of pseudomorphs (μ_{pmo} = 0.511097, s.d. = 7) at the 90% confidence level, suggesting that fluids were (late-)magmatic in origin. However, zircon-type pseudomorphs yield higher $^{143}Nd/^{144}Nd_{t=1160}$ (0.511166±7), which, combined with stronger HREE depletion and enrichment in Sr (130%) and Ba (79%) hints at a different origin for the zircon-forming fluid.

POSTER

Mineralogy and petrology of mafic dikes from the Siilinjärvi carbonatite complex, Finland

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The 2.6 Ga Siilinjärvi carbonatite complex in central Finland is transected by a large number of mafic dykes. Here we combine field-relations, with mineralogical and petrological analysis to infer dike emplaced in three distinct stages. The older two generations (Gen I and II) are intesely deformed in constrast to the composite dike of Gen III.

Mineralogically the dykes are comparable, containing plagioclase, amphibole, quartz, calcite

as major phases, with accessory chlorite, apatite, epidote, titanite and opaques. Gen I dykes have characteristically allanite and near-euhedral chamosite crystals (chlorite), surrounded by fine-grained titanomagnetite/ilmenite. These chamosites are likely pseudomorphs replacing original phlogopite crystals.

The alkaline composition of Gen I dykes (predominantly K-rich foidites, with up to 13 wt.% Na2O+K2O) suggests that they are related to different degrees of mantle melting. It is simply not possible to produce the observed compositions by fractionation of any potential phenocryst phase. The two younger dyke generations can be reproduced by a relatively "normal" basaltic fractionation series (spanning from basalts, via K-rich alkali-basalts to trachytic compositions).

The Gen I dykes seem to be directly associated with a mantle source similar to that which produced the apatite-bearing carbonatites. The later dyke generations have bulk-rock compositions that are not normally found in direct relation to carbonatites, indicating a significant time gap between the Gen I dykes and subsequent generations in which time the mantle source had changed significantly to produce these chemically contrasting magma suites.

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POSTER

Geochronology of the Särna alkaline complex, Dalarna, Sweden

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The Särna alkaline complex is a well-known yet poorly studied locality of highly peralkaline igneous rocks in middle Sweden. It mainly consists of two rock types: varieties of intrusive cancrinite nepheline syenite (särnaite) and crosscutting tinguaite dikes. While different whole-rock särnaite samples did not form an isochron, mineral separates derived from särnaite have yielded a Rb–Sr age of 287±14 Ma (2σ) (Bylund and Patchett, 1977), broadly coeval with the Permian Oslo Rift magmatism (ca. 308–245 Ma: Larsen et al., 2008), but not precise enough to draw confident parallels.

To further constrain the timing of magmatic activity at Särna, we are studying the Rb–Sr systematics of these alkaline igneous rocks by a newly developed technique for in situ Rb–Sr dating by LA-ICP-MS/MS (Zack and Hogmalm, 2016). Detailed characterization of mineral textures and chemistry by SEM in combination with micro-analytical dating can give reliable Rb–Sr ages of alkaline rocks, which are notorious for pervasive alteration and open-system behaviour. Preliminary results include the first radiometric age of a Särna tinguaite, which was dated at 296±7 Ma (2σ) in biotite phenocrysts and confirms that the särnaite and tinguaite are coeval. Deriving more precise ages from a variety of rock types will also allow us to make more robust connections with the phases of formation of the Oslo Rift.

POSTER

Thorium in eudialyte ore deposits from Greenland studied by synchrotron radiation (μ-XRF/-XAFS) and electron microscopic techniques (SEM, TEM)

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The Nordic region holds some of the world's largest eudialyte deposits, which contain promising rare earths concentrations. Due to low content of actinides (including thorium / Th) in such rocks, eudialyte would avoid many of the issues of potential radioactive contamination in tailings that bedevil e.g., monazite and xenotime extraction. Here, we study the nature of Th associated with rare earth elements (REE) in eudialyte ore deposits from Greenland in micro-/nano-scale using the technical advance of combining synchrotron radiation (SR μ-XRF/-XAFS) and electron microscopic (SEM, TEM) techniques. Preliminary synchrotron radiation & electron microscopic observations of altered eudialyte reveal the presence of Th-bearing phases at the micro-/nano-scale. Similar heterogeneity is observed for the REE in eudialyte replacement products. We collected Th L_{III}-edge extended x-ray absorption fine structure (μ-EXAFS) spectral data of Th-enriched microareas, identified by SR μ-XRF mapping that confirmed the heterogeneous distribution of Th, which provide information on the local structural environment of Th within altered eudialyte. Th-bearing phases were detected along altered margins of eudialyte, in secondary phases, and interstitial to primary phases such as feldspar, amphibole and eudialyte. Concerning fresh eudialyte, Th is undetectable by SR μ-XRF. However, further research is needed to clarify these phenomena.

POSTER

Varena suite in the crystalline crust of the Southern Lithuania: implication to the genesis and mineralization.

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Crystalline crust in Southern Lithuania is covered by 200-500 m thick sedimentary cover and is investigated by potential field mapping and drilling. It is composed by amphibolites (metabasalts), biotite-quartz-plagioclase gneisses (metapsammites and porphyry metadacite and metaandesite) of Orosirian period. Each lithology is predominant in alternating bands extended NNE-SSW. Supracrustals are metamorphosed on the level of amphibolite facies and migmatized. Intrusive rocks are represented by coeval rare bodies of gabbro, peridotite and widespread Calymmian granitic plutons (Motuza 2005; Linnemann et al. 2008).

Varena suite comprises olivine, enstatite, diopside, olivine-magnetite, magnetite, apatite-bearing, and presumably also dolomite rocks. They form integrated bodies few sq. km large, concentrated in the ~300 km^2 area extended in N-S direction(Motuza et al. 2016).

Rocks of Varena suite and the country rocks (amphibolites, metaporphyres) are affected by strong metasomatic alteration. The mineralization of REE (up to 2759-3100ppm of La and Ce respectively), Th, U, P hosted by monazite, apatite(?), allanite is spatially related to the Varena suite and some metasomatized supracrustals.

The views on the genesis of Varena suite are contradicting. By various authors they are regarded as skarns, presuming metasomatic origin, as layered intrusions or products of alkaline and carbonatitic magmatism(Motuza et al, 2016).

In this presentation the genetic model is reviewed based on reinterpretation of structural, geochemical, petrographical data, and new isotopic studies of O, C, Sr in the rocks of Varena suite. It is also an attempt to raise methodological questions such as Lu-Hf dating of apatite and find opportunities for cooperation in further studies.

POSTER

New Rb-Sr and Zircon U-Pb dating of the Grønnedal-Íka igenous complex, SW Greenland

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Dating of the Grønnedal-Íka igneous complex in Southwest Greenland is important to understand the continental rifting event – the Gardar episode. In this study, three different methods have been applied to rock specimens and previously published data to better constrain the age of the complex: a) U-Pb dating of zircons extracted from hand specimens of Upper Series nepheline syenites and from drillcore samples of a central carbonatite plug collected by Kryolitselskabet Øresund A/S, b) new in-situ Rb-Sr analysis on Lower Series granular syenite, and c) re-calculation of whole rock Rb/Sr data by Blaxland et al. (1978).

Prismatic zircons, 100-200 µm in size, light brown in colour, showing magmatically zoned cores and irregularly shaped alteration rims with overgrowths of U and Th oxides were analysed with ThermoFinnigan Element 2 Inductively Coupled Plasma Sector Field Mass Spectrometer instrument at GEUS. This gave an U-Pb age of 1325±6 Ma after having selected suitable data points from CL.

In-situ Rb-Sr dating using an Agilent 8800 ICP MS/MS on selected minerals from granular syenite gave an isochron age of 1314±14 Ma on the basis of 20 spots in biotite and k-feldspar using the technique outlined in Zack and Hogmalm (2016). Re-evaluation and re-calculation of the whole-rock dataset from Blaxland et al. (1978) with the newly revisioned Rb-Sr decay constant (Villa et al., 2015) yields an age of 1311±26 Ma.

This confirms the Grønnedal-ìka complex as the oldest of the Gardar intrusions and most likely marks the onset of the Gardar continental rifting of South Greenland.

POSTER

Experimental simulation and predictive modelling of rare earth element enrichment in carbonatites and alkaline magmas

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Carbonatites and alkaline magmas are key pieces of the deep carbon cycle and constitute one of the principal resources of rare metals including REE. Several experimental studies have tackled the rare metal partitioning between immiscible carbonate and silicate liquids (Martin et al. 2013; Veskler et al. 1998, 2012). They show negative to massive enrichments in the carbonate liquid. However, no prevailing cause has been clearly isolated as such enrichments can be ruled by experimental conditions (P, T, fO_2), melt compositions (water and alkali contents), or technical issues such as unequilibrated experiments.

The aim of this study is to simulate, by HP-HT experiments in the nephelinite-carbonatite system, crystal fractionation and immiscibility between carbonate and silicate liquids, in order to assess the factors ruling REE enrichment during the differentiation of alkaline magmas.

Thirty experimental charges were synthetized using piston-cylinder and internally heated pressure vessel. The partitioning of REE between

carbonate liquids, silicate liquids and crystals (pyroxene, calcite, nephelinite, perovskite, titanite) has been characterized. REE partition coefficients between carbonate and silicate liquid increase while Ca partition coefficient increases, suggesting that both have the same behavior. Also, the more the silicate liquid is polymerized, the more REE are concentrated into carbonate liquids. The Ca partition coefficient has been thus calibrated by an empirical model based on the silicate melt composition.

This study reveals the optimum conditions for which carbonatite melts get enriched by >10 times with respect to the residual silicate melts. This predictive approach may serve as guide for prospection of REE-enriched carbonatites.

POSTER

Polymetallic, REE and precious elements new results within Suwalki Anorthosite Massif, NE Poland

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The Suwalki Anorthosite Massif (SAM) is located in NE part of Poland, within Mezoproterozoic, beltiform magmatic AMCG [anorthosite - mangerite - charnokite - granite rapakivi] suite known as a Mazury Complex. This complex associate with tectonic deep rift crustal structure. The SAM occupies an area of 250 km^2 of the oval shape diapiric structure. Its central part is made up of anorthosites surrounded by rings of norites, gabronorites and diorites. Fe-Ti-V ore minerals concentrations with subordinate Fe-Cu-Co-Ni sulphides that represent 1 to 4% of the rock volume (Wiszniewska J., 2002, Wiszniewska J. et al. 2002) locally even more to a maximum content of 8%.

Chalcopyrite, pyrrhotite, cubanite, pentlandite, cobaltite, bornite, chalcocite, millerite and sphalerite are most common magmatic sulfide minerals. These minerals coexist with Fe-Ti oxides in variable proportion and forms of monomineral aggregates of 3-100 μm, interstitial veins or schlieren of 30-250 μm dimensions. Pyrrhotite makes up nearly 75% of sulphides bulk. Pyrrhotite, chalcopyrite and pentlandite have magmatic origins confirmed by sulfur isotopes of $\delta 34S_{CDT}$ of about 0 ‰. (Wiszniewska J. et al.) Sulfides contain often nanoforms of REE (La, Ce and Nd) and precious elements (gold, platinum) mineral admixtures of 10-100 μm or even up to 300 μm in sulfides. Untypical zircon grains of blown candle flame structure and rims around ore minerals were observed and prepared for age determinations.

New results of polymetallic and precious metal sulfides together with REE dispersed mineralization may increase an economic value of Fe-Ti-V documented deposits in SAM.

1.7. Magmatic Plumbing Systems.

ORAL

A seismic study of the 2014-15 Bárðarbunga-Holuhraun rifting event

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On 16 August 2014 an unusual sequence of earthquakes began near the southeastern rim of the ice-covered Bárðarbunga caldera in central Iceland. Over the course of two weeks a dyke propagated 48 km beneath the glacier northeastwards and into the Holuhraun lava field, where it erupted for six months, becoming the largest eruption in Iceland for over 200 years. During this time, a gradual, incremental caldera collapse took place in the Bárðarbunga central volcano. This study analyses the seismic response to the event, both due to the dyke propagation, and the associated caldera collapse. Approximately 35,0000 earthquakes were recorded during the pre-intrusive, intrusive, eruptive and post-eruptive periods, whereof ~4,000 earthquakes were associated with the caldera collapse, delineating faults accommodating the subsidence and showing good correlation with geodetic data. Detailed analysis of the earthquake source mechanisms shows that ~90% can be explained by a double-couple solution. The dominant failure mechanism during the collapse is steep normal faulting, with sub-vertical P-axes, striking sub-parallel to the caldera rim. The northern and southern sides of the caldera, however experienced very different seismicity rates, highlighted by the order of magnitude difference in the cumulative seismic moments. We present evidence of a complex asymmetric caldera collapse, not controlled by a single caldera ring fault. The ~31,000 earthquakes delineating the segmented, lateral dyke intrusion fractured a pathway through the crust, utilizing pre-existing weaknesses. Despite the extensional rift setting, the dyke emplacement generated exclusively double-couple earthquakes with solely strike-slip faulting mechanisms.

ORAL

Dyke tip processes and large-scale deformation: implications for geodetic modelling

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Geodetic modelling of dykes using the Okada dislocation model has become a standard approach when interpreting geodetic data monitored over active volcanoes. The Okada model assumes that (1) dykes are tensile fractures and (2) the host is purely elastic. However, recent field observations and laboratory results suggest an alternate dyke propagation mechanism; the viscous indenter, i.e. the dyke tip propagates by pushing its host rock ahead, failing in shear. To which extent different dyke propagation mechanisms affect the associated surface deformation is currently unknown. To address this, we compare two series of laboratory models of dyke emplacement, during which we monitored surface deformation at high resolution and precision. In the first series, the model crust was elastic gelatine and the dyke propagated as tensile fracture; the resulting surface deformation was comparable with the predictions of the elastic Okada model, i.e. an elongated topographic trough above the dyke apex, surrounded by two uplifted zones.

Conversely, in the second series, the model crust was a cohesive Coulomb silica flour and the dyke propagated as a viscous indenter; the resulting surface deformation was only uplift. The first-order differences between the two series of models show that local tip processes indeed control large-scale deformation induced by propagating dykes, and so the surface deformation patterns. Our results question the

systematic use of tensile elastic fracture models to interpret geodetic measurements associated with dyke emplacement. Finally, our results show that relevant interpretation of geodetic measurements requires a proper physical understanding of dyke propagation mechanisms.

ORAL

Seismic Interpretation of Sill-Complexes in Sedimentary Basins: The 'Sub-Sill Imaging Problem'

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Application of 3D-seismic reflection-data to igneous systems in sedimentary basins has led to a revolution in the understanding of mafic sill-complexes. However, there is considerable uncertainty on how geometries and architecture of sill-complexes within the subsurface relates to those imaged in seismic reflection-data. To provide constraints on how sill-complexes in seismic data should be interpreted, we present synthetic seismograms generated from a seismic-scale (22x0.25 km) outcrop in East Greenland constrained by abundant field-data. This study highlights how overlying igneous rocks adversely affect imaging of underlying intrusions and rocks by decreasing seismic amplitude, frequency and making steeply dipping features near-impossible to image. Furthermore, seismic modelling in this study shows that, because of the high impedance contrast between siliciclastic host-rock and dolerites, very thin (1-5 m) intrusions should in principle be imaged in reflection-seismic data at 3 km depth. However, comparison with actual seismic data with well-data shows significant amounts of un-imaged sill intrusions, and this is likely due to limited seismic resolution, overburden complexity, inadequate velocity-models, and interference between reflections from closely spaced sills and sill-splays. Significant improvements to sill imaging and interpretation could be made by better predicting occurrence and geometry of sill intrusions and including these in velocity models.

ORAL

Fracture networks in and around igneous intrusions on Svalbard: implications for fluid flow

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Igneous intrusions exert a strong influence on petroleum systems, groundwater aquifers and CO_2 storage reservoirs. This is especially true for migration pathways, as any given intrusion may act as a barrier to, or a carrier for fluid flow, potentially compartmentalizing a reservoir or creating seal by-pass structures. The fracture network in the intrusion and its surroundings will control the permeability along and across a single intrusion. However, the various fracturing processes are relatively poorly constrained, being controlled by magma emplacement, magma cooling and tectonic events, and field data are required to better understand this interplay. In this study we investigate 15 outcrops from central Spitsbergen, Arctic Norway, in order to constrain the impact of Early Cretaceous igneous intrusions on subsurface fluid flow. We combine traditional field mapping with photogrammetry to construct high-resolution 3D virtual outcrop models, providing 330 m of scanlines, 928 fracture measurements using a geological compass and an iPhone and 7993 fracture measurements from virtual outcrop models. Fracture sets, both within the dolerites and the nearby host rocks, are predominantly oriented either parallel or perpendicular to the intrusion contact. At one of the study sites, the fracture frequency in the intrusion-proximal host rocks increases toward the intrusion contact, from 6 fractures/m (f/m) in the background to 10 f/m approximately 1 m from the intrusion contact. Calcite cemented fractures are frequently observed in within intrusions, but also within intrusion-proximal host rocks. A conceptual

model for rock evolution and fracture development in and around igneous intrusions is presented.

ORAL

The relevance of sills and related flat-lying intrusions in volcanic plumbing systems

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Although dykes are considered to be the main upward magma pathways through the Earth's crust, the last two decades of research showed that significant parts of volcano plumbing systems consist of flat-lying igneous intrusions, namely sills. The aim of this contribution is to provide a didactic overview of our current understanding of the formation of sills and of their scientific and economic relevance (Galland et al., accepted).

Sills form mainly in the layered parts of the crust, principally in volcanic deposits and sedimentary basins where lateral magma flow through sill complexes and networks can reach several hundreds kilometers. Sill exhibits various shapes, from strata-concordant, transgressive sheets to saucer shapes. Furthermore, sills represent intermediate feeder structures for volcanic eruptions and, therefore, a better understanding of sill emplacement and evolution is essential for assessing volcanic hazards. Sills emplaced in sedimentary basins also deeply affect petroleum systems and are essential components in exploring hydrocarbons. Finally, the massive and fast emplacement of sills resulting from LIPS in sedimentary basins triggered catastrophic climate changes and mass extinctions during Earth's history.

In this presentation, I will develop the main points of our understanding of sill formation, i.e. the feeders of sills, the factors controlling their initiation, their propagation mechanisms and subsequent evolutions to saucer-shaped intrusions or laccoliths.

ORAL

Deep and shallow magma storage on Bali

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The architecture of sub-volcanic magma supply systems exerts a fundamental control on eruptive behaviour and thus on volcanic hazards. The island of Bali in the Sunda arc, Indonesia, is densely populated and home to two active stratovolcanoes, Agung and Batur, but relatively little is known of their underlying magma plumbing systems. Here we reconstruct magma storage and evolution under Bali by employing clinopyroxene and plagioclase mineral-melt equilibrium thermobarometry, oxygen isotope crystal stratigraphy, and He isotopes in pyroxene. Clinopyroxene records magma storage at the crust-mantle boundary, consistent with mantle-like He isotope pyroxene values and mildly submantle $\delta^{18}O$ values. Plagioclase, in turn, reveals upper crustal magma storage and mantle-like $\delta^{18}O$ values, indicating differentiation of ascending primary magma in upper crustal reservoirs. Indeed, recent arc-wide InSAR data for the Sunda arc revealed frequent shallow-level magma storage along the arc, which contrasts

traditional petrogenetic models for arcs. Multi-level magma storage likely favours prolonged differentiation of Sunda arc magmas, which could promote future hazardous eruptions on Bali.

ORAL

Dyke induced quasi-2D deformation in a Coulomb britte host — the influence of host strength on propagation and emplacement

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The emplacement of magmatic dykes within the Earth's crust represents a fundamental process of magma transport and feeding of volcanic eruptions. Understanding the dyke emplacement mechanism requires an understanding of how the host deforms to accommodate the dyke propagation and growth. Most established dyke emplacement models solely account for tensile opening of an elastic host, whereas the Earth's crust also exhibits prominent inelastic Coulomb brittle behavior. In this study, we aim to encompass how brittle deformation affects dyke emplacement in cohesive Mohr-Coulomb material.

We present quantitative experimental results obtained from a quasi-2D experimental setup (Hele-Shaw cell type), which consists of two vertical glass plates (3 cm gap) containing fine-grained dry Coulomb mixes of silica flour and glass beads with varying cohesions. Golden syrup is slowly injected into the silica flour via a bottom inlet at a constant flow rate for ~1 hour. While the quasi-2D setup restricts the injected syrup to a "sheet-like" intrusion, it allows direct observation of the host deformation such that we can measure displacement maps, shear strains, and surface deformations accommodating dyke emplacement from strong to weak host rocks.

To further interpret our experimental dataset we attempt a numerical comparison using a static elastoplastic 2D code to investigate the expected elastic and plastic deformation using the imposed experimental intrusion geometry and host rock properties.

ORAL

Ground deformation in the Bárðarbunga Volcanic System, Iceland, Following the 2014-2015 Lateral Dyke, Caldera Collapse and Major Effusive Eruption

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The largest instrumentally recorded ground deformation event in Iceland occurred during 2014-2015 within the Bárðarbunga volcanic system. A 48-km-long lateral dyke propagated away from the caldera, followed by six-month-long effusive eruption at the far end of the dyke, while the Bárðarbunga caldera gradually collapsed by 65 meters (Sigmundsson et al. 2015, Gudmundsson et al. 2016). We study ground deformation in the volcanic system after these events, in order to provide an improved understanding of the deformation that follows the events, and distinguish signals induced by visco-elastic responses from those related to renewed melt supply.

We observe ground deformation using Interferometric analysis of Synthetic Aperture Radar (InSAR) and GPS geodesy. Two year interferograms (2015-2017) from Sentinel-1 satellites are created to observe the overall deformation field. Interferogram stacking is implemented to reduce atmospheric noise. Observed deformation is a superpostion of several sources, including glacial isostatic adjustment and steady plate movements. These

effects are subtracted from the observations (Drouin et al., 2017) to reveal excessive displacement rates we attribute to post-rifting relaxation in the dyke area. The movements are attributed to visco-elastic response of the Earth, which results in gradual recovery of the area and higher displacement rate after eruption events. The post-rifting relaxation is modelled by a two-layer model with elastic crust and visco-elastic upper mantle.

In the caldera area, a similar study will help to understand if present inflation and earthquake activity at Bárðarbunga is induced by magma inflow or is a visoelastic response to the large deflation in 2014-2015.

ORAL

Syn-emplacement fracturing in the Sandfell laccolith, eastern Iceland

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Felsic magma commonly pools within mushroom-shaped magma chambers, so-called laccoliths or cryptodomes at shallow crustal levels, which can cause collapse of the volcanic edifice. While deformation of magma in volcanic conduits is an important process for regulating eruptive behaviour (Pistone et al., 2016), the bulk of the deformation associated with laccolith emplacement is considered to occur in the host-rock (Pollard & Johnson, 1973), and the effects of magma deformation on the intrusion emplacement is largely unexplored. Here we describe the deformation associated with the emplacement of the 0.5 km^3 rhyolitic Sandfell laccolith in eastern Iceland, which formed in a single intrusive event. By combining field measurements, 3D modelling, anisotropy of magnetic susceptibility, and microstructural analysis, we quantify deformation that occurred in both the host-rock and the magma to investigate its effect on intrusion emplacement. Magmatic and magnetic fabric analyses reveal contact-parallel magma flow during the initial stages of intrusion emplacement. The magma flow fabric is overprinted by strain-localisation bands, which indicate that the magma subsequently became viscously stalled and was deformed by consecutively intruding magma. This change in magma rheology can be attributed to the interaction between the strain-localisation bands and the flow bands, which caused extensive fracture-rich layers in the magma and led to decompression degassing, crystallization, and rapid solidification of half of the magmatic body. Our observations indicate that syn-emplacement rheology change, and associated fracturing of intruding magma not only occur in volcanic conduits, but also play a major role in the emplacement of shallow viscous magma intrusions.

ORAL

How do sills become laccoliths? An answer from integrated laboratory and numerical modelling

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Igneous intrusions in the upper brittle crust exhibit diverse shapes ranging from thin sheets (dykes, sills, cone sheets), to thick, massive intrusions (laccoliths, plutons, plugs). Presently, none of the established models of magma emplacement have the capability to simulate this diversity because they account for end member rheology of the host rocks (elastic, viscous or plastic), whereas natural rocks are complex elasto-plastic materials. We investigated the effects of host rock rheology on magma emplacement using scaled laboratory models. The model rocks were dry Coulomb granular materials of variable strength (cohesion). We show that strong (high-cohesion) host rock, results in the emplacement of thin, sheet intrusions (sills, cone sheets). Conversely, weak

(low-cohesion) host rock results in the emplacement of massive intrusions (laccoliths, plugs). We integrate our laboratory results with numerical simulations to constrain the host rock deformation mechanism that accommodates magma emplacement in the experiments. Our results show how both sills and laccoliths result from initial thin sills that spread horizontally until triggering shear failure of the overburden at a critical radius. Two scenarios can then happen: (1) the overburden is cohesive enough and allows space opening in the sub-surface to accommodate viscous magma inflow along the failure planes, so sills evolve as sheets (saucer shape or cone sheets), or (2) the overburden is not cohesive enough and does not allow sub-surface space opening to accommodate viscous magma inflow along the failure planes, so the sill inflates and lifts up the overburden along shear zones to form a massive laccolith.

ORAL

Structure and dynamics of the Krafla magma domain and its associated geothermal area: Ground deformation and magma plumbing at the Krafla Magma Testbed, Iceland

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We interpret extensive volcano geodesy results at Krafla volcano, Iceland, together with results from various other observations, including geophysical surveying and drilling. The combined data is interpreted in terms of a magma domain model, which we consider to represent the crustal volume hosting magma at a shallow level. It may be of variable size and shape, containing variable amounts of magma, melts and crystals and comprising magma bodies with variable connectivity. At Krafla caldera, multiple constraints can be applied, including direct constraints from accidental drilling into rhyolitic magma at 2.1 km depth. We interpret the data in terms of at least two magma bodies at shallow depth: (i) a basaltic magma body with a pressure center near the center of the Krafla caldera in the 3-5 km depth range, contributing to S-wave shadows and influencing seismic propagation, as well as being responsible for an inflation/deflation pattern during the 1975-1984 Krafla rifting episode, and (ii) a shallower body of rhyolitic magma with an upper surface at 2.1 km depth underlying a high-temperature geothermal area. This rhyolitic body was inactive during 1975-1984, but also contributes to S-wave shadows. It has been drilled close to or into multiple times and is responsible for superheated steam near the bottom of several geothermal wells. Future advance in our understanding volcano interiors is expected from the Krafla Magma Testbed initiative (http://kmt.is); an international effort to establish an in-situ magma laboratory at Krafla, including drilling again to magma and coring of the magma-geothermal interface.

ORAL

Impact of host rock heterogeneity on failure mechanism around magmatic intrusions

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Rock failure mechanism accommodating the emplacement of magmatic intrusions is dominantly controlled by the local stress regime within the host rock. Most of the mechanical models addressing rock failure conditions (e.g., for a given tectonic regime or magma overpressure) simplify the stress calculation by

assuming the homogeneity of the host rock properties.

In this study, we highlight the importance of local heterogeneity in controlling the failure mechanism ahead of a magmatic intrusion. The heterogeneity is introduced by mean of a stochastic perturbation with given wave-length and amplitude on the host rock cohesion. We numerically model and quantify the elasto-plastic deformation of the system in response to the overpressurization of an intrusion. Depending on the characteristics of the heterogeneity, we observe the development of plastic zones representative of either tensile or shear failure. We show that shear failure is the dominant mechanism as soon as heterogeneities are introduced, even for relatively large dilatancy property of the host rock (up to the limit of associative plasticity). We conclude that heterogeneities within the host rock may locally "seed" shear faults ahead of the magmatic intrusion in the propagating direction. We further illustrate the implications of these results by considering the emplacement of a dyke in an extensional setting (Icelandic case) and show that shear failure may be a dominant mechanism in pre-eruptive seismic activity consequent to dyke emplacement, in good agreement with seismic data monitored during recent magmatic events.

ORAL

The effect of the host-rock rheology on dyke propagation energy balance: a numerical modelling study.

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Propagation of magmatic intrusions such as dykes and sills is an essential factor that controls volcano dynamics. It has been shown that an intrusion, or a fracture in general, will propagate when G, the energy released due to crack extension, exceeds a critical energy release rate value Gc, which is considered a material property of the host-rock. Estimates of Gc from observations of dyke length and aperture are generally around 100kJ/m^2 for competent rock, whereas lab measurements on similar rocks yield estimates Gc which are significantly lower.

In order to understand the discrepancy between in-situ and lab measurements of Gc, we test host-rock rheologies that are more realistic than the commonly used linear elastic theory. These rheologies take additional processes into account which affect the Griffith energy balance of a growing crack, such as: (1) pressure dependent elasticity with reduced moduli in regions of low-pressure, (2) plastic failure where shear stresses exceed a critical yield stress, and (3) viscous flow affecting the host rock during the cooling phase of the magmatic intrusion.To test these hypotheses, we construct three numerical models, each testing one of the host-rock rheologies described above.

Our results show that the most significant changes to the Griffith energy balance are obtained from the elasto-plastic model where G values are almost 100 time lower than results from the linear elastic solution. We thus find that large-scale fracturing, which we model as plasticity, can resolve the long-standing problem of disparate critical energy release rate Gc obtained by different means.

POSTER

A new model for saucer-shaped intrusions: shear failure versus tensile opening at sill tips

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Sills with a characteristic saucer shape are common features in many sedimentary basins worldwide. Previous models of sill emplacement usually assume that pure elastic bending of the overburden of growing sills control their evolution to saucer shape. However, field observations show that significant shear damage

also accommodate sill emplacement. To which extent such damage plays an active role on sill emplacement or not is not understood. To address this, we study the condition for shear failure and the distribution of damage in the overburden of sills using the limit analysis software Optum G2. Through a parameter study, we investigate the effect of the length-to-depth ratio (L/D) of the sill, the cohesion of the host rock and the emplacement depth on the over-pressure within the sill at failure. The results show that the characteristic saucer shape is ubiquitously reproduced using this approach (Haug et al, 2017). The over-pressure required for shear failure scales linearly with the host cohesion and as a power-law of L/D. From these observations, we propose a scaling law for a new shear failure criterion in the overburden of a sill. We compare our scaling law to an analytical solution of hydrofractures, and show that tensile tip propagation is favored for small sills, but overburden shear failure may become favorable for large sills. From these results, we suggest that sills initially grow laterally by tensile propagation until reaching a critical L*, when the overburden fails in shear, leading to the emplacement of saucer-shaped sill's inclined sheets.

POSTER

THE SEILAND IGNEOUS PROVINCE: IMAGING A WELL PRESERVED EDIACARAN DEEP SEATED MAGMATIC SYSTEM BY 3D GRAVITY AND MAGNETIC MODELLING

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The Ediacaran Seiland Igneous Province (SIP) is the largest complex of mafic and ultramafic intrusions in northern Fennoscandia, and one of the few examples in the world of a well preserved deep-seated magmatic plumbing system. The intrusive rocks of the SIP cause a prominent gravity anomaly. A model for the subsurface structure of the SIP has been constructed by forward modelling of 3D gravity and magnetic data using density and magnetic attributes from the outcrops.

There are multiple roots, two of which reach a depth of 9 km. The annular distribution of the roots suggests that this is close to the original geometry, which, despite the complex geodynamic history, has been preserved. Therefore, the Kalak nappe unit hosting the SIP, may not have experienced a strong tectonic reworking.

Forward magnetic modelling of the SIP allowed for estimating the geometry and the magnetization of the magnetic sources. This indicates that most of the sources of the magnetic anomalies are related to gabbroic bodies, and to a lesser extent to the contacts of the ultramafic intrusions with the country rock, possibly indicating these contacts have some degree of serpentinization, or mineralization. Based on the combined results of 3D gravity and magnetic modelling we suggest that the SIP is weakly magnetic at depth. Furthermore, the depths of the numerous mafic and ultramafic complexes vary geographically within the SIP. A low angle detachment fault dipping towards the north truncating the deeper part of the SIP would explain these observations.

POSTER

Rock magnetic properties and magnetic carriers of a deep crustal magmatic system, the Reinfjord Ultramafic Complex, Seiland Igneous Province, Northern Norway

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The Reinfjord Ultramafic Complex (RUC) is part of the 5000km2 Seiland Igneous Province (SIP) in

northern Norway. The SIP is considered to be a deep-seated conduit system of a large igneous province. The SIP was emplaced into continental crust at 25-30 km depth at 570-560 Ma. The RUC intruded into gabbros and meta-sedimentary gneisses resulting in three formations. 1) Central Series consisting of dunites; 2) Upper Layered Series consisting of dunites and wehrlites, and 3) Lower Layered Series containing the most pyroxene-rich rocks, with an associated but mineralogically distinct marginal zone resulting from contact metamorphism of the melts and host rocks. Exposures of deep ultramafic systems are rare, and RUC gives a unique opportunity to study the magnetic properties of the roots of a deep seated magmatic system.

The rock magnetic properties of the different formations give insight in the magnetic carriers, and can be associated to primary (spinel, and exsolution in pyroxene), or secondary processes, such as serpentinization. Scanning SQUID microscopy of thin sections combined with optical and electron microscopy indicate which minerals carry the magnetization, that then can be linked to the rock magnetic properties. Characterizing the primary, and secondary, magnetic carriers, allows for assessing the contribution of bodies such as the RUC to magnetic signals from deep crustal rocks. Understanding the nature of the magnetic properties of deep ultramafic rocks now exposed at the Earth's surface will aid in the interpretation of ground-, aeromagnetic, and satellite surveys and paleomagnetism.

1.8. Building Baltica

ORAL

Fennoscandia, Sarmatia and Volgo-Uralia: the building stones of the East European Craton/Baltica

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The three lithosphere segments Fennoscandia, Sarmatia and Volgo-Uralia (Fig.), which constitute the East European Craton (Baltica), have each specific crustal architecture and evolution (Bogdanova, 1993; Gorbatschev & Bogdanova, 1993; Bogdanova et al. 2008). While Volgo-Uralia is nearly all Archean, but complicated by thorough Paleoproterozoic reworking, Fennoscandia is Archean in the north-east but Proterozoic in the south-west, while Sarmatia features several separate Archean blocks cemented by Archean and Paleoproterozoic collisional belts. The segments are separated by the major ca. 2.1 Ga Volga-Don and ca. 1.8 Ga Central Russian Paleoproterozoic collisional belts followed by Meso- to Neoproterozoic aulacogens.

Baltica was built up during numerous collisional and accretionary orogenies, and also breakups (in Ga):

- 2.8-2.7: most Archean blocks amalgamated forming the protocratons of Fennoscandia and Volgo-Uralia but still separated by oceans in Sarmatia

- 2.5-2.4: first records of protocraton breakup (Fennoscandia and Volgo-Uralia)
- 2.4-2.0: continuing breakup of Archean Fennoscandia when several small oceans were opened
- 2.1-2.0: the Sarmatian and Volgo-Uralian Archean blocks collided forming megacontinent Volgo-Sarmatia
- 2.0-1.95: the combined NW margin of Volgo-Sarmatia became the site of a wide continental magmatic arc facing an ocean;

strong deformation of Volgo-Uralia 's crust and upper mantle

- 1.94-1.90: the Lapland-Kola collision encompassed Archean Fennoscandia
- 1.93-1.83: the Svecofennian accretionary orogeny at SSW edge of the Karelian protocraton
- 1.80-1.75: collision of Fennoscandia and Volgo-Sarmatia; Baltica was created 1.7-1.5: Gothian and Telemarkian accretion at the western Baltica margin
- 1.55-1.40: the Danopolonian (in part Hallandian) intracontinental orogeny
- 1.35-1.25: intracontinental mafic magmatism
- 1.0-0.9: Sveconorwegian collisional orogeny; Baltica participate in Rodinia supercontinent

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ORAL

Trace element geochemistry and Sm-Nd isotopes of 2.1 Ga mafic magmatism in the Karelia-Kola, Wyoming and Superior cratons

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The Karelia-Kola, Wyoming, and Superior cratons are proposed "nearest-neighbours" within the Superia supercraton reconstruction (Bleeker and Ernst, 2006). At 2.1 Ga, their kinship is best constrained by matching paleolatitudes in the Marathon (Superior) and Bear Mountain (Wyoming) mafic dyke swarms, and overall similar apparent polar wander paths (Halls et al., 2008; Kilian et al., 2015). Although Karelia's position within Superia is not as well constrained by paleomagnetic data, it is hypothesized to have been positioned at the southeast margin of Superior based on the overall correlation of mafic magmatic events ("magmatic barcodes") and the geometry of associated giant dyke swarms, including the 2.1 Ga Tohmajärvi dykes and Misi gabbro sills (Pekkarinen and Lukarinen, 1991; Niiranen et al., 2003; Bleeker and Ernst, 2006; Salminen et al., 2014, Davey et al., 2017). Here we use whole-rock and trace element geochemistry and Sm-Nd isotopes to test whether Marathon (Superior), Bear Mountain (Wyoming) and Tohmajärvi dykes and Misi sills (Karelia) were generated under similar conditions and from a common source. Halls et al. (2008) report a transition from enriched to flat trace element patterns through time between 2125 to 2100 Ma in the Marathon dykes. This geochemical progression provides an ancillary means in which to compare contemporaneous dyke swarms found in other cratons. If the Bear Mountain and Tohmajärvi dykes and Misi sills were fed by the same magmatic pulses as the Marathon dykes, then the same secular changes in geochemistry should be observed, in addition to sharing comparable paleolatitudes, geometry, and geochronology.

ORAL

Polyphase, transpressive deformation of the Archean Siilinjärvi carbonatite complex, central Finland

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The 2.6 Ga Siilinjärvi carbonatite complex is one of few known Archean carbonatites and the oldest currently being mined. The 16 x 1.5 km N-S trending curved and tabular complex comprises dominatly glimmerite with subordinate carbonatite, enclosed within a fenite halo, all cut by three generations of mafic dykes. The complex has been affected by polyphase deformation, including emplacement of the dykes and their subsequent structural overprint. Strain is heterogeneously distributed with the highest strain localised into the glimmerite and the

contacts of more competent rocks represented by fenite blocks, mafic dykes, and glimmerite hosting richterite and carbonates. The relationship between dyke emplacement and deformation has been obtained using a combination of structural data and magnetic fabric measurements. The older dykes are mainly steep, N-S to NW-SE trending, parallel to both the overall structural grain and the magnetic foliation, and narrow dykes are characterised by boudinage observed in both steep and sub-horizontal sections. Streching lineations within and along the margins of these dykes are sub-vertical and coincides with the magnetic lineation. Shear zones at dyke margins and elsewhere in the complex show dextral horizontal shear with a W-block-up vertical component. Later conjugate NNW-SSE dextral and NNE-SSW sinistral zones are likely related to folding of the youngest dyke generation. The consistency between structural and magnetic fabric measurements indicate two episodes of dextral transpressive shear separated by an extensional event related to emplacement of the youngest dyke generation.

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ORAL

Building or breaking Baltica – the Svecofennian 'intraorogenic' Herräng dyke swarm, east-central Sweden

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The mafic Herräng dykes are found in the Roslagen coastal area of east-central Sweden, where they intrude early Svecofennian metavolcanics and granitoids (ca. 1.87-1.91 Ga), but are themselves cut by late- to post-orogenic pegmatites and metamorphosed to greenschist- or amphibolite-grade. This dominantly E-W-trending dyke swarm has thus traditionally been referred to as 'intraorogenic' with respect to the Svecofennian orogeny, e.g. by Stålhös (1991).

In the present study, twentyone samples of mafic dykes have been obtained from the Herräng type area (Magnusson 1940), from the area around lake Limnaren south of Norrtälje (Lundegårdh 1946), and the islets Fogdö and Riddarskäret between Väddö and Singö (Lundqvist 1959). The sampled rocks are dominantly composed of plagioclase and amphibole (presumably hornblende), with variable amounts of quartz and biotite, and accessory titanite, apatite, zircon and opaque minerals. A couple of samples, however, have deviating mineralogy and geochemistry.

Geochemically, the sampled dykes are subalkaline basalts to andesites, with 48-60 wt% SiO_2. They have variable character on different discrimination diagrams: calc-alkaline or tholeiitic; MORB, volcanic arc or within-plate, possibly reflecting their origin during extension (perhaps incipient back-arc spreading) of juvenile subduction-related continental crust.

Initial Epsilon-Nd (at 1.87 Ga) falls between -0.1 and +1.6, and initial Epsilon-Sr between +5 and +24, suggesting a similar 'mildly depleted' mantle source as for other Svecofennian mafic rocks. Spot analysis of eleven titanite grains from one sample yields a weighted average $^{207}Pb/^{206}Pb$ age of 1848 ± 13 Ma, interpreted to date amphibolite-grade metamorphism, and yielding a minimum age of crystallization.

ORAL

High-Nb and adakite-like 1.86 Ga magmatism in southern Finland

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Mafic to intermediate c. 1.86 Ga magmatism has been discovered within the boundary area between central and southern Svecofennia in

southern Finland (Kara et al. 2016). The magmatism occurs as NW-SE trending dykes and small intrusions which crosscut the surrounding migmatitic country rocks. The magmatism can be divided into three different varieties based on their geochemical and isotopic characteristics: i) high niobium basaltic dykes (HNB), ii) high magnesium basaltic dykes (HMB) and iii) high silica adakite-like rocks (HSA).

The HNB are alkalic and enriched in HFSE, particularly Nb (>20 ppm) and show high LREE, P_2O_5, TiO_2 and F contents. In-situ zircon Hf-analyses show very high average initial ε_{Hf} value of c. +10. The HMB exhibit high MgO (up to 12 wt%) and Cr concentrations and show high average initial ε_{Hf} values of c. +3 and +5 (two dykes). The HSA group is enriched in Sr and LREE and depleted in Y (<20 ppm) and Yb (mostly <1.9 ppm) among the other high silica adakite characteristic signatures (Martin et al. 2005). Two HSA-intrusions exhibit average initial ε_{Hf} value of zero and c. -3.

The ages as well as geochemical and isotope data are clearly different from the adjacent, c. 1.90-1.88 Ga, arc-related igneous rocks suggesting a different kind of petrogenesis for these two age groups. The similar ages and close spatial occurrences support a genetic link between the 1.86 Ga groups. However, separate sources are likely due to differences in geochemistry and isotope signatures.

ORAL

Paleoproterozoic Inari orocline of northern Fennoscandia: progressive or secondary orocline

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Oroclines are curvatures of previously linear arcs (or belts), and are divided into two main types: progressive and secondary (Johnston et al., 2013). Progressive oroclines are formed by strain heterogeneity experienced during progressive thin-skinned thrusting: a common feature of modern orogens. Secondary oroclines are formed in response to an orogen-parallel shortening, as witnessed by Paleoproterozoic coupled Bothnian oroclines of Fennoscandia (Lahtinen et al., 2014). The main component of the Inari orocline is the Lapland granulite belt (LGB) having an arcuate shape geometry in the northern Fennoscandia. Recent studies of Tuisku and co-workers (e.g., Tuisku et al., 2006; 2012; cf. Cagnard et al., 2011) provide a solid base for the age and tectono-metamorphic history of the belt. Based on the existing studies, new field and age data, and re-interpretations of geophysical data, we propose following stages for the evolution of the LGB: 1) extension and intrusion of enderbites at ca. 1.92 Ga in a linear rift basin; 2) thrusting and recumbent folding during basin inversion at 1.92-1.91 Ga leading to peak metamorphic conditions; 3) intrusion of post-collisional appinites at ca. 1905 Ma; 4) extension and decompression melting at 1.90-1.88 Ga; 5) renewed shortening of the linear orogen at 1.88-1.87 Ga that lead to upright folding and SW vergent thrusting; 5) orogen-parallel shortening at ≤1.87 Ga. Our preliminary interpretation is that the Inari orocline, including the LGB, is a secondary orocline formed during buckling about a vertical axis of rotation.

ORAL

New paleomagnetic and isotopic data for the Late Paleoproterozoic mafic intrusions in the Blekinge Province (southeastern Sweden)

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To the east of the Sveconorwegian orogen, the Precambrian bedrock in Blekinge contains granitoids of the Transscandinavian Igneous Belt to the north of the Småland-Blekinge

Deformation Zone (SBDZ), and the c. 1.76 Ga Tving granitoids in the south (Johansson et al. 2006). In this study, we have investigated the mafic intrusions cutting the Tving granitoids.

The new paleomagnetic and AMS examinations of the Tving granitoids in eastern Blekinge show NW-striking foliation parallel to the SBDZ. The studied mafic intrusions carry a stable component with shallow downward NNW direction. The primary remanence is supported by positive contact tests. New isotopic data for olivine gabbro and metabasic rocks using U-Pb baddeleyite and Ar-Ar amphibole geochronology suggested a protolith age of ca 1760 Ma for these rocks. The mean paleopole for these mafic intrusions from Blekinge thus corresponds to the c. 1.76 Ga pole for Fennoscandia.

In the entire Blekinge, AMS lineations mainly dip NW. The NNE upward overprint component is found in the Tving granitoids near the Karlskrona Deformation zone, that is close to that in the 1.45 Ga Karlshamn granites, probably due to regional heating and deformation of the Blekinge block (Čečys & Benn 2007). AMS and structural data indicate that the magnetic fabrics of the mafic intrusions are continuous and the metamorphic fabrics in the country rocks were formed during ENE–WSW compression, and can be referred to the Danopolonian orogeny. The new paleomagnetic pole is close to 1.45 Ga pole for Baltica (Lubnina et al. 2010).

ORAL

Early Paleoproterozoic paleogeography of Karelian and Superior Cratons: new paleomagnetic and AMS data from 2.45-2.1 Ga mafic intrusions of Central Karelian and Kianta terranes

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We present a new paleomagnetic and Anisotropy of magnetic susceptibility (AMS) data from the Early Paleoproterozoic mafic dykes and Archean host rocks within two terranes of the Karelian Craton, eastern Fennoscandian Shield. Three groups of dykes have been collected within Pyaozero area of Central Karelian terrane: NE-trending ca. 2450 Ma gabbronorite and diorite dykes, NW-trending ca. 2310 Ma dolerite dykes, and NNW-trending ca. 2130 Ma continental MORB-type tholeiitic dykes (Stepanova et al. 2014). All these dykes were typified based on the AMS data. Samples from 2130 Ma dolerite dykes within Tulos area of Kianta terrane were also collected.

The paleomagnetic results show that a strong Svecofennian overprinting is pervasive in the area.

All studied mafic dykes carried two stable components. Most typical is component of intermediate down to the NNW, corresponds to the Svecofennian remagnetisation (Mertanen 1995). Component of SE intermediate down direction yielding a paleomagnetic pole 2450 Ma based on a positive baked contact test is interpreted to represent the primary magnetization.

The paleomagnetic results for dolerite dyke within Tulos area show that a strong Svecofennian overprinting is pervasive in the area, based on a negative baked contact test.

The new paleomagnetic data from the Karelia Craton compared to similar-aged paleomagnetic data from the Superior Craton does not support the recently proposed Superia configuration (Bleeker & Ernst 2006), based upon dyke swarm trajectories.

We propose a new Early Paleoproterozoic paleogeography at 2.45-2.1 Ga for the Karelia and Superior craton.

This is a contribution to projects RFBR 17-05-01270.

ORAL

Development of the Paleoproterozoic Svecofennian orogeny, new constraints from Central Finland

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Significant amounts of new field and analytical data (whole-rock geochemistry, age determinations) were gathered by Geological Survey of Finland from a little studied area along the southeast boundary of the Central Finland Granitoid Complex (CFGC). As the area is the culmination point of several major geological units this new data allows revaluation of previous interpretations and correlations. The new data mostly affects the following aspects:

Units belonging to the older Svecofennian magmatic phase (1.93–1.91 Ga) extend 100 km further southeast as tentatively suggested earlier. All of the paragneiss units in the area display similar detrital zircon patterns, defining ~1.92 Ga as the maximum depositional age for most of the samples. The eruptive ultramafic units occurring as interlayers in different paragneiss units display differences in trace element patterns. But otherwise the earlier division of paragneisses mainly reflects differences in deformation and metamorphic history. The arc-type calc-alkaline magmatism in the area is similar in age (1895–1875 Ma) and composition to that of the classical Tampere group 200 km further west. The voluminous granitoid magmatism took place in two stages, at ca. 1895 and 1885–1875 Ma. The latter phase can be divided into separate units on compositional bases, which display distinct field relationships, although the obtained ages overlap within errors. Thus the earlier division into syn- and post-kinematic units should be abandoned. Instead the units represent coeval magmas originating from different levels of the crust. Lower crust melts rose only locally to the present erosion level via favorable structures.

ORAL

Kinematics and deformation regime of the Kynsikangas ductile shear zone, SW-Finland.

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The NW-striking Kynsikangas Shear Zone (KSZ) is one of many prominent Paleoproterozoic ductile shear zones in SW Finland that formed during the Svecofennian orogeny. The Kokemäki segment of the KSZ consists of an approximately 16 km long and 2 km wide core of highly strained metagranitoid and migmatite rocks displaying variable mineral foliation (S) - lineation (L) geometry. Moreover, the core hosts abundant small-scale kinematic indicators, such as C-S fabrics, rotated rigid objects and folded metamorphic layering. Besides unravelling the significance of major shear zones in the Svecofennian orogen, the KSZ allows us also to elucidate to what extent small-scale kinematic indicators are useful for identifying the overall sense-of-shear of ductile deformation zones in general. The central portion of the shear zone is characterized by pronounced sub-horizontal L fabrics, which merge along-strike of the shear zone in both directions into S > L fabric geometry. East of the fault core, the curvature in the strike of foliations, sub-horizontal mineral stretching lineation and C-S fabric geometry point to a strong component of left-lateral displacement. By

contrast, foliation pattern and moderately to steeply plunging mineral lineations west of the core indicate dip-slip. Despite complex internal ductile flow, evident by the along-strike variation in S-L fabric geometry, the KSZ seems to have accommodated a strong component of left-lateral transpression.

ORAL

Long-lived Late Paleoproterozoic to Mesoproterozoic connection of Baltica and Laurentia - a paleomagnetic view

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To understand processes occurring from the planetary interior to the surface environment, a robust paleogeography of tectonic plates is important. Paleomagnetism coupled with geochronology is powerful quantitative method for providing ancient latitudes and azimuthal orientations of continents. Mafic dykes are amenable for precise U-Pb dating and often preserve a stable record of ancient magnetic fields. Recently new high quality paleomagnetic and geochronological data from Meoproterozoic mafic dykes in Southern Finland have been produced allowing reconstructions of position of Baltica (Salminen et al., 2014; 2016; 2017).

There is a general agreement that Baltica and Laurentia form a tectonic "core" of the Mesoproterozoic Nuna supercontinent in a geologically and paleomagnetically viable connection between Northern Europe and North America (NENA), where Baltica is in “upside-down” position relative to Laurentia (Gower et al., 1990; Salminen and Pesonen, 2004). However, contradicting reconstructions have been proposed (Halls et al., 2011). We show that new high quality Mesoproterozoic paleomagnetic data with new geochronology results for Baltica support NENA connection. Those include data from 1.64 Ga Häme, 1.64 Ga Suomenniemi, 1.58 Ga Åland, and 1.58 Ga Satakunta dyke swarms in Southern Finland.

The rotational transition to right-way-up Baltica within Rodinia (e.g. Patchett et al., 1978; Piper, 1980) is proposed to occurred between 1.12 Ga and 1.05 Ga (Salminen et al., 2009; Evans, 2009). It agrees with distinctive patterns of orogenesis and sedimentation around the common pivot point shared between Scoresby Sund, East Greenland, and Finnmark, Norway (Cawood et al., 2010; Evans, 2013).

ORAL

Paleoproterozoic Osnitsk–Mikashevichi-Moscow Igneous Belt (OMMB): new geochronology and petrology data for the Russian segment and tectonic implication

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The OMMB is a large Paleoproterozoic north-east-trending belt in the central part of the East European Craton (EEC). It is traced from Ukraine through Belarus to Central Russia (Bogdanova et al., 2006, 2016). The main part of the OMMB is covered by platform sediments, thus sampling of the belt is mostly provided by deep drill-hole cores. Petrology, U-Pb zircon geochronology and Sm-Nd isotope data for the Russian segment of the OMMB will be presented.

Major results are listed as below:

1) In the Russian segment, the OMMB consists of tonalite, trondhjemite, granodiorites (TTG) and granites with subordinate gabbros, diorites and mafic metavolcanic rocks.

2) Granites from north-west flank of the OMMB (Vorob'evo and Roslavl' wells) yield U-Pb zircon ages of 1963 – 1970 Ma that is somewhat younger than the 2005 – 2028 Ma TTG and granites from south-east flank of the belt (Yasnogorsk, Kaluga and Vorotilovo holes) . The latter may have caused high-T low-P metamorphic event at 2020 – 2036 Ma, which has affected metapelites from Ingul-Sevsk and Volgo-Don orogens of the Volgo-Sarmatia block near the OMMB rocks (Bogdanova et al., 2004; Savko et al., 2017 and our data).

3) The OMMB TTG, granites and related mafic igneous rocks have calc-alkaline affinities, subduction-related geochemical features and show variation of eNd(T) values from +2,5 to -1,4 where juvenile rocks with eNd(T)>0 predominated.

4) All the data suggest that the OMMB was formed in two stages, at 2.03 and 1.97 Ma along the Andean-type active margin of Volgo-Sarmatia.

ORAL

1.86-1.79 Ga magmatic events in the western East European Craton: from subduction to back-arc settings

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Remnants of a ca. 1.86-1.84 Ga continental margin were found in southern part of the Mid-Lithuanian domain (MLD), the western East European Craton (Bogdanova et al., 2015), while some new data supports its continuation to the NW, towards central Sweden.

The Randamonys gabbro-diorite-granodiorite-granite in southern Lithuania of calc-alkaline affinity, metamorphosed in amphibolite facies, was emplaced between 1.86 and 1.84 Ga. The suite has volcanic-arc, and hence, subduction-related characteristics. Ca. 100 km to northwest, the ca. 1.85 Ga diorites metamorphosed in granulite facies at 1.80 Ga (Skridlaite et al., 2014) were interpreted as evidencing the MLD margin continuation in central Lithuania. A new ca. 1.85 Ga SIMS age obtained from a felsic granulite (metatonalite) further west (in western Lithuania) confirms the extension of margin northwestwards.

Gabbro-norites which intruded into the Randamonys complex at 1.79 Ga are tholeiitic, have positive initial ε_{Nd}, hence juvenile, mantled-derived characteristics. Some slightly older (ca. 1.82-1.81 Ga) fine-grained gabbro-norite with a very primitive REE distribution and positive initial ε_{Nd} resembles oceanic crust.

The 1.86-1.84 Ga continental margin appears to continue through the Baltic Sea and merge with the 1.87–1.84 Ga Askersund-Loftahammar magmatic belt along southern Bergslagen in Sweden (cf. Stephens et al., 2009). Later, an Andean-type subduction in the present west was responsible for the formation of back-arc basins and 1.79 Ga mafic magmatism in the MLD, coeval with the intrusions of the 1.81–1.76 Ga TIB-1 suite. Some remnants of ca. 1.82-1.81 Ga oceanic crust completely reworked elsewhere may be preserved in these back-arc settings.

ORAL

Paleoproterozoic mafic dyke swarms in Archean Kola-Murmansk and Karelia provinces, eastern Fennoscandia: barcode comparison and implications for paleocontinental reconstructions

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Eastern Fennoscandia consists of Archean Kola-Murmansk and Karelian provinces, separated by ca. 1.98-1.85 Ga Lapland-Kola orogen (Daly et al., 2006). New baddeleyite U-Pb (ID TIMS) and zircon (SIMS) ages, geochemical and isotopic data for 2.65-1.86 Ga mafic dyke swarms in Kola-Murmansk province give insights into Lapland-Kola Ocean lifespan and clarify a position of Kola-Murmansk province within Superia supercraton (Bleeker and Ernst, 2010).

Wide-spread mafic magmatism of age 2650 Ma is recognized in Murmansk domain. It is well correlated with 2640-2660 Ma magmatic event in Keivy terrane, Kola domain (Bayanova, 2004). Mafic magmatism of this age in Karelia is unknown. It suggests strong differences in the Neoarchean history of Karelian and Kola-Murmansk provinces.

Nevertheless both Karelian and Kola-Murmansk provinces most likely belong to the Superia supercraton as suggested by Bleeker and Ernst (2010). It supported by similarity in the events succession since 2500 to 2400 Ma.

The noteworthy differences occur within the period 2400-2060 Ma. Mafic dykes of such age do not recognize in the Kola-Murmansk province yet. In contrast, several voluminous events of age ca. 2310, 2220 and 2140 Ma occur in the Karelian province (Stepanova et al., 2014, 2015, Vuollo, Huhma, 2005).

Since 2060 Ma Karelian and Kola-Murmansk provinces are similar in events succession and composition of mafic rocks. So huge ca. 1980 Ma event widespread both in Kola-Murmansk and Karelian provinces indicates Lapland-Kola Ocean closure.

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POSTER

Mineral shape fabric analysis of the Kynsikangas Shear Zone: Evidence for a transpressive origin?

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The NW-SE trending Palaeoproterozoic Kynsikangas Shear Zone (KSZ) is a prominent ductile shear zone in the Svecofennian Orogen of SW-Finland. The shear zone is located at the boundary between the Western Finland and Southern Finland Subprovinces. In the Kokemäki area, the KSZ formed under high-grade metamorphic conditions in migmatite and gneissic rocks. The shear zone is believed to have formed under left-lateral shear. A more complex kinematic, possibly transpressive, origin of the shear zone, is evident from our analysis of kilometer-scale pattern of metamorphic foliations, maximum principal stretching orientations and small-scale kinematic indicators. In order to elucidate the kinematic regime of shear zone formation, we quantify the geometry and intensity of shape-preferred orientation (SPO) of metamorphic minerals. Therefore, oriented block samples from 50 stations are cut according to the principal planes of finite strain and the SPO of elongate minerals and other strain markers are quantified by image analysis. The results of this classical analysis of

SPO will be used to calibrate visual estimates of fabric intensity across the Kokemäki segment of the KSZ and will be compared with more sophisticated 3D fabric analysis techniques.

POSTER

Provenance of Paleoproterozoic clastic metasedimentary rocks in Norrbotten, northern Sweden

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Provenance zircon ages (U-Pb geochronology by LA ICPMS) were obtained from twenty samples of clastic metasedimentary rocks from several supracrustal units in Northern Norrbotten. The majority belong to the Svecofennian sequences, with a few samples representing stratigraphically lower Karelian units.

The Karelian rocks generally have unimodal age distributions with the main peaks at c. 2.7 Ma and 2.55-2.60 Ga. The maximum depositional age vary from c. 2.6-2.5 Ga for Tjärro quartzite and a similar quartzite collected in the Vakko Zone. Early Paleoproterozoic depositional ages (c.2.3Ga) occur in quartzite at Tärendo and in arkosic metasandstone from the Sockberget group.

In the Svecofennian metasedimentary rocks, bimodal age distributions dominate with major peaks at Middle Paleoproterozoic and subordinate ones at Archean. The oldest single ages are found in the Hauki quartzite (3742±19Ma), the Kiilavaara quartzite (3649±44Ma), the Stora Sjöfallet quartzite (3732±10 Ma) and in metasandstone from the Råneå group (3628±31 Ma). Maximum depositional ages vary between 1.9 and 1.8 Ga. Ages as young as 1.75-1.8 Ga are reported, however, they may have been affected by metamorphism, hydrothermal alteration or inaccurate common lead corrections.

The presumed source of the clastic sediments is generally thought to be local.

The obtained geochronology data from northern Sweden, together with available detrital ages from northern Norway and Finland constitute a major database for building models of tectonic and lithostratigraphic evolution of the Fennoscandian Shield.

POSTER

Petrogenesis of c. 1.9 Ga meta-volcanosedimentary rocks in the Nautanen-Aitik area, northern Sweden: Geological, lithogeochemical and Sm-Nd isotopic constraints.

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In northern Sweden, Orosirian metasupracrustal successions provide critical insights into Svecofennian-cycle tectonothermal processes. Additionally, they commonly host iron oxide-apatite and/or Cu ± Au mineralization, and thus represent key exploration targets. Characterising such rocks from a primary perspective is an important prerequisite in understanding subsequent deformation, metamorphic and/or hydrothermal events. We present new petrogenetic constraints for a polydeformed, c. 1.9 Ga metasupracrustal package in the Nautanen-Aitik area (Norrbotten) hosting several economically significant Cu-Au deposits.

The investigated sequence mainly comprises tuffaceous metavolcaniclastic rocks and

intercalated metasedimentary (epiclastic) horizons. Primary volcanic features include remnant feldspar phenocrysts, accretionary lapilli-like features/clasts and inferred agglomeritic horizons. Epiclastic layers locally display trough- and herring bone-type cross-stratification, suggesting relatively shallow, subaqueous depositional conditions. Compositionally, the rocks are mainly andesitic, with lesser basaltic andesitic and dacitic varieties, and have calc-alkaline series affinities. Chondrite-normalized REE patterns are LREE-enriched (La_N/Yb_N = 4.2 – 18.6), with flat to weakly negative Eu anomalies ($[Eu/Eu^*]_N$ = 0.59 – 1.16; avg = 0.88). Whole-rock $\varepsilon Nd_{(1.88\ Ga)}$ values range from -4.5 to -0.3 (n = 10), while corresponding T_{DM} model ages range from c. 2.2 to 2.5 Ga.

The sequence attributes are broadly consistent with formation in a continental arc-type setting undergoing extension, where precursor tephra accumulated within a syn-volcanic depocenter (cf. Wanhainen et al. 2012). Geochemical signatures also suggest parental magmas derived from a mixed continental-juvenile source. Given the spatial overlap of Orosirian and older (Rhyacian) successions across the region, however, a contribution from intracratonic tholeiitic greenstones, remobilised by Svecofennian-related magmatism, may also be valid.

POSTER

Deformation history of the Archipelago of Southern Finland

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The Paleoproterozoic Svecofennian orogenic domain of Southern Finland consists principally of belts of strongly migmatized infra- and supracrustal rocks and granitoids in upper amphibolite to granulite facies, with areas of less migmatized rocks in between. The granite-migmatite belts are presumably related to each other, but their structural setting, deformation stages and thus tectonic setting are vaguely known.

Our focus is the onshore area and the archipelago around the Hanko peninsula. As the site was last researched before the plate tectonic theory was established, the goal of this study is to update the geological interpretations of the area. The project is ongoing and the results presented here are preliminary.

In the study area, at least three different ductile deformation stages are recognized (D1, D2, D3). During D1, the metasedimentary rocks were folded into tight to isoclinal folds with E-W striking nearly vertical axial plane. The E-W trending horizontal to moderately plunging mineral lineation is in places stronger than the foliation. The D2 developed open asymmetric folding with SE plunging fold axis. At this stage, mineral lineation is common, but the foliation is difficult to observe. The D3 is represented by a mineral lineation plunging towards NE.

The leucosomes in the migmatites are folded twice. This suggests that melts were generated before or during D1. The E-W trending structures indicate N-S (at present) compression at stage D1. During D2, the main shortening direction was likely in the NE-SW direction, whereas the D3 structures seem to represent a NW-SE shortening.

POSTER

A ca.1.89 Ga magmatic complex in eastern Lithuania: a link connecting with the domains in Estonia and the Bergslagen terrane in Sweden

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Concealed crystalline basement of the Latvia-East Lithuania (LEL) domain is covered by 200-500 m thick sediments. It is mostly composed of basic to acidic intrusive rocks and their volcanic counterparts that host ore deposits. Bogdanova et al (2015) suggested correlations between the 1.89-1.87 Ga Bergslagen microcontinent and Livonia megadomain (including Latvia-East Lithuania, South Estonia Granulite and West Estonia domains). However, apart from a ca. 1.887±7 Ma metadiorite in the south-western LEL (Bogdanova et al., 2015) and a much younger ca. 1.5 Ga AMCG suite in the south (Sundblad et al, 1994), almost none of the rocks from the LEL have been properly dated.

Four samples with calc-alkaline affinity from the LEL were selected for zircon U-Pb SIMS dating: two samples of granodiorite from the southern part of the LEL that might be a part of a TTG suite, a sheared diorite and a meta-rhyolite from the western border of the LEL. The two granodiorites yielded concordia ages of 1892.3±5.7 Ma (MSWD 1.01) and 1893.7±7.4 Ma (MSWD 1.9), whereas diorite is somewhat younger yielding 1876.1±4.8 Ma (MSWD 1.6). The meta-rhyolite recorded a concordant age of 1898±8.3 Ma (MSWD 1.4).

Our newly obtained U-Pb zircon ages support the model proposed by Bogdanova et al. (2015) in which the Livonia and Bergslagen terranes formed simultaneously and can be correlated across central part of the Baltic Sea. It is also consistent with the general southwest younging of terranes in the western East European Craton (and Baltica).

POSTER

The Nisser Shear Zone – Discovery of a Sveconorwegian crustal-scale detachment zone in southern Norway

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In the Telemarkia Lithotectonic Unit, S Norway, thick successions of metasedimentary and metavolcanics rocks, known as the Telemark- and Nissedal supracrustals, are structurally overlying gneiss complexes. The contact relationships between low- and high-grade rocks, whether depositional or tectonic, are contentious, although notably poorly documented.

As part of an ongoing multi-disciplinary project in the Nissedal-Drangedal area (Bedrock Infrastructure in Telemark–BITE), field mapping reveals that the c.1200 Ma basalt-dominated Nissedal supracrustal rocks are separated from the underlying c.1200 Ma granitic gneisses of the Vråvatn Complex by a ductile to brittle shear zone, here called the Nisser Shear Zone (NSZ). The shear zone corresponds to a pronounced asymmetric negative magnetic anomaly, at least 50 km long, on the high-resolution aeromagnetic map. The NSZ is up to 200 m thick and comprises a variety of high-strain rocks ranging from ultramylonite to cataclasite and fault gouge. Brittle structures appear to overprint ductile structures. It dips shallowly to the SE (c. 150/25) and carries strongly developed SE-plunging mineral lineations and slickenlines. These are associated with kinematic indicators (e.g. sigmoidal porphyroclasts and s-c shear bands) that consistently show a top-to-the ESE normal shear sense. Mylonites developed in the footwall granitic gneisses show dynamic recrystallization of K-feldspar, testifying to deformation above 500°C.

Provisionally, we interpret the NSZ as a crustal-scale extensional detachment linked to the late-

Sveconorwegian orogenic decay. It exhumed lower-crustal gneisses and juxtaposed them against upper-crustal sequences of a similar age. Future studies will constrain the age, tectonic setting and environmental conditions of the NSZ.

POSTER

AMCG Mazury Complex in NE Poland – a time frame of the suite formation

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A Mesoproterozoic AMCG suite known from covered part of the Eeast European Craton on the border of Poland with Lithuania and Russia, was emplaced along E–W trending linear thrusting zone. An ~1.50 Ga crystallization age of the rapakivi-like granitoids of Mazury Complex, obtained on zircon grains, was one of the first geochronological contribution, initiating more detailed investigations in the frame of EUROBRIDGE programme. Further age studies have been focused mostly on the spatial chronology of the suite, controlled by A-type granitoids as a dominant phase across the region.

A principal goal of recent studies was to constrain the time of emplacement of all AMCG components, using U- Pb zircon ages determined by SHRIMP method. The metaluminous, within-plate, A-type Mazury granites were intruded between 1.53 and 1.50 Ga. The last pulse at 1498±10 Ma was deciphered from westernmost part (Filipów hole). The geochemical and isotopic investigations pointed out that AMCG suite was formed by multiple magma batches, assembled by pulses, often in the same locality. AMCG merged pluton was finally intruded by a net system of peraluminous granite veins, that were crystallized between 1495 ±11 Ma -1488.7 ±4 Ma. This event recorded in Mazury AMCG suite, predates a formation of AMCG massifs in western Lithuania (1447 -1445±8Ma Nemunas- Geluva), and regional magmatism (1.45 Ga) in Bornholm - Blekinge area. It also predates a dynamic high-grade metamorphism in SW Sweden related to convergent active-margin processes during the Danopolonian orogeny.

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POSTER

A link between Mesoproterozoic basement of Lithuania and NE Poland by inherited metamorphic zircon data

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A number of metamorphic events between 1.7-1.6 Ga were recognized within the hidden basement of Lithuania Skridlaite et al., 2014) . In Baltica, , this period marks a tremendous change in tectonic evolution (cf Bogdanova et al., 2008, 2015), when an active accretionary margin shifted to its western edge (cf Bingen et al., 2008).

At present, 1.7-1.6 Ga old zircons were found in the Mazury area (NE Poland) by U-Pb age determinations carried out at SHRIMP Lab, PGI, Warsaw; cf Krzeminska & Wiszniewska, 2017). They represent an inherited component from 1.49-1.48 Ga peraluminous granite veins cross-cutting the Suwalki Anorthosite Massif (SAM). The most of zircon grains have cores, containing material derived from various Paleoproterozoic sources. Important coherent group of inherited grains (about 20%) has cores in range of 1710±12 Ma - 1617±9 Ma, with signature typical for metamorphic crystallization e.g. Th/U<0.1, but the host rocks with these characteristics have not been identified so far in proximity of SAM .

This inherited population corresponds however with the records of magmatic and metamorphic activity common in Lithuania and Belarus (Skridlaite et al., 2014; Vejelyte et al., 2015, Bogdanova et al., 2001), where zircons and monazites from Randamonys (Lithuania) and

Grodno (Belarus) have documented reworking at 1668±9 Ma (and 1569±12 Ma) and granulite facies metamorphism at 1727±30 Ma. This may indicate genetic link between peraluminous the Mesoproterozoic vein granites and their basement, that could be similar in NE Poland and Lithuania at the level of magma generation.

1.9. Micro-beam frontiers in magmatic, metamorphic, and hydrothermal systems

ORAL

U-Pb calcite and zircon dating by LA-ICP-MS image mapping

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Traditionally, LA-ICP-MS geochronology employs spot ablations, with the limitation that the laser excavates material several tens-of-μm below the sample surface. LA-ICP-MS mapping (ablating a series of parallel, adjacent lines in a single experiment) yields much shallower ablation depths (0.3-3 μm). The data contained in the parallel line scans are reduced with software (e.g. Iolite) to produce x-y-element concentration and/or isotopic maps. We employ here a new flexible interrogation tool for LA-ICP-MS maps called Monocle (Petrus et al., 2017), and add-in for Iolite. In addition to inspectors tools such as size-and-shape adjustable loupes, user-defined regions-of-interest (ROIs) and live graphs (e.g. Wetherill or Tera-Wasserburg concordiae), Monocle allows the selection and pooling of pixels that meet user-defined criteria. Potential applications of zircon U-Pb imaging include characterisation of complex polyphase zircons and characterising the U-Pb systematics of key samples for TIMS dating. U-Pb calcite dating has important applications including dating unfossiliferous sedimentary rocks or ore-bearing mineralization events. The functionality of Monocle can circumvent limitations of the U-Pb calcite system, including low U concentrations and/or high amounts of initial Pb. Pixels on a map can be pooled into "analyses" based on ECDFs of elements or isotopic ratios (e.g. $^{238}U/^{204}Pb$) to create a spread of U-Pb data on concordia. Portions of the sample with elevated detrital components or chemically-different generations of carbonate can be rejected by defining exclusion

criteria (e.g. Rb<1ppm; Mg/Ca<0.004). Stratigraphically well-constrained Paleozoic limestones and shell fragments yield accurate ages with internal age uncertainties as low as ±1%, confirming the feasibility of the technique.

ORAL

Promises and pitfalls of in situ Sr isotope ratio measurements by LA-MC-ICPMS

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The Rb-Sr isotopic system has been used for decades for geochronology and radiogenic isotope geochemistry. The advent of laser-ablation plasma-source mass spectrometry (LA-MC-ICPMS) enhanced the efficiency of Sr isotope analysis and—more importantly—enabled spatially resolved measurements. However, over two decades since the first measurements of Sr by LA-MC-ICPMS, there is still no standard routine for accurate and precise determination of Sr isotope ratios in Ca-bearing silicates with variable Rb/Sr ratios. This is largely because of the analytical challenges inherent to this method, including numerous elemental (Kr, Rb, doubly charged REE) and molecular (CaAr, Ca_2, among others) interferences on the Sr isotopes of interest. Previous studies have successfully measured Sr isotopes in situ in plagioclase, carbonates, and phosphates, but interferences have thwarted accurate measurements of materials with Rb/Sr > ~0.05. We test the effectiveness of several commonly used data-reduction approaches on a large set of LA-MC-ICPMS measurements of two in-house plagioclase standards and widely used rock glass standards with Rb/Sr up to ~0.7. Most approaches effectively reproduce the plagioclase standards but yield highly inaccurate results for higher Rb/Sr standards. We have developed custom data-reduction approaches that now accurately reproduce rock standards with a range of Rb/Sr and compositional matrices, expanding the utility of this method. We highlight several applications of the method, including measurements of plagioclase, volcanic groundmass, and archeological glass samples, and also simultaneous measurements of Sr isotopes and trace elements by laser-ablation split-stream analysis.

ORAL

In tandem K–Ca and Rb–Sr dating of potassic minerals by LA-ICP-MS/MS: Method and prospective applications

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Recent technical development in ICP-MS instruments facilitates on-line chemical separation of isobaric ions (e.g. $^{87}Rb^+$ and $^{87}Sr^+$) by gas reactions, which enables dating of beta-decay systems such as Rb–Sr by laser ablation of minerals without wet chemistry (Zack and Hogmalm 2016; Hogmalm et al. 2017). We have analysed mica-group minerals of various ages for K–Ca and Rb–Sr isotopic ratios in tandem by LA-ICP-MS/MS. Both Ca^+ and Sr^+ ions are highly reactive with SF_6 gas, whereas K^+ and Rb^+ are not. Ca and Sr isotopes were measured as interference-free fluoride reaction products CaF^+ and SrF^+, whereas ^{40}K and ^{87}Rb isotopes were inferred from $^{85}Rb^+$ and $^{39}K^+$. Overlap from isotopes of Ar, present in the plasma, was suppressed by adding H_2 gas.

By analysing K–Ca and Rb–Sr isotopes in tandem, these dual systems with different decay rates are analogous to the U–Pb decay series. Rb–K isotope ratios can be assessed on various concordia diagrams and reveal single-spot ages or open-system disturbances. Since the non-radiogenic Ca composition for the purpose of mica dating can be regarded as practically constant (cf. Valdes et al. 2014), the isochron method is not required and

single-spot ages can in principle be derived, which would be useful inter alia in provenance studies of sedimentary micas.

ORAL

Behaviour of boron isotopes during magmatic degassing: a case study from Lesbos Island, Greece.

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Boron is a fluid mobile trace element routinely employed as a tracer of slab-derived fluids in subduction zones. The fidelity of boron in volcanic glass as an accurate tracer of slab degassing is called into doubt, however, by experiments that show that boron isotopes (expressed as $\delta^{11}B$) can fractionate by up to several permil (‰) during magmatic evolution and degassing at high temperature. In order to test for isotopic fractionation during magmatic degassing in a natural case, we carried out SIMS analyses of boron-rich rhyolitic glass from Lesbos Island, Greece. Analytical points were set as traverses from bubbles into the surrounding glass in order to test for variations in $\delta^{11}B$ values due to volatile exsolution. The glass records a post-eruptive average water content similar to the calculated water solubility in the final pre-eruptive melt, suggesting minor pre-eruptive degassing took place. The average boron concentration and $\delta^{11}B$ value of the glass is 102 µg/g (n=61) and -4.9‰ (2SD=1.6‰, n=60), respectively, making it one of the most boron-rich subduction zone glasses yet recorded. Moreover, the glass is statistically homogeneous at the 2σ level, with mild heterogeneity at the 1σ level. This observation implies that during degassing at magmatic temperatures in rhyolitic systems, boron is relatively immobile and its isotopes do not significantly fractionate. Our findings allows us to reconstruct the Lesbos magma's $\delta^{11}B$ values at its final holding stage prior to eruption, and suggest that volcanic glass may be a reliable tool for investigation of subduction fluids in arcs.

ORAL

Melt Inclusion studies on basaltic magmas in Iceland

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Investigations of melt inclusions and their host macrocryst in erupted basalts from Iceland have provided important insights into subsurface magmatic processes. This presentation is intended as an overview of studies on melt inclusion in mafic magmas in Iceland. High-Mg# (>65) melt inclusions are among the most primitive liquids known from Iceland, yet record modification of mantle-derived melts by differentiation and mixing. Furthermore, major and trace element compositions of inclusions spanning the basaltic spectrum demonstrate a trace element disequilibrium between primitive and evolved mafic melts, indicating that a range of mantle melt compositions must have contributed to the formation of the relatively evolved and compositionally constrained mafic magmas typifying the erupted products within the volcanic zones of Iceland. The erupted magmas appear to have evolved with time via polybaric storage at 1.5-8 kbars (= depths of ~5 to 30 km), with further modification up on ascent to eruption as evident from a common 0-1.5 kbar signal overprinted onto macrocrysts. Oxygen isotope measurements on host macrocrysts as well as melt inclusions reveal highly variable $d^{18}O$ (3.3–5.4 per mil) implying some oxygen isotopic variation within the mantle source. Volatile measurements in melt inclusions indicate a typical pre-eruption concentration in the range of 0.2-1.0 wt% H_2O, 250->3000 ppm CO_2 and 1000-2500 ppm sulphur. The sulphur data were used to propose a two-stage degassing model for basaltic fissure eruptions in Iceland, which now has been confirmed by recent study on the

sulphur degassing during the 2014-15 eruption at Dyngjusandur, North Iceland.

ORAL

Explosive ocean island volcanism caused by high water contents in ocean island basalts

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Water fundamentally influences the physical properties of the mantle and mantle-derived magmas, including rheology, viscosity, buoyancy, and explosive potential at the surface. Ocean island basalts (OIBs) usually erupt effusively and generally contain ≤1 wt. % H_2O. However, explosive eruptions of OIBs occur on occasion and are thought to relate either to a volatile-enriched mantle source or to shallow gas segregation processes. Here we report on explosively erupted, upper-mantle derived crystal-rich ankaramite lavas from Tanganasoga volcano on El Hierro (Canary Islands) that record magmatic water contents up to 3.2 ±0.64 wt. %. These H_2O values are among the highest known for OIBs to date and were determined through the analysis of hydrogen defects in clinopyroxene crystals. Notably, the Tanganasoga volcano formed within the recent El Golfo giant landslide embayment (87 – 39 ky), and its formation likely reflects rapid magma ascent due to unloading following the El Golfo landslide. Our data also imply that the Tanganasoga magmas are not primary melts but record a usually hidden snapshot of magma evolution in the sub-Canary mantle. At this point strong volatile enrichment in the magma is caused by fractionation processes within the underplating zone beneath the active ocean island, yet the vertical load of the island impedes the magma's ascent. However, in exceptional cases, sudden external pressure changes, such as from large crustal unloading caused by large landslides, may, similar to the "un-corking" of a champagne bottle, trigger fast ascent and explosive eruptions of water-rich magma and associated explosive ocean island eruptions.

ORAL

Improved control on interferences in laser ablation studies utilizing N2O as a universal reaction gas: Applications to ore mineral related studies

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Control on reaction chemistry of ions with a range of gases are instrumental in the development of minimizing interferences in ICP-MS applications. A recent breakthrough was achieved in this regard with the introduction of a new generation of ICP-MS that utilizes a configuration called QQQ. It turns out that this is of particular importance for laser ablation-based studies as this technology precludes other chemical treatments to remove interferences.

In the Microgeochemistry Laboratory at the University of Gothenburg we are in the process of evaluating different gases for their use of interference removal/minimization. It turns out that nitrous oxide (N_2O) is particular potent reaction gas. Rigorous testing has revealed that this gas is not only able to remove ^{87}Rb from ^{87}Sr (therefore allowing in-situ Rb-Sr dating; Hogmalm et al. 2017, JAAS 32, 305), but also serves as an almost universal reaction gas for routine in-situ trace element analysis. Significant improvement in detection limits is achieved for a wide suite of elements: Si, P, Ca, Ti, V, Cr, Mn, Fe, Ge and Se. A major reason for this is the minimization or removal of MAr^+ and M^{2+} interferences, respectively.

I will demonstrate that N2O as a universal reaction gas leads to a more reliable analytical

protocol in laser ablation studies, in particular in ore related studies where a wide variety of matrixes (sulphides, oxides, etc) leads to multitude of severe interferences that can easily lead to false results (e.g., the well-known false Rh and Pd values in the presence of Cu).

POSTER

New Scanning Electron Microscope for automated mineralogical, crystallographic and chemical analyses

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The Geological Survey of Denmark and Greenland (GEUS) recently acquired a ZEISS Sigma 300VP Field Emission Scanning Electron Microscope (SEM), and can now make automated mineralogic, crystallographic and chemical analyses on entire thin sections or polished mounts relevant for all areas of geoscience research, including mining and exploration, as well as investigations of reservoirs (oil & gas and geothermal energy). The instrument is equipped with 2 Bruker Xflash 6|30 129 eV EDS detectors, an Bruker e-FlashFS EBSD detector, a 185-850 nm Light-Guide Cathodoluminescence detector, a back-scattered electron detector and three secondary electron detectors, including an in-lense detector. The SEM is able to work under variable pressure conditions, with high vacuum condition of 3.25 x 10^{-4}Pa and low vacuum conditions between 2-133 Pa. Also it is equipped with the Zeiss Mineralogic software platform for mining and reservoir rocks. With this software, we will be able to perform automated mineralogy on entire thin sections, polished mounts (e.g. drill cores, heavy mineral separates, cuttings samples, ores) or parts thereof. The strength of the new SEM instrument lies in the combination possibilities for the different detectors and imaging techniques, which will shed a completely new light on geoscience microanalysis. In the presentation, we will give an overview over the range of new possibilities, with a focus on magmatic, metamorphic, and hydrothermal processes. We are open to discuss collaboration opportunities.

POSTER

In situ Rb-Sr dating of snowball Earth tillite clasts for provenance study on the Chuos formation, Namibia.

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Provenance studies can assist with valuable insights into transportation distance and mode of transportation when producing reconstructions on ice sheet movement and mechanics. Recent advancements in in situ Rb-Sr dating makes dating felsic clasts with Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) possible. This study applies these techniques to produce accurate and precise Rb-Sr dates on clasts from the Chous formation.

The Otavi group in Namibia, which contains both the Ghaub and Chous formations, has been the subject of intense study focused on the snowball Earth hypothesis. The Ghaub and Chous formations have been hypothesized to represent snowball Earth deposits because of their cap carbonates (Hoffman et al., 1998). Some of the clasts in the tillite are of felsic composition, with abundant K-bearing mineral phases, making them suitable for dating using Rb-Sr.

Using in situ Rb-Sr dating with LA-ICP-MS paired with an reaction chamber with N_2O (Zack and Hogmalm, 2016, Hogmalm et al., 2017), clasts from the Chuos tillite will be dated to examine whether their provenance can be determined. The aim of this study is to investigate if a continental-scale transportation distance during the Sturtian glaciation can be inferred. The results could potentially have an impact on how we view and interpret snowball Earth ice-sheet dynamics. Initial tests have yielded ages from pegmatite clasts, 925 Ma and 975 Ma

respectively, which does not appear to have been reset or altered during the Damaran orogeny (550-495 Ma).

1.10. Geochemistry and modeling of Igneous Systems.

ORAL

Markov Chain Monte Carlo Inversion of Mantle Temperature and Composition Beneath Iceland

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Basalts are formed by adiabatic decompression melting of asthenosphere, and thus provide records of the thermal, chemical and dynamical state of the upper mantle. However, uniquely constraining mantle temperature, composition and flow through the lens of melting is challenging given the inevitability that primary basalts are aggregates of partial melts derived from heterogeneous mantle over a range of P-T conditions. We aim to place more rigorous constraints on the uniqueness and uncertainties of mantle source properties by coupling a Markov Chain Monte Carlo (MCMC) sampling technique with forward modeling of polybaric near-fractional fusion of heterogeneous mantle using REEBOX PRO [1]. The MCMC method systematically samples the distribution of mantle potential temperature (T_P), and initial abundances and compositions of the source lithologies that produce models that "fit" geochemical and geophysical observations within their associated uncertainties. We have applied the model to magmatism along Reykjanes Peninsula in Iceland, exploring melting of depleted peridotite ± G2 pyroxenite [2] ± enriched KG1 peridotite [3] ± harzburgite. Best-fit models have depleted peridotite + enriched peridotite/pyroxenite sources having T_P ~122 ± 15 °C above ambient mantle with ~95% depleted peridotite and ~5% pyroxenite spanning likely compositions for G2 and KG1. The enriched lithologies have EMORB-like [4] trace element compositions and Paleozoic mean ages, whereas the depleted peridotite exhibits very-incompatible element enrichments relative to DMM [5]. These results advance our

understanding of the petrogenesis of the Iceland source that differs significantly from depleted mantle sampled by the global spreading ridge system.

ORAL

Enriched lithosphere contribution to the genesis of the Freetown Layered Complex (Sierra Leone): Isotope systematics of a high-Ti CAMP intrusion.

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We present a geochemical and geochronological study of a mafic layered intrusion cropping out along the Atlantic coast of Sierra Leone – the Freetown Layered Complex (FLC). Geochronology ($^{40}Ar/^{39}Ar$ on plagioclase: 201.7±0.7 and 202.3±2.3 Ma; U-Pb on baddeleyite: 198.794 ± 0.048/0.071/0.22 Ma) and crystal chemistry (high-TiO_2 pyroxene) demonstrate the connection between the FLC and the high-Ti magmatism of the Central Atlantic Magmatic Province (CAMP). Yet, Sr, Nd, Hf, Pb, and Os isotopes reveal an unusual signature for the FLC compared to most other CAMP occurrences previously studied. Particularly distinctive of the FLC rocks are their low $^{206}Pb/^{204}Pb$ and high $^{207}Pb/^{204}Pb$, suggesting involvement of an ancient component in the genesis of these magmas. Although some lower crustal assimilation is isotopically confirmed and also suggested by the presence of a granulite xenolith in one of the analysed rocks, this process alone cannot be responsible for the observed isotopic fingerprint of the FLC. We rather propose that the most straightforward way to confer the distinctive isotopic signature to the FLC is by hybridization of an upper asthenospheric melt with small volumes (1-3%) of highly enriched alkaline melts derived from the sub-continental lithospheric mantle, possibly lamproites. This scenario is also supported by the geodynamic setting of the FLC, emplaced within a Proterozoic mobile belt (Rokelide) and bordering an Archean craton (Man), as well as by the reported presence of lamproites and kimberlites in the area. Origin of high-Ti magmatism of other Gondwana Large Ignoeus Provinces (Karoo, Paraná-Etendeka) can likewise be explained by similar processes.

ORAL

Evidence of liquid immiscibility in the 1.8 Ga Raftsund monzonite, Lofoten, Northern Norway

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The significance of silicate liquid immiscibility and its petrogenetic role has been debated for many years. Although well documented in mafic layered intrusions, it is not clear if liquid immiscibility can occur in more evolved alkaline rocks. Here, we present evidence for this process in the 1.8 Ga Raftsund batholith; a monzonitic to locally granitic ferroan intrusion. Fe-Ti-P-rich mineralizations occurs as cm-scale up to 200 m x 50 m large scattered bodies, displaying both sharp and gradational contacts with the surrounding host pigeonite-clinopyroxene monzonite to syenite. The mineralizations are composed of anhedral rare pigeonite, Fe-rich olivine (Fo_{22-29}), subhedral clinopyroxene (Wo_{34-45} En_{20-46} Fs_{23-44}), anhedral magnetite and ilmenite, scattered late hornblende and variable proportions of subhedral ternary feldspars. Inclusions of apatite, which can reach up to 12 modal percent, are present in all minerals but ternary feldspars. The scarcity of pigeonite in the Fe-Ti-P-rich rocks and the presence of Fe-rich olivine indicate that these rocks cannot represent

direct cumulate from the host monzonite and syenite. Bulk-rock compositional variations are well explained by recent experimental work on liquid immiscibility (Charlier & Grove, 2012) with enrichment in Fe, Ti, P, Mg, Ca, Sc, Co, Zn, Cu, V and REE in the mineralizations. Clinopyroxene from the mineralizations is enriched in Sc and to a lesser extent in Ti, Zn and depleted in V, Co, Sr, Y, Nb, LREE and Al, which is consistent with co-precipitation of apatite and magnetite and the formation of such a melt by liquid immiscibility.

ORAL

Evolution of a deep crustal magma conduit system

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Seiland Igneous Province (SIP), Northern Norway represents the lower crustal plumbing system of a LIP where large volumes of ultramafic, mafic and alkaline-carbonatite melts were transported from the mantle to shallower levels of the crust. The Reinfjord mafic-ultramafic intrusion is a magma conduit system and offers an excellent location in which to study differentiation processes as magmas enter the crust (Larsen et al 2016).

Field relationships clearly show the Reinfjord intrusion formed by progressive influxes of new melts into earlier cumulates, resulting in a sequence of gabbro – olivine clinnopyroxeneite – wehrlite – dunite from the margins to the core (Grant et al 2016). Here, we determine the relative contributions of fractional crystallization, assimilation and recharge on the compositions of ultramafic cumulate layers.

Trace elements in clinopyroxenes were determined using LA-ICP-MS. Melts in equilibrium with the clinopyroxenes from Reinfjord have OIB-like characteristics, similar to picrite dykes in the SIP. For dunites and wehrlites, fractional crystallization was the dominant processes. The magmas did not fractionate by more than 30%, implying large volumes of magma were transported vertically to shallower levels of the crust. For olivine clinopyroxenites, LREE/HREE ratios record the importance of assimilation as well as fractional crystallization.

With time, the intrusion evolved to more olivine-rich and ultramafic cumulates, fractional crystallization become more dominant over assimilation, and the magmas leaving the conduit system became increasingly MgO-rich. These results may explain geochemical variations observed in flood basalt sequences (Yu et al 2015).

ORAL

Unraveling the differentiation of a flood basalt sequence using Magma Chamber Simulator

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The Magma Chamber Simulator (MCS; Bohrson et al., 2014) models the effects of recharge, assimilation, and crystallization on phase equilibria, mineral chemistry, major elements, trace elements, and radiogenic isotopes through mass and enthalpy balance in a multicomponent-multiphase magma + wallrock system. Here we provide an example of utilizing MCS in deciphering the differentiation history of a compositionally uniform continental flood basalt sequence characterized by strong crustal geochemical signature from the Antarctic portion of the Karoo large igneous province. Our modeling shows that only a few percent of assimilation of sialic crust may have profound impact on the composition of the parental magma (major elements, 16 trace elements, and Nd isotopes). Isobaric and continuously assimilating

models fail to produce the observed eruptive compositions. Instead, we suggest that contamination of the picritic parental magmas by assimilation of mid-crustal Archean TTGs (by stoping + hybridization or partial melting or both) must have first taken place at depths of ~10–20 km, where orthopyroxene and olivine are stable phases in the magma. Most of the subsequent differentiation happened in a complex network of dikes and sills in the shallow upper crust without additional assimilation. There, the large temperature gradient between magma in narrow feeding channels and country rock precluded anatectic melt formation and effectively shielded the magma from incorporation of wallrock partial melts. This example illustrates the capabilities of MCS in testing possible petrogenetic scenarios and encourages application of the MCS tool to different igneous environments and tectonic settings where assimilation takes place.

ORAL

Deep crustal homogenization of diverse mafic and ultramafic LIP-forming mantle melts: Lessons from the Ediacaran Seiland Igneous Province (SIP), Norway

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SIP contains >5000 km2 of mafic/ultramafic intrusions with minor alkaline, carbonatite and felsic rocks emplaced at depth of 25 - 35 km during the formation of the Central Iapetus Magmatic Province at 610-550 Ma (CIMP) and exposes 85-90 % layered gabbros, 8-10 % peridotitic complexes, 2-4 % alkaline intrusion emplaced within <10 Ma. Gravimetric data suggests that SIP features six deep lithospheric roots of ultramafic rocks extending in the depths of > 9 km that resembles the conduit systems. Four of the ultramafic complexes are exposed at SIP in a right-way-up setting. They feature a marginal hybrid zone at the country rock contacts, then an olivine-mela-gabbro grading to pyroxenite, then an olivine-clinopyroxenite zone which is followed by a wehrlite zone and, finally, pure dunite in the centre. From pyroxenite to dunite, olivine composition changes from Fo_{72} to Fo_{85} and clinopyroxene from Di_{80} to Di_{92} i.e. forming a reverse fractional crystallization inwards. Parental melts were komatiitic to picritic with 16-21 wt% MgO, 1594 ppm Cr and 611 ppm Ni and were emplaced at 1450-1500 ^{o}C. Melts are OIB-like with LREE enriched over HREE. The high abundance of carbonated and hydrated mineral assemblages imply a volatile-rich nature of the mantle source region also corroborated by unusually high abundance of magmatic sulphides.

Essentially, the ultramafic complexes in SIP comprise deep-seated transient magma chambers that facilitated mixing and homogenization of a rich diversity of fertile asthenospheric melts en route to the upper parts of the continental crust.

ORAL

Geochemistry of the Feragen ultramafic body, Central Norway.

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Tectonically dismembered ophiolite fragments stretch for several hundred kilometres along the Swedish-Norwegian border [1]. One of the fragments, the Feragen ultramafic body, located 30 km east of the town of Røros represents an excellent natural laboratory for studying upper mantle melting and melt extraction processes. Upper mantle rocks in Feragen are represented by harzburgite, that occasionally changes composition towards lherzolite and a subordinate amount of dunite. In the north-

western part of the massif, close to a presumed mantle-crust boundary, the amount of dunite exceeds that of harzburgite. Dunitic rocks were observed both as replacive dunites with gradual transitions to harzburgite up to several meters wide, and as dunite channels with sharp borders to host harzburgite and a maximum width of 50 cm. Harzburgite relicts of various shape are often present within the dunite channels and the replacive dunites.

Olivine present in the rocks is higly magnesian with Mg numbers ranging from 90 to 91 in harzburgite and from 92 to 94 in dunite. NiO content of olivine in all the rock types does not exceed 0.4 wt %. Some of the dunites are rich in chromian spinel. Cr numbers for spinel are between 0.4 and 0.6. TiO_2 content of spinel minerals is as low as 0.15 wt % [2]. Chromitites show extreme depletion in Pt and the overall PGE content implies depleted mantle composition for the rocks analysed. Low TiO_2 content of spinel and high Fo content of olivine suggest a high degree of melting, that is greater than 25%

ORAL

Mica chemistry - a genesis indicator of the Sveconorwegian pegmatites, southern Norway

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Mica minerals are the third most common component of granitic pegmatites. They contain important major and trace elements including Li, F, and Rb, which can be used for pegmatite classification and to better understand the origin and genesis of pegmatites (Marchal et al. 2003; Breiter et al. 2017). Southern Norway is known for its large pegmatite province with more than 5000 pegmatite bodies, occurring in the Sveconorwegian orogeny (1.1-0.9) and forming one of the world's largest pegmatite clusters. We present the first comprehensive comparison of mica from the Tørdal, Evje-Iveland and Froland pegmatite fields. Mica from Tørdal is significantly enriched in both Li_2O wt% and F % compared to mica from the Evje-Iveland and Froland. The Tørdal mica contains up to 5.4 wt% F and 6.0 wt% Li_2O, while only up to 2.6 wt% F and 0.6 wt% Li_2O are measured from the Evje-Iveland field and 1.2 wt% F, 0.3 wt% Li_2O in the Froland mica. A similar pattern is seen in the K/Rb ratios with the lowest values found in the Tørdal mica ranging from 3.63 to 27.5 contrary to 16.5-365 and 29.9-62.5 from Evje-Iveland and Froland, respectively. The Tørdal pegmatite field contains the most evolved mica and thereby the most evolved pegmatites. The strong enrichment of Li, F and Rb suggests that the source of the Tørdal pegmatite melts might be different than for the Evje-Iveland and Froland fields. The latter are thought to be of anatectic origin.

ORAL

Chronology of the Nebo Granite, Bushveld Complex

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The world's largest A-type granite unit (the Nebo Granite)overlies the layered mafic and ultramafic cumulate rocks of the Rustenburg Layered Suite (RLS) Together with minor granophyre and other granites these units make up the Bushveld Complex, South Africa. The Nebo Granite often cuts the RLS and existing zircon U-Pb chronology supports the view that the granite is slightly younger and essentially unrelated to the RLS.The age of the RLS is very well constrained at 2055.91±0.26 to 2054.89±0.37 Ma (Zeh et al., 2015)We present new ID-TIMS zircon U-Pb chronology for 9 samples of the Nebo Granite and a related granophyric variety. We show that the ages obtained from the Nebo Granite are indistinguishable from each other and from the age of the RLS. Moreover, the granite also

contains minor amounts of zircon that are slightly (<9 m.y.)older than the crystallization age. The older zircons are morphologically similar to the young zircons and are found in all samples we have investigated. Their ages also overlap the age of the earliest phase of magmatism in the Bushveld LIP.These observations suggest that the older zircons are inherited from magmatic rocks that formed during the earliest phase of Bushveld magmatism and are not xenocrysts from older basement rocks. Even though the Nebo Granite is probably an assembled body, it crystallized too fast for its temporal evolution to be resolved. Contemporaneity between the RLS and the Nebo Granite challenges the view that they are essentially unrelated and introduces the possibility of consanguinity between the two units.

ORAL

Fe and Si isotope systematics of the Thingmuli volcano, Iceland: the roles of crystal – melt fractionation, oxygen fugacity and melt structure

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The Tertiary Thingmuli volcano, Eastern Iceland, is a classic example of tholeiitic differentiation spanning the compositional range of basalt to rhyolite. Whole rock and mineral compositions coupled with forward modeling indicate fractionation of olivine, pyroxene, plagioclase and FeTi-oxides buffered at an oxygen fugacity slightly below the FMQ buffer. The well-constrained liquid line of descent for Thingmuli provides an opportunity to investigate stable isotope crystal-liquid fractionation for the two most abundant major elements, Fe and Si. Iron isotope fractionation is expected to be sensitive to redox condition, while Si is not. Fe and Si were chemically purified and analyzed for δ^{56}Fe and δ^{30}Si with a Nu Plasma II MC-ICPMS at Aarhus Geochemistry and Isotope Research Platform (AGiR), Aarhus University, using pseudo-high resolution and sample-standard bracketing. Fe isotope compositions of Thingmuli lavas range from δ^{56}Fe = 0.042 ‰ to 0.118 ‰ for mafic and intermediate compositions, and 0.124 ‰ to 0.650 ‰ for rhyolites. The heaviest values correspond to the most evolved, Fe-poor lavas. Preliminary Si isotope data ranges from δ^{30}Si = -0.36 ‰ to -0.06 ‰ and shows a positive linear correlation with whole rock SiO_2 (wt. %) content. Forward modeling of the stable isotope compositions shows that Fe^{3+}/Fe^{2+} partitioning between melt and crystallizing solids is the principal contributor to iron isotope fractionation, except during the final stages of crystallization where high melt polymerization affects the coordination environment and fractionation of iron. In contrast, Si isotope fractionation reflects the degree of Si-polymerization of melt and solid phases throughout the crystallization sequence.

ORAL

Geochemical discrimination criteria for indium-potential granites in the Fennoscandian Shield

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Spectacular discoveries of indium-rich polymetallic sulphide/oxide deposits have recently been reported from the Fennoscandian Shield; Pitkäranta, Russian Karelia (Valkama et al., 2016a) and Sarvlaxviken, southern Finland (Cook et al., 2011; Valkama et al., 2016b; Broman et al., 2017). These sulphide/oxide deposits are closely associated with A-type granites, hosted by marbles (Pitkäranta) at km-distance from the 1.54 Ga Salmi Batholith or various granite types (Sarvlaxviken) within the 1.64 Ga Wiborg Batholith.

The batholiths display complex magmatic evolution trends from gabbro-anorthosites, via wiborgites, pyterlites and transitional granite phases to evolved late-stage plutons. The wiborgites and pyterlites have typical WPG geochemical patterns with shallow REE patterns and significant negative Eu anomalies but did not create any hydrothermal systems or metal accumulations.

In contrast, some (but not all) late phase granite plutons (≤ 1 km diameters), provided metals and heat for the metal-rich hydrothermal fluids and thus indium-rich polymetallic accumulations. These plutons have also WPG characteristics (although fake "syn-collisional granite" signals are seen in some discrimination diagrams due to hydrothermal influence).

Zr/Hf Rb/Ba

Wiborgites, Sarvlaxviken 43-50 < 0.2

Pyterlites, Pitkäranta 28-40 < 0.3

Transitional phases (Repomäki and Nietjärvi), Pitkäranta 15-24 2- 18

Late granite phase (Marviken), Sarvlaxviken 17-22 11- 23

Late granite phases, Pitkäranta 7-14 10-150

The late igneous phases can be evaluated by several geochemical criteria but the low Zr/Hf ratios, high Rb/Ba ratios and enrichments of heavy REE are the most characteristic features for the ore fertile granites (Torppusuo, Ristinoja-Mosautodor and Uuksu in the Pitkäranta area and Marviken in the Sarvlaxviken area).

POSTER

Chronology and geochemical and structural evolution of dykes intruding the Reinfjord ultramafic to mafic intrusion in the Seiland Igneous Province

Alf Andre Orvik[1], Bjørn Eske Sørensen[1], Rune Larsen[1] and Thomas Grant[1]
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This study investigates the chronology, geochemical and structural evolution of dykes intruding the Reinfjord Ultramafic Complex (RUC) consting of large volumes of ultramafic, mafic, silicic and alkaline melts intruded the lower crust (~30 km) from 570-560 Ma in an extensional regime. The RUC was nested to baltica the Caledonian orogeny. Earlier studies have indicated horizons with anomalous concentrations of Pt+Pd+Au+Os and enriched horizons of Cu-Ni.

The ultramafic rocks are cut by several generations of dykes ranging from replacive dunite dykes intruded into the semi-consolidate host-rock with gradual contacts, to late gabbroic dykes that has a chilled margin. The dykes have complex crosscutting relations and in areas it constitutes up to 50 % of the outcrop volume. Large variability in chemistry and volatile content ranging from wherlites, olivine clinopyroxenites, hornblende bearing olivine clinopyroxenites, hornblende gabbro, alkaline and lamphrophyric dykes.

A relative chronology of the dykes was established by the cross cutting relations of the dykes during field work and post processing of 3D photogrammetry from drone images will be used to estimate the melt volumes within the different dyke types and their orientation evolution over time within selected locations of the central series. Petrographic descriptions of attained samples together with chemical analysis, and hopefully radiometric dating, will in combination with the photogrammetric data give insight in the evolution of the melt related to the

dykes. Our ambition is that the data will provide valuable information and constrain the chronological progression of the geochemistry and tectonomagmatic association of the dykes.

POSTER

Platinum Group Minerals in the Reinfjord Ultramafic Complex

Even Sunnanå Nikolaisen[1], Rune Berg-Edland Larsen[1], Thomas Grant, Bjørn Eske Sørensen[1] and Suzanne McEnroe[1]

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An upwelling mantle plume 560 - 570 Ma formed the Seiland Intrusive Province (SIP), a 5400 km^2 area of felsic to ultramafic rocks in Northern Norway. The Reinfjord Intrusive Complex (RUC) is the southernmost part, exposing 25km^2 of ultramafic rocks that are generated from three intrusive magmatic events and crystal fractionation. These events show evidence that RUC is representing an open magma chamber, connected to a conduit system at 25-30km depth and subjected to extensive magma replenishment.

Exploration drill cores in RUC in 2011 (RF-1 and RF-2) show two spikes for economic elements, one Cu-Ni reef low in PGE at depth of 86-93m and a PGE reef low in Cu-Ni at 107-113m

A detailed analysis of a 6 m drill core section, suggest PGE being segregated in different lithologies, which combine to a total of 0.79 ppm PGE. When comparing the $\delta^{34}S$ signature of the PGE reef with the Cu-Ni reef shows a distinct difference -0.40 (PGE) and -4.56 (Cu-Ni), indicating different sources.

This study looks into the details of the PGE's, with the aim of identifying the ore forming processes. SEM imaging and mapping, EPMA, magnetic analysis and whole rock geochemistry are used to find cryptic variations in the PGE rich lithologies. BSE and EDS detects and identify the PGE's, with EPMA data to calculate empirical formulas for PGM identification. Based on the results, it is clear that despite a sub-economical grade, the RUC provide a valuable insight in to the ore forming potential for deep-seated layered intrusions.

1.11. Open session on petrology and geochemistry

ORAL

Additional constraints to the evolution of the early solar system? A U-Pb systematics study of ungrouped differentiated achondrite NWA4587.

Yuri Amelin[1] and Elin Rydeblad[2]
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The study of meteorites can help us answer questions still under debate regarding the early solar system and the processes therein. It could help us unify a timescale for the development of the solar system, help us fully understand how our planets formed, and tell us about the nature of elemental dispersal throughout the early solar system (Amelin and Ireland, 2011). It will also allow us to investigate how our solar system compares to other solar systems – giving us an invaluable tool in the search for other habitable planets and possible life, and future celestial exploration (White, 2011).

This study aims to add additional constraints to the evolution of the early solar system by the isotopic analysis of ungrouped differentiated achondrite North West Africa (NWA)4587.

All sample processing was performed at the SPIDE^{2}R laboratory facilities, located at the Research School of Earth Sciences (RSES) at the Australian National University (ANU). For the U-Pb systematics, four separate hand-picked pyroxene fractions were analysed. The fractions were chosen based on mineral grain texture, colour, and size. This study employed an acid leaching and dissolution protocol, combined with single- and double pass μ-column protocols. The Pb ratios and isotopic composition of the samples were analysed using a thermal ionisation mass spectrometer.

The age of NWA4587 is 4563.63±0.55 Ma, suggesting that its parent body was formed during early planetary accretion. Further analyses of Rb-Sr isotope systematics are currently being conducted, and the preliminary results are concordant with the age determined by the U-Pb systematics.

ORAL

The EARTHTIME Initiative: A community working to accelerate the development and application of integrated methodologies for the quantification of geological time.

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The EARTHTIME Initiative is an international community effort to 'To accelerate the development and application of integrated methodologies for the quantification of geological time for the underpinning of Earth sciences'. The first phase (from 2004 and ongoing) was focused on addressing urgent shortcomings in the 'high-precision' geochronometers (e.g., U-Pb and ^{40}Ar-^{39}Ar), issues that limit widespread application at the quoted levels of precision/accuracy. Many of these (e.g., inter-laboratory bias) have been addressed through experiments conducted over the past 13 years and the accuracy and precision of both of these widely used dating systems has been significantly improved. The EARTHTIME Initiative has brought the ^{40}Ar-^{39}Ar and U-Pb isotope dilution sides together (for both experiments and application) but also expanded to include a range of decay schemes (e.g., Re-Os and U-Th) and analytical approaches (e.g., microbeam U-Pb). Perhaps the most significant outcome has been the development of a strong and lasting sense of a 'geochronology community'.

Whilst these Phase 1 activities continue, the original motivation for accelerating progress in the various dating methods has been that they underpin a wide range of Earth science research areas. Starting in 2016 a second phase of EARTHTIME has been initiated, following two

community workshops, with a renewed emphasis on engagement of the geochronology community with the 'end-users' of geochronology. This presentation will provide a summary of EARTHTIME efforts since 2004 to present to calibrate and inter-calibrate the geochronometers, and will provide a vision and strategy for the second phase of the EARTHTIME Initiative.

ORAL

Pangea assembly and its implications to the mid Permian–Triassic magmatism on the southwestern margin of South America

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The Chilean Frontal Andes batholiths (28°–31°S) represent part of the extensive late Paleozoic–Triassic magmatism along the southwestern margin of South America. Despite its importance, a consensus regarding the tectonic model controlling the magmatism has not been reached. Several models[1,2,3] have proposed cessation of subduction as the reason behind the apparent lack of typical arc magmas and abundance of within plate signatures. Yet the causes for this cessation differ and do not provide a comprehensive model for coeval units along the margin. Here, new LA-ICPMS U–Pb in zircon ages, and geochemical and isotope analyses (Rb-Sr, Sm-Nd, Lu-Hf, Re-Os and d^{18}O) indicate that mid Permian–Triassic granitic magmatism originated in a slab rollback extensional setting with increasing thinning towards Triassic times. Subduction and anataxis of lower crust were the main magma-generation mechanisms, the latter caused by decompression and subsequent accumulation of underplating basalts. A comparison with other igneous units along the Chilean–Argentinian border allows extension of this model from at least 21° to 40°S. The key element triggering intense extension in a subduction setting (slab rollback) is low subduction velocities -as numerical models have predicted[4], which can be attributed to the transitory stage of Pangea (mid Permian–Triassic). Hence, subduction of the paleo-Pacific oceanic plate beneath paleo-South America has been a continuous process from early Paleozoic times onwards; and Pangea assembly, the setting behind the observed changes in the magmatism and not the cessation of subduction as previous models have invoked.

ORAL

Tourmaline textures and structures as a tracer for the magmatic-hydrothermal transition in SW England

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Tourmaline is a common mineral throughout the granites of SW England. It occurs in multiple textural and structural varieties, including veins, quartz-tourmaline orbicules, massive quartz-tourmaline rocks (MQT), pegmatitic pockets, and disseminated in the granite. Field relations indicate both magmatic tourmaline and post-magmatic, hydrothermal tourmaline, occuring as disseminated grains and veins, respectively. In addition, more genetically complex textures are observed as gradual exsolutions of quartz-tourmaline rocks within the granite, with or without associated veining. These appear on the cm scale and up to several meter large bodies. Such structures are observed in localities several km apart, and are a regional feature. Occasionally, the gradual transition from granite to MQT to miarolitic tourmaline or a pure tourmaline zone, can be observed over tens of cm. The microtextures are strongly linked to the macroscopic structures, reflecting the diverse processes that formed the different tourmaline occurrences. Strongly birefringent, green,

acicular tourmaline dominates in vein-style tourmaline; disseminated tourmaline in the granite is weakly zoned and brown; tourmaline from MQT is brown with blue rims. Later tourmaline generations overgrow earlier generations, adding to the complexity. Cassiterite is only associated with the hydrothermal green acicular tourmaline. Tin concentrations in other tourmaline-rich rocks are less than 100 ppm, and these rocks are not a part of the mineralizing events of the Land's End granite.

ORAL

Dendritic Core Crystallization in Minor Planets – An empirically constrained Numerical Simulation Study

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The Cape York meteorite shower typifies the magmatic iron meteorites. The Agpalilik mass displays characteristic oriented, elongated troilite nodules, interpreted to testify to a dendritic crystallisation mode of surrounding (Fe,Ni) metal phase (Esbensen (1981, 2017); Esbensen & Buchwald (1982); Esbensen et al. (1982; Haack & Scott (1992). The troilite accessory mineralogy testifies that the fractional crystallisation / late magmatic differentiation history of asteroid cores can be modelled in the Fe –Ni –S- P system. Accessory schreibersite and high-Ni taenite are found lining the metal/ troilite interface, representing very late crystallisation from an evolved Fe-Ni-S-P liquid. A troilite/taenite eutectic represents the ultimate liquid-solid transformation product (the paragenesis shows that schreibersite precipitated prior to taenite crystallization, effectively purging the system for P), allowing the ultimate crystallisation to be modeled in the residual Fe-Ni-S system, which thus defines an iron meteorite analogue to the petrogenetic residual system for silicate magmatic rocks. The inter-dendrite residual melt pocket physiography (3rd or 5th order arms) allows to attempt an ambitious fractal numerical simulation modelling of the crystallization of the early solar system asteroid/planetoid metallic cores. Agpalilik will serve as an empirical constraint for numerical dendritic crystallization modelling, based on a simplified Fe-S system, believed to approximate (Fe,Ni)-S well. It is first in the latest years that it has been possible to tackle the numerical simulation challenges involved, Misztal MK, Bærentzen JA (2012); Misztal MK, Erleben K, Bargteil A, (2014). We present a first foray overview of the scope of this challenging multi-disciplinary study.

ORAL

Age and geochemistry of granitoids in the Precambrian basement of Öland, SE Sweden – implications for the extension of the Transscandinavian Igneous Belt in the Baltic Sea region

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The Precambrian crust in the Baltic Sea region is mostly covered by Phanerozoic sedimentary rocks but can be studied in drill cores. Two granitoids from the crystalline basement below Öland were collected from the archives of the Geological Survey of Sweden and analyzed for geochemistry and dated with the U-Pb method on zircons. The Böda Hamn granitoid (northern Öland) has a monzodioritic composition and an age of 1799.8±3 Ma while the Valsnäs granitoid (central Öland) has a quartz monzonitic composition and an age of 1784.9±5.7 Ma. These geochemical-isotopic characteristics are compatible with those of generation 1 of the Transscandinavian Igneous Belt (TIB) in the Fennoscandian Shield, ≥30 km west of Öland.

A more detailed review of the TIB-1 generation shows that two sub-generations (1a and 1b) can be distinguished on each respective side of the Oskarshamn-Jönköping Belt (OJB). Sub-generation 1a (north of OJB) has an age span of 1794-1808 Ma while sub-generation 1b (south of OJB) has an age span of 1769-1793 Ma. According to this subdivision, the Böda Hamn monzodiorite belongs to sub-generation 1a, which also can be followed to southernmost Gotland (Sundblad et al. 2003) and the Valsnäs quartz monzonite belongs to sub-generation 1b, which can be followed to the Latvian/Lithuanian border, where a marginally younger granitoid was reported from off shore drill core E-7 (Salin et al. 2016). Taken together, these data suggest that the Transscandinavian Igneous Belt can be traced across the Baltic Sea from the exposed parts within the Fennoscandian Shield to the Latvian/Lithuanian border.

ORAL

Sr isotope zoning in plagioclase from Cenozoic andesites from Cabo De Gata, Spain: evidence for shallow and deep contamination

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Subduction-related andesites from the Cabo De Gata region in Southern Spain are part of the larger Alboran Magmatic Province which stretches from Northern Africa, through the Alboran Sea into Southern Spain. The province is of interest due to the penecontemporaneous occurrence of a wide variety of magma compositions (incl. tholeiitic basalts, calc-alkaline andesites, explosive rhyolites, peraluminous crustal melts and lamproites) and temporal overlap with the Messinian Salinity Crisis. Many plagioclase phenocrysts within andesite domes at Cabo De Gata are characterized by resorbed high-An% cores (An_{73-85}) surrounded by oscillatory zoned plagioclase (An_{40-60}). Sr isotope analyses of the high An% cores of these plagioclases show consistently radiogenic $^{87}Sr/^{86}Sr$ compositions (0.7127-0.7129). These compositions are inconsistent with an origin as xenocrysts from early formed mafic volcanics or from metamorphosed carbonates in the basement. We interpret these high-An% cores to be early formed phenocrysts crystallizing from more primitive and relatively water-rich magmas in the deep crust. Their radiogenic Sr isotope compositions suggest that these early magmas already had a significant crustal component, consistent with other evidence for important involvement of a subducted sediment component during magmatism. The resorbed nature of the high-An% cores is interpreted to reflect resorption during rapid magma migration into the upper crust. Lower An% rims of these same plagioclases show increases in $^{87}Sr/^{86}Sr$ (up to 0.7132) that are consistent with interactions with crust in upper crustal magma chambers. The plagioclase Sr isotope data therefore provide evidence for both source and crustal contamination during petrogenesis of the Cabo De Gata andesites.

POSTER

Recycling of continental material through the suprasubduction zone Mawat ophiolite, NE Iraq

Heider Al Humadi[1], Markku Väisänen[2], Sabah Ismail[3], Yann Lahaye[4], Hugh O'Brien[4], Jaakko Kara[2] and Marja Lehtonen[4]
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The fate of subducted continental material is not fully understood. It is estimated that up to 20% of it is recycled back to the crust (Clift et al. 2009), mainly in volcanic arcs. Recently, suprasubduction zone ophiolites formed above subduction zones have also been shown to contain recycled continental minerals (Robinson et al. 2015).

We have analysed zircons and monazites from three felsic dykes and zircons from two mafic rocks from the mantle section of the suprasubduction zone Mawat ophiolite in NE Iraq. Laser ablation single-grain U-Pb results show a wide range of ages from the Late-Cretaceous to Paleo-Archean (c. 95-3500 Ma). The youngest 95 Ma age represents the formation of the Mawat ophiolite whereas the bulk of the zircons are inherited from older unknown mixed continental material. Lu-Hf isotopes on zircons from a felsic sample show average initial ε_{Hf} = –2.4. The results indicate that the magma originated from an older source possibly contaminated in the mantle wedge. In contrast, the initial ε_{Hf} values of the mafic sample display an average of + 9.4, indicating a juvenile magma source.

The results show that the felsic rocks of the Mawat ophiolite formed in a forearc position partly from recycled older continental material which was most likely subducted as the upper layer of the Neo-Tethyan oceanic crust. The effect of the older crustal material on the newly-formed mafic crust is significantly less based on the Hf data, but nevertheless is in clear evidence by the occurrence of old xenocrystic zircon.

POSTER

Oxidative weathering in the Late Neoproterozoic: Preliminary Cr Isotope results from the Urucum District, Brazil

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The Fe and Mn deposits in the Urucum district (Banda Alta Fm.) in Mato Grosso do Sul, Brazil, which are associated with glaciogenic deposits, are among the youngest and largest Cryogenian sedimentary Fe and Mn formations (IF, MnF). The Urucum IF comprise plane-parallel, stratified hematite-chert iron with interspersed manganese micro- and mesobands. A lower age limit of 695 ± 17 Ma is defined by detrital zircon U-Pb from shaley beds in the Banda Alta Fm. (Frei et al. 2017). Preliminary results from borehole samples (Vetria borehole 28-32) support previous findings with a positively fractionated authigenic Cr isotope signature throughout the stratigraphic section ($d^{53}Cr_{SRM979}$ = 0.80 ± 0.25 ‰, 2s, n=26/28). This indicates a continental source of oxidized Cr, implying high atmospheric O_2 levels in the late Neoproterozoic.

POSTER

Quadlab – A $^{40}Ar/^{39}Ar$ and noble gas isotope laboratory at the Natural History Museum of Denmark

Michael Storey[1] and Daniel Wielandt[1]
[1]Quadlab, Natural History Museum of Denmark

In this poster presentation we provide an overview of Quadlab, a Villum Foundation funded $^{40}Ar/^{39}Ar$ age-dating and noble gas isotope laboratory that has recently been established at the Natural History Museum of Denmark. The laboratory has two noble gas mass-spectrometers: (1) A Nu Instruments Noblesse from 2005 - equipped with 3 ion counters (high, axial and low mass positions) and a high mass Faraday detector; (2) A Thermo-Fischer Helix MC high-resolution noble gas mass-spectrometer (commissioned spring 2016), equipped with 5 dual faraday/ion counting detectors with 10^{12} and 10^{13} ohm amplifiers for improved (signal to noise ratio) of argon isotopes. The Helix has a 120 degrees magnet with a standard resolution of 900, allowing full resolution of hydrocarbon isobars in the Ar mass range 36 to 40. The high-resolution mode on channel L2 has a resolution of 1700 allowing psudeoresolution of the HCl isobar from ^{36}Ar. Three independent laser-sample gas preparation systems supply the 2 mass-spectrometers, with one preparation system designed and dedicated specifically for cosmogenic nuclide exposure dating (^{3}He, ^{21}Ne) applications. This system is equipped with a Janis closed cycle cold trap system (CCSTRAP-HT/204N) to 7K for sequential release and

measurement of the different noble gases. We are mainly applying these tools to Quaternary problems, such as hominin evolution and the relationship between volcanism and climate. We are also currently working on projects related to meteorites and impact structures.

2. Metamorphic rocks and processes

2.1. Geodynamic and geological evolution of the Arctic

ORAL

When a platform-edge meets a platform: 3D sedimentary architecture of a large-scale prograding paralic system, SW Edgeøya, Svalbard

Ingrid Anell[1], Daniela Röhnert[1], Alvar Braathen[1], Kei Ogata[2], Per Terje Osmundsen[3], Aleksandra Smyrak-Sikora[4], Harmon Maher[5], Snorre Olaussen[4], Gareth Lord[6], Ivar Midtkandal[1], Mark Mulrooney[1] and Simon Buckley[7]

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The study combines facies analysis from sedimentary logs with pseudo 3D photogrammetric observations to provide a large-scale regional understanding of the Carnian depositional development around SW Edgeøya, which was filled by strongly tidally influenced deltaic systems. Prism-scale NW advancing Triassic clinoforms are documented in seismic data on the northern Barents Shelf. The sigmoidal clinoforms progressively form low-angle, linear tabular geometries, as the prograding system approaches Edgeøya. The studied succession documents very low angle infill from deep basin to coastal plain reflecting the advance of the clinoform system across the high. The study provides understanding of how the scale of the system, sandbody geometry and sedimentary processes were affected by more limited accommodation and increased tidal reworking.

The studied succession documents an early base-level fall during which large amounts of sand were arrested in fault-bounded half-grabens at Kvalpynten, while bypass and erosion is apparent towards the East. Accretion during a subsequent transgression documents continued high sedimentary input during relative sea-level rise. Paleocurrent and shaling out attest to local influx from an E/NE source around Kvalpynten, while at Svartpynten the regional NW trend is apparent. Svartpynten reveals a more shore-line proximal location, and following transgression, tidal bars indicate proximity to the fluvial source. At Kvalpynten laterally extensive subtidal sand-sheets grade into distinctly flat-based lens-shaped sand-bodies, likely shoaling barrier sands. A variety of channel-fills is documented in the overlying succession, which consists predominately of highly bioturbated sheltered intertidal mud-flats grading and interfingering with vegetated coastal plain.

ORAL

Late Triassic sandstone provenance of the Barents Shelf; a regional comparison of preliminary detrital zircon geochronological and petrographic data

Trond S. Harstad[1], Mai Britt E. Mørk[1] and Trond Slagstad[2]

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Several scientific contributions have been published in the last years on Triassic sandstone provenance in the Barents Shelf and Arctic areas. A southern or eastern Uralide component is well established in parts of the Triassic, in particular in south-eastern areas of the shelf. More recently, possible sediment contributions from a possible northern Uralide source area in the Late Triassic has been discussed. In our study, we aim to identify and compare sandstone provenance signatures in selected locations of the Upper Triassic De Geerdalen and Snadd formations in a north - south transect from Svalbard to the

Nordkapp Basin. Petrographic observations reveal lithic and feldspathic sandstone compositions, notably with plagioclase dominating over K-feldspar, and characterised by lithic fragments of volcanic, metasedimentary and sedimentary origin. The polycrystalline quartz content represents deformed quartzite as well as chert and spiculites. Chromium spinel, apatite, garnet, rutile, tourmaline and zircon heavy minerals are observed in varying abundance. Preliminary detrital zircon age spectra from Svalbard, are similar to published zircon spectra of the larger Arctic region, including Triassic peaks of nearly syn-depositional ages. A dominance of Permian to Carboniferous zircons is compatible with an earlier inferred Uralide provenance to the east. However, a significant Caledonian age component has also been identified, which suggests a possible contribution from western areas. Currently, petrographic analysis of central and southern areas of the transect will be compared with results in progress from ongoing zircon analysis, and current regional geological knowledge, for better constraining alternative source area signatures.

ORAL

Formation and Origin determination by geochemical fingerprinting of ruby and pink sapphire from the Fiskenæsset complex, Greenland

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Metamorphic petrology observations on rubies found in-situ in their host-rock are combined with geochemical measurements and optical microscopy observations on the same rubies, with the aim to connect the ruby-forming metamorphic reaction to a unique fingerprint for these minerals. The Fiskenæsset complex in Greenland is used as an area of case study. Isochemical pressure-temperature sections were calculated based on electron microprobe and whole-rock geochemistry analyses, and compared to field observations. Rubies were formed resulting from a reaction between olivine/serpentine and anorthite, triggered by the intrusion of a pegmatite. Al is sourced from the anorthite, the pegmatite reacts to anthophyllite, Cr^{3+} is mobile in the pegmatitic fluid, giving colour to the rubies. The ruby-forming reaction occurs at 640 °C and 7 kbar. In order to establish the unique fingerprint for this ruby-bearing ultramafic complex, laser-ablation inductively-coupled-plasma mass-spectrometry trace element measurements, oxygen isotope compositions, optical microscopy and scanning electron microscopy were applied. Due to the setting in an ultramafic rock-anorthosite-leucogabbro complex, the fingerprint of the rubies from the Fiskenæsset complex is rather unique. Fiskenæsset complex rubies contain high Cr, intermediate Fe, and low V, Ga, and Ti concentrations, low oxygen isotope values (1.6 to 4.2 ‰) and a rarely-observed combination of optical growth features and mineral inclusions like anthophyllite+biotite. Results for other Greenlandic localities are presented and discussed as well. Even though these are derived from ultramafic rock settings too, they record different trace element ratios and oxygen isotope values, resulting from variations in the ruby-forming reaction.

ORAL

Norsk Polar Navigasjon's archive of old exploratory wells on Svalbard

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During a 30 year period from the 1960's to 1990's several deep exploratory wells for oil drilled on Svalbard . The deepest well at Ishøgda was 3304m deep. Norsk Polar Navigasjon (NPN), the

first Norwegian oil company, was involved in nine of the drillings. NPNs archive with information from the drillings has been made available for this study.

Though oil or gas was detected in the wells at Ishøgda, Tromsøbreen and Sarstangen, all wells was plugged and abandoned.

Geological and geophysical information from the wells are limited, but there are interested information of borehole stratigraphy, gas hydrates and geothermal gradients that will be presented and discussed

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ORAL

DEVELOPMENT OF THE AMERASIA BASIN: WHERE ARE WE NOW?

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[1]Stockhkholm University, [2]Uppsala University, [3]University of Gävle

The Amerasia Basin is separated into the Canada Basin and the Makarov-Povodnikov basins by the Alpha-Mendeleev Ridges. Published data supports a conjugate relationship between the Alaskan and Canadian Arctic margins, in which counterclockwise rotation of Arctic Alaska from Arctic Canada resulted in the opening of the Canada Basin. Thus the tectonic development of the Canada Basin is 'broadly' understood, although the precise timing and the role of the Chukchi Plateau remain disputed. This leaves the Amerasia Basin and we identify two significant barriers to understanding its tectonic development: i) The northward extent of the Canada Basin fossil spreading ridge, and ii) the role of LIP magmatism. In assessing the former, we simulated extension in a series of two-plate analogue models with properties homologous of homogeneous continental crust around a common rotation axis. In all models, a triangular (ocean) basin forms between the two 'diverging' plates, however, depending on the mode of opening and initial plate configuration transpressive, transtensive, and 'pure' strike-slip structures can be generated and account for the following first order observations: i) curvature in the fossil ridge, ii) transcurrent margins of opposite motion, and ii)asymmetry of the basin. These results elucidate the consequences of sea-floor spreading in the Amerasia Basin and help to constrain opening scenarios.

ORAL

Tectonostratigraphic atlases: further perspective in Arctic research

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Intensive study in the Arctic during last 15 years has resulted in the accumulation of new data on the geology of the region, including those obtained during geophysical sounding of the ocean floor, examination of bottom rock material, studying geology of islands and the continental part of the Russian Arctic. One of the international projects is the Atlas of Geological Maps of the Circumpolar Arctic at a scale of 1:5,000,000, which includes geological and tectonic maps, potential field maps, and mineral resources map. Modern level of knowledge of the Arctic allows the analysis of tectonostratigraphy and litho-geodynamics of the region and interpretation of geological complexes in terms of tectonic settings of stratigraphic sequences formation based. The Atlas "Geological History of the Barents Sea" (2009) by Russia and Norway was first experience in the implementation of this work.

In 2014, geological surveys of the Arctic states complied the "Tectonostratigraphic Atlas of the North-East Atlantic region". Currently, the Russian Geological Research Institute (VSEGEI) actively works on compilation of the "Tectonostratigraphic Atlas", covering the eastern Russian Arctic continental part and eastern Eurasian basin.

Compilation of the Atlas as a set of systematic modern geological information is of great importance for understanding the geology and history of tectonic development of this insufficiently studied region.

Together with the NPD and the NGU, we are going to compile the Tectonostratigraphic atlas for the Barents-Kara region. The work at Tectonostratigraphic atlases is a new stage in the development of the international cooperation in the Arctic.

ORAL

Crustal structure of the Eurekan Orogen on Ellesmere Island, Arctic Canada

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Receiver function analysis of new broadband-seismological data provides images of crustal structure along an approx. 500 km long transect across Ellesmere Island. The gravity response of this crustal transect is consistent with regional gravity anomalies. The new data are, furthermore, integrated with existing crustal information to produce regional maps. Distinct crustal features are identified, such as crustal thickness variations, the presence of high velocity/density lower crust, thick metasedimentary layers as well as shallow younger sedimentary successions.

Moho depths can be interpreted in terms of Eurekan (Cenozoic) and Ellesmerian (Palaeozoic) deformation. A zone of thick metasedmentary layers in central Ellesmere Island correlates with areas of dominantly Ellesmerian accretion. A WSW-ENE orientated zone of shallow Moho (Hazen Stable Block) underlies crust strongly deformed in the Palaeozoic but essentially undeformed in the Cenozoic. A block of thick crystalline crust in the north of Ellesmere Island is clearly separated from the North American-Greenland Craton by the deep (meta-)sedimentary successions, possibly a hint for a northern microcontinent. High velocity lower crust may be related to igneous activity during several rift episodes and/or impact by High Arctic Large Igneous Province magmatism. A correlation appears to exist between topography, Moho depth and the location of dykes in Nansen Sound suggesting the same tectono-magmatic origin of these features. Lincoln Sea shows consistently thin crust likely related to rifting.

POSTER

Details on the Cretaceous ocean formation in the High Arctic based on satellite gravity data

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Understanding the evolution of ocean basins, critical for global studies in plate tectonics, mantle dynamics, and sea-level through time, relies on identifiable tectonic plate boundaries. Based on the latest generation of global satellite gravity models, recent marine geophysical data and vintage aeromagnetic data, we document consistent tectonic details on the remote and ill-defined Canada Basin spreading system: the oldest ocean system in the High Arctic and part of the long-disputed greater Amerasia Basin. We interpret two distinct phases of possibly Cretaceous sea-floor spreading: the early stage being sub-orthogonal and intermediate-spreading (~50 mm/yr) of possible Barremian-Aptian age, while the late stage being highly oblique, segmented, and slow-spreading (20–40 mm/yr) of possible Aptian age. We further demonstrate that the southern part of the Canada Basin spreading system may serve as an ancient analogue of modern mid-ocean ridge propagation into continental crust.

POSTER

Soapstone from Nuuk: fingerprinting the origin and geological history of soapstone (steatite) suitable for carving in the Godthåbsfjord-Ameralik region (southern West-Greenland).

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Soapstone was mined and traded by the Saqqaq, Dorset, Norse, and Morovian cultures living in Greenland through time, and still has a good potential for small-scale mining as a raw material for carving of art products and for the tourist industry. We collected soapstone from outcrops around Nuuk, which hold Greenland's best quality of soapstone, and analysed their whole-rock geochemistry, Sm-Nd and Rb-Sr isotopes for fingerprinting for geological and archaeological purposes, such that historic artefacts that were traded far away from Nuuk through time, might be traced back to the Nuuk area. Fieldwork in the Nuuk area showed that the quality of the soapstone in the Godthåbsfjord-Ameralik region actually varies widely; however, a correlation exists with the age and/or the metamorphic history of the rocks. The best quality soapstone occurs in a broad band cutting through the fjords in the Nuuk area. This area roughly covers the area with occurrence of Eo-Archaean gneisses. However, the same area was also subject to intense metasomatism of the soapstone precursor-rocks associated with fluid activity along the Ivinnguit fault zone. Further work will be directed to investigate which of those processes played the major role. Expectedly, one or both factors will provide a good fingerprint of the Nuuk soapstone. Additionally, this information will narrow down the area with good soapstone occurrences considerably, such that citizens wanting to investigate for undiscovered localities with good quality soapstone will know to which part of the Godthåbsfjord-Ameralik region their investigations for new small-scale mining areas should be directed.

POSTER

A large Devonian ultra-high-pressure province in northeastern Greenland

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The Caledonian orogen in northeastern Greenland consists of a 1200 km long, west-vergent nappe pile. It has traditionally been viewed as the retro-wedge of the Scandinavian Caledonides. This concept, however, was challenged by the finding of widely distributed eclogites as well as the large amount of horizontal shortening accommodated in the nappe pile. Existing U-Pb-zircon- and Sm-Nd-garnet ages for high-pressure metamorphism in the central section of the Greenlandic Caledonides scatter around 420 to 390 Ma. A single UHP-metamorphic location in a structurally internal position yielded an exceptionally young zircon age of 360 ±5 Ma and a Sm-Nd-garnet age of around 330 Ma interpreted to record peak-pressure conditions and cooling, respectively (Gilotti et al. 2004). We present new petrologic and Lu-Hf garnet age data from three locations. Samples from Danmarkshavn record ultra-high-pressure metamorphic conditions in eclogites and grt-pyroxenites by means of SiO_2-exsolutions in cpx, opx-exsolutions in cpx and thermobarometric estimations. An eclogite yielded a Lu-Hf garnet-whole-rock age of 357.5 ±2.9 Ma thus confirming the existing zircon age for UHP metamorphism obtained 140 kilometers to the north. Samples from two other locations preserve the typical high-temperature-

moderate-pressure eclogite-facies conditions and yield ages of 383 ± 17 Ma and 398 ± 14 Ma, respectively. Results suggest that besides the 400 Ma event, Devonian ultrahigh-pressure rocks in northeastern Greenland may be much wider distributed than previously known creating major puzzles for tectonic reconstructions.

POSTER

New heat flow measurements from central Arctic Ocean

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Constraining the thermal evolution of the Arctic Ocean is hampered by notably sparse measurements of heat flow. Furthermore, previous results from the central Lomonosov Ridge and the adjacent central Amundsen Basin reveal variable magnitudes, including those higher than expected considering plate cooling or simple uniform stretching models. Here we present new heat flow results gathered from 17 sediment cores acquired during the "Arctic Ocean 2016" and "SWERUS-C3" expeditions on the Swedish icebreaker Oden. Three sites located in the Amundsen Basin reveal heat flow in the order of 71-95 mW/m^2, in line-with or slightly higher (1-21 mW/m^2) than expected from oceanic heat flow curves. These values are substantially lower than values of another study, with 104-127 mW/m^2 found on similarly aged oceanic crust in the Amundsen Basin located approximately 100-200 km away. Sites from the submerged continental fragments of the Lomonosov Ridge and Marvin Spur recovered heat flow in the order of 53-76 and 51-69 mW/m^2 respectively. When considering the potential enhanced surface heat flux from radiogenic heat production in the crust, these variable measurements are broadly in line with predictions from uniform extension models for continental crust. An upper mantle seismic anomaly in the vicinity of the North Pole might therefore have a compositional as well as thermal component. This complexity highlights the difficult in disentangling temporally and spatially evolving crustal, lithospheric and mantle processes to present-day surface heat flow contributions.

2.2. Deformation and metamorphism of rocks: Microstructures, processes, and physical properties

ORAL

A novel gel-mediated reaction mechanism in metamorphic rocks

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Fluid-mediated mineral dissolution and re-precipitation is a key mechanism for mineral reactions in different fields of Earth and Material Science. Mineral reactions in the solid Earth constrain many geodynamic and geochemical processes, such as density changes in subducted oceanic crust, the release of carbon dioxide in subduction zones and the precipitation of ore minerals from percolating fluids. Detailed knowledge about rate-limiting mechanisms during such mineral reactions is fundamental for the quantification of rock transformations and the associated element transport. Unresolved questions regarding fluid-mediated mineral dissolution and re-precipitation are the formation of permeability and the quantification of the element transport during mineral transformation. Here we present examples where the entire cycle of mineral dissolution, element transport and re-precipitation of new equilibrium phases is visualized in high-pressure metamorphic rocks that experienced re-hydration in a subduction zone. The replacement of primary amphibole and pyroxene in our samples occurs via coupled dissolution-re-precipitation that involves the formation of an amorphous alkali-Al-Si-rich material. This amorphous material forms directly from the reacting minerals by de-polymerization of the original crystal lattice. De-polymerization starts along dislocation cores in the crystal lattice that serve as element exchange pathways and are also sites of porosity formation. In our samples, the amorphous material resulting from this de-polymerization occupies large volumes in a syn-metamorphic interconnected porosity network. The direct transformation of the mineral into the amorphous state enables element transfer decoupled from the presence of ionic solutions. Precipitation of secondary amphibole occurs directly by re-polymerization of the amorphous material at the product surface.

ORAL

Connection between grain shape, chemical zonation and texture as indicator for fabric development in eclogites

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Eclogites are the most important piece of evidence of high pressure conditions in subduction zones. Their fabric development is an interesting topic and may allow to determine the deformation rates in subduction zones. Most previous studies suggested dislocation creep to be the principal process causing the fabric development, because many eclogite fabrics are quite strong. The viability of this may be tested by studying the chemical zonation of garnet and omphacite in order to track and quantify texture and microstructure development in eclogites. The aim of this study is to assess the influence of crystal growth on mineral preferred orientation and therefore its role in fabric development in eclogite-facies rocks.

Variscan and Alpine eclogites from two different locations have been studied. In both cases, asymmetric but still concentric chemical zoning developed during prograde garnet growth

together with elongated garnet grain shape and can be related to a corresponding prograde (in terms of pressure change) chemical zoning in omphacite grains. Crystal plastic deformation of garnet can be excluded based on chemical zonation patterns. Chemical, microstructural and texture data indicate a direct relationship between the growth of garnet and omphacite grains in the principal stretching direction, causing a strong fabric development during prograde and peak metamorphic conditions. No dynamic recrystallization microstructures were detected. Thus, the textures are interpreted as growth fabrics. Dislocation creep as a possible fabric formation process is excluded. Instead, diffusion creep (grain scale precipitation producing elongation in the stretching direction) is concluded to be the dominant deformation mechanism.

ORAL

Shear deformation in the transformation of gabbro to eclogite: Potential key to rheological contrasts in the change from HP/UHP conditions to later amphibolite-facies deformation

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The Proterozoic ~1700-1550 Ma Baltican basement of the northern Western Gneiss Region, Norway, consists of coarse granitoid gneisses locally intruded by 1466 and 1250 Ma gabbros. Progressive relative rheological behavior of this diverse assemblage during Scandian (420-375 Ma) subduction to HP/UHP metamorphic conditions (2.5-4 GPa) and exhumation back to near-surface conditions, is key to understanding tectonic development through multiple phases of thrusting, recumbent folding, and extension.

Recent studies of deformation-enhanced reactions en route to eclogite-facies conditions within sheared gabbro have demonstrated progressive destruction of plagioclase in reaction with pyroxene and oxides and growth of garnet, to superplastic behavior in garnet by grain-boundary sliding. Plausibly, during this, rheological differences between deforming gabbro and gneisses were minimal. Thus, gabbro-gneiss contacts are most commonly decorated by 1-10m thick layers of strongly foliated, fine-grained garnet-rich eclogite, and nearby small eclogite bodies are usually similar in texture and composition.

These observations suggest that the gneisses may not have partially melted during HP-UHP conditions, but rather by fluid-absent partial melting of micas during exhumation to <2 GPa. The resulting changed ductility contrast between mafic and felsic rocks produced myriad gabbro and eclogite boudins that characterize the region, allowing access to aqueous fluids facilitating growth of secondary hornblende. Contacts of some gabbros show various processes: Some contacts decorated by fine-grained foliated eclogite, locally retrograded to foliated garnet amphibolite. Other contacts with little eclogitized gabbro, directly sheared against gneiss at a late stage, but converted locally by infiltrating fluid to isotropic hornblende gabbro.

ORAL

Record of a Lower Crustal Fossil Earthquake Initiated by CO_2 Flux and Reaction-driven Strain Softening

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The ultramafic rocks of the Reinfjord intrusion in the Seiland Igneous Province is cut locally by narrow (mm-cm) thick extensional shearzones, containing extremely fine-grained material with a distinct shape-preferred orientation. These shearzones offset dykes across numerous micro-

faults are documented in areas close to the major fault zone cutting through the area. Within the shearzones olivine and clinopyroxene reacts to form orthopyroxene and dolomite at approximately 7-11 kb and 750-850 degrees Celsius according to the reaction:

Olivine + Clinopyroxene + CO_2 = Dolomite + Orthopyroxene

As evidenced by coronas of orthopyroxene and dolomite between olivine and clinopyroxene and by large olivine grains proximal to the shearzones displaying a microstructure with subgrain walls decorated by rounded grains of dolomite and more irregular and elongated grains of orthopyroxene. With clinopyroxene at least hundreds of microns away this suggested at least some material transport within the shearzone.

The shearzones thus gives a unique view into CO_2-Metasomatism of the lower crust. Moreover the shearzones provide a unique insight into the interplay between CO_2-metasomatism and reaction accommodated strain softening. This is also confirmed by fractures extending into large olivine grains proximal to the shearzones. The CO_2 cracking and mineral reaction also serves to reduce grain-size , making grain-boundary sliding an efficient process, further enhancing the rheological contrast between the shearzone and the host rock. The sudden decrease in rock strength lead to sudden fast deformation and we suggest a relation to pseudotachylites and hence also earth quakes in near proximity of the micro-shearzones.

ORAL

The effects of confinement on reaction-induced fracturing during an hydration reaction

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Several geological processes involve mineral transformations where nominally dry rocks transform into hydrated ones when left in contact with water (i.e. eclogitization, serpentinization). In these systems, the transformation may induce density variations which generate stresses controlled by the rock confinement, also called force of crystallization. Here, we study a retrograde metamorphic reaction model, the hydration of periclase, MgO, into brucite, $Mg(OH)_2$, to quantify the coupling between reaction, stress generation, porosity evolution and fracturing. Samples of a microporous MgO ceramic were reacted at 170-210°C, 5-80 MPa confining pressure, 6-95 MPa differential stress and 5 MPa pore fluid pressure. Three-dimensional X-ray microtomography images were acquired in situ every five minutes during the reaction. Results imply that below 30 MPa mean pressure, the hydration reaction coupled with the MgO ceramics fracturing. The transformation rate followed a sigmoidal kinetics curve with a slow initiation, a fast reaction coupled to fracturing and the generation of a transient porosity pulse, and a slow-down until an almost complete transformation of periclase into brucite. Conversely, above 30 MPa, the reaction kinetics was slower and following the commonly admitted reaction curve but without fracturing. Considering the driving force of the hydration reaction, stress generation should be several hundreds MPa, whereas the present experiments show that fracturing occurs only below 30 MPa. One interpretation is that the stress created by the reaction may overcome the disjoining pressure at the grain-grain interface, expelling the water film trapped there and reducing dramatically the kinetics of reaction.

POSTER

Late magmatic-hydrothermal alteration and deformation of ultramafic rocks and dikes from the Reinfjord Ultramafic Complex

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This study concerns hydrothermal alteration of ultramafic rocks comprised by dunites and subordinate wehrlite and dykes of ultramafic to mafic and lamprophyric composition in the the Reinfjord Ultramafic Complex the Seiland Igneous Province, northern Norway. The dikes and host ultramfic rocks went through three main alteration stages:

Alt1. Microfaults with orthopyroxene, dolomite and olivine. Alt2. Yellowish magnesite-tremolite-talc alterations, comprised by central thin magnesite veins (orientation 55/110) surrounded by thicker metasomatic sides of tremolite and magnesite and then a thin talc rim towards the host ultramafic host. When intersecting the more pyroxenitic dykes the alteration gives a blueish green color. Alt3 Late serpentinisation intersecting all other structures.The study focuses on alteration type 2. The usually less than cm wide magnesite-bearing veins are surrounded by up to dm wide metasomatic sides. The weathered surface of the veins form massive, creamy yellow to rust red colored magnesite bearing mineral assemblages. The metasomatic sides stand out with a more yellow color than the weathered host rock and is comprised by a magnesite and tremolite bearing assemblage, rimmed by a mm-thin talc rim towards the host rock. Furthermore the veins also crosscut the different generations of dykes, resulting in different alteration assemblages.

The aim of the study is to use different alteration assemblages to constrain PTX-fluid conditions and determine ore remobilization. Furthermore stable isotope data of O, H, S, and C will be used to constrain the fluid source which is thought to be either magmatic or meteoric.

3. Sedimentary rocks and processes

3.1. Sedimentology posters

POSTER

Early mid-Devonian volcanism dates initiation of the Orcadian basin in the Orkney Islands, Scotland

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Early mid-Devonian sedimentary rocks forming the Orcadian basin constitute large parts of the exposed geology on the Orkney Islands. The lower sedimentary pile rest unconformably on foliated granites of the ca. 430 Ma Orkney granite complex and marks the onset of Lake Orcadia in the Orkney Islands with deposition of the lower Stromness flagstones (LSF), comprising alternating lacustrine strata of fine grained sandstones and shales. In the lower part of the Stromness flagstone sequence we have identified and dated, using zircon U-Pb ID-TIMS, a rhyolite dome or flow that constrain the age of the LSF and essentially the onset of Lake Orcadia to ca. 390 Ma. This new age combined with recent cyclostratigraphic results provide an improved estimate for the Efelian-Givetian boundary and the Kačák event marked by the top of the Achanarras level (Sandwick Fish Bed) constituting the top of the LSF. The rhyolite magmatism on Orkney is overlapping in age with intrusive rocks on Shetland and we suggest that this magmatism is related to an episode of important displacements on the Great Glen Fault.

POSTER

Topographic Development as a result of regional incision, faulting, and deposition at the onset of relative sea-level rise; The upper Entrada Sandstone and the lower Curtis Formation, Utah, USA.

Sigrid Østmo da Costa[1], Nikoline Bromander[1], Valentin Zuchuat[1], Alvar Braathen[1], Anja Sundal[1] and Ivar Midtkandal[1]
[1]University of Oslo

A 43 km North-south section on the North-Eastern margin of the San Rafaell Swell has been studied, focusing on the Upper Jurassic eolian Entrada Sandstone, the J-3 regional Unconformity, and the overlying Curtis Formation of Oxfordian age. Emphasis is on the distribution of sedimentary facies in direct contact with the unconformity, and those affected by erosional topography during deposition.

The J-3 Unconformity displays at least 3 generations of erosive incision, possibly 6. The composite unconformity has been subaerially eroded by eolian and fluvial action, besides tidal denudation postdating the onset of regional deposition. Present-day erosional relief, magnitude, and wavelength contribute to multi-phase erosional processes resulting in inconsistent erosional patterns, and distribution of sedimentary facies above and below the unconformity. Tectonic activity has influenced the development concerning substratum fluidisation and brittle deformation.

Generations of J-3s erosive incision varies regionally and locally across the section. A series of 5-10 m deep channel-like scours linked to a stratigraphic level several meters above the J3 Unconformity, erode to a deeper stratigraphic level than J3s original level. Intra-formational faults in Entrada Sandstone suggest contribution to focused erosion at the Entrada-Curtis boundary.

Similarly, erosive lower boundaries of tidal sandstone bodies in direct contact with J3 suggest that repeated relative sea-level changes lead to deeper stratigraphic erosion of the J3 Unconformity.

The on-going investigation will improve constraints on how reservoir-quality sandstone volumes are affected by erosional topography in tidal environments, by determining distributional factors. Distinguishing between local and regional variability is a target, to filtrate basin-specific anomalies.

POSTER

Recognizing sandstone diagenesis from outcrop to microscopic scale

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[1]GEUS (Geological Survey of Denmark and Greenland),
[2]GEUS

Sandstone diagenesis is visible on many scales, ranging from the microscopic scale to the outcrop scale. Traditionally, diagenetic features are investigated by optical microscopy on core and outcrop samples. Extending the investigations to micron scales may help to define a set of features, which might be recognized in the field and hence useful for future field campaigns. The mineralogy and petrography of the sandstones are evaluated from thin sections by transmitted and reflected light microscopy, and from carbon-coated thin sections and gold- or platinum-coated rock chips by scanning electron microscopy (SEM), applying GEUS' Zeiss Sigma 300VP field emission SEM, besides X-ray diffraction of bulk rock samples. Among the studied sandstone types, 'rusty' sandstones proved to be siderite-cemented where the siderite had partly altered to iron-oxide/hydroxides during diagenesis. Sandstone boulders or cliffs were intensively calcite-cemented, though with calcite of smaller/larger crystal sizes and different morphologies. Spectacular reddish and purple colored sandstones contained opal cement, which enclosed iron-oxides/hydroxides. Bluish or yellowish concretions or cemented intervals proved to be pyrite, altered to different alteration products (e.g. jarosite, szomolnokite). The mineral distribution at the microscopic scale can easily be shown by applying the Mineralogic software of the SEM. Altogether, investigations at a smaller scale can therefore explain the appearance of sandstones at the outcrop scale, and this appearance is largely depending on the type and abundance of the cementing phases.

3.2. Depositional basins

ORAL

Triassic of the Wandel Sea Basin, North Greenland

Morten Bjerager[1], Peter Alsen[1], Jussi Hovikoski[1] and Sofie Lindström[1]
[1]GEUS

In Triassic times the Wandel Sea Basin formed the western continuation of the basins in the southern part of the Barents Sea and the northern continuation of the Danmarkshavn Basin offshore Northeast Greenland. The results of recent GEUS fieldwork campaign in the area show that the exposed Triassic of North Greenland spans a near complete Induan (Dienerian) – Norian succession, up to 700 m thick. The succession rests unconformably on Upper Permian sediments and it is unconformably overlain by Upper Jurassic – Lower Cretaceous deposits.

The Lower Triassic (Dienerian, Induan) consists of marine sandstones, fluvial conglomerates and sandstones, and muddy flood-plain deposits. It is conformably overlain by the Lower Triassic (Smithian – lower Spathian) offshore mudstones with minor sand-dominated intervals. The upper Spathian to Ladinian is represented mainly by shallow marine sandstones in the western proximal part and laminated mudstones with minor thin sandstone units that were deposited in slope and deep basinal settings in the eastern deeper part of the Wandel Sea Basin. A marked erosional unconformity characterises the base of the overlying Upper Triassic (Carnian – Norian) of marine massive sandstones, conglomerates as well as cross-bedded and biomottled marine sandstones and minor mudstone units. The Triassic succession of the Wandel Sea Basin represents a well-constrained basin margin to deep basin transect and thus forms an excellent outcrop analogue to the time equivalent intervals in the western Barents Sea basins and the Danmarkshavn Basin offshore North-East Greenland.

ORAL

Flint in the Danian København Limestone Formation

Jens Galsgaard[1]
[1]Rambøll

The Danian age København Limestone Formation was examined in 219 cored boreholes drilled in connection with the "Cityringen" metro project in central Copenhagen. Shape and colour of flint bodies were described during macroscopic visual inspection of core samples, as well as from digital core photos, and four diagnostic flint types were identified in the limestone. They are 1) grey flint bands, 2) light grey flint bars, 3) irregular flint bodies, and 4) dark grey flint blots. The well-known informal tripartition of the København Limestone Formation into the upper regularly bedded, the middle nodule-rich and the lower laminated unit (Stenestad 1976, Knudsen et al. 1995, Klitten et al. 1995, Olsen & Nielsen 2002) is largely supported by the distribution of the four flint types: Type 1 dominates the upper unit, Type 2 dominates the middle unit, while Type 4 is the only type found in the lower unit. Types 1, 2 and 3 all occur to some extent in both the upper and middle unit. Type 4 is also characteristic of the underlying Bryozoan Limestone, making it difficult in core samples to determine the boundary between København Limestone and Bryozoan Limestone.

The conspicuous changes in shape and colour of flint bodies up through the København Limestone Formation seem to indicate that the flint bodies display different stages of flint formation and that this limestone may conceal narratives yet to be told about flint formation and depositional environment.

ORAL

Evidence of hyperpycnally fed turbidites in a basin floor setting, Eocene of Spitsbergen, Arctic Norway

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The Eocene of Spitsbergen, Svalbard, has received considerable attention in the literature because of its spectacular seismic-scale clinoforms exposed along many fiords and valleys. Previous investigations particularly focused on the slope segment of the clinoforms and demonstrated how sustained-type, hyperpycnal flows deriving from shelf-edge deltas played a major role in bringing sand onto the slope, contributing to slope accretion. Periodic sand delivery beyond the slope is evident by the presence of sandstone-dominated turbidite lobes in the basin floor segment of some clinoforms. By combining outcrop and core data from central Spitsbergen, our study focus on sedimentary processes that formed these turbidite lobes. At bed-to-bed scale, many of the turbidite beds deviate from the classical Bouma-type facies patterns typical of deposition from surge-type, low-density turbidity currents. Thick (0.5–3 m) turbidite beds characterized by pervasive amalgamation, internal scouring surfaces, and various soft-sediment deformation structures dominate. Further, beds exhibiting a lower sandstone-dominated turbidite division succeeded by a mud-rich upper division containing abundant coal/plant fragments occur frequently. The latter bed architecture is typical of deposition from hybrid sediment gravity flows and indicate that some turbidity flows transformed into slurry flows or debris flows on their way to their final destination on the basin floor. The dominance of thick, amalgamated turbidite beds and the abundance of coal/plant fragments documented in this study, as well as the presence of hyperpycnal flow turbidites on the slopes documented in previous studies, suggests that hyperpycnal flows are capable of delivering sand onto the basin floor.

ORAL

Stratigraphic treasures of an "ugly duckling": towards an integrated basin model of the Lower Cretaceous Rurikfjellet Formation, Arctic Svalbard

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The Lower Cretaceous (Valanginian–Hauterivian) Rurikfjellet Formation in Spitsbergen, Svalbard, forms an up to c. 300 m thick succession of fine-grained shelf and lower shoreface shales, siltstones and sandstones (Dypvik et al. 1991). The formation constitutes the regressive part of an >1000 m thick first-order sequence which formed during a long-term shoreline progradation (the Rurikfjellet Formation) and back-stepping (the Helvetiafjellet and Carolinefjellet formations) in response to a full cycle of relative sea-level change (Gjelberg & Steel 1995). In contrast to the overlying Lower Cretaceous succession, the Rurikfjellet Formation has received relatively little attention and is relatively poorly exposed. Its age is also rather uncertain. We present a revised basin-scale sedimentological and sequence stratigraphic model of the formation, tied to a new biostratigraphic framework. The model is based on data recently collected across the Lower Cretaceous outcrop belt, including >3500 m of measured outcrop sections; seven subsurface cores; >130 palaeocurrent measurements; >50,000 photos; three bulk-rock $\delta^{13}C_{org}$ curves with a mean resolution of 2 m; and hundreds of dinocyst, ammonite, belemnite and bivalve

biostratigraphic samples. Our data reveal a regionally persistent regressive–transgressive sequence development of the formation, as well as several hitherto unrecognised progradational pulses of apparently diachronous clastic wedges. We argue that their depositional architecture and interfingering were controlled by prodeltaic coupled storm-dominated and hyperpycnal sedimentation across a wide, low-gradient ramp, with important implications for palaeogeographic reconstructions for the Valanginian–Hauterivian of Svalbard and nearby areas.

ORAL

Elastic moduli, stiffness and effective stress of chalk from Zealand (Denmark) and from Dan field (North Sea).

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The successful employment of the Underground Thermal Energy Storage in the subsurface of Copenhagen is investigated. The study considers the geotechnical and physical properties (i.e. stiffness and porosity) of the medium depth (400-800 mbgl) Chalk Group. The majority of geotechnical data available covers shallow depth, while deep well logs data are fewer and of variable quality. In order to overcome the lack of information, this work evaluates Dan field as an analog for the chalk from Zealand comparing the effective stress and stiffness at the two locations. The chalk formation is found at much greater depth in the Dan field (1800 mbsl compared to an average of 200 mbsl in Zealand), resulting in a greater overburden stress. However, the effective stress is comparable to the maximum value encountered in Zealand (i.e. before uplift and erosion), due to overpressure. The results shown were obtained calculating the maximum effective stress based on the burial anomaly as studied by Japsen (1998). In addition, the stiffness was calculated by means of P-wave velocity and density data (Fabricius, 2003). The model allows to estimate the degree of cementation and hence the Biot´s coefficient by comparing the elastic modulus obtained by P-wave measurements with the theoretical one obtained under the assumptions of either particles in suspension or close-packed particles. The results show similarity between the two locations concerning the elastic moduli and porosity, but not for the same sample. This discrepancy could be caused either by a different heating history or by different texture.

ORAL

The Miocene-Pliocene Skade-Utsira aquifer, North Sea: Updated maps and new insights in depositional patterns and syn-sedimentary deformation

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During Miocene-Pliocene the deltaic system east of Shetland prograded into the Norwegian sector of the North Sea. Sands were deposited in a slope and basin setting. Thick deposits of high porosity and high permeability Utsira and Skade formations cover an area more than 300 km long and 60 km wide. The maximum total thickness of sands in the aquifer reaches more than 500 m. Maps of the aquifer were published by the NPD as part of the CO_2 Storage Atlas (www.npd.no).

In this updated study, NPD has included new well and seismic data, as well as new results from micropaleontology and Sr isotope stratigraphy. In addition to the lower Miocene Skade Formation and the upper Miocene to lower Pliocene Utsira Formation, the top of the middle Miocene sandy unit (Eir formation, informal) is also available. The depocenter of the Skade Formation is found in the central part of the area. During the middle Miocene there was a shift to the north, while in the late Miocene, a major lobe developed in the south. During the latest late

Miocene and the Pliocene the basinal depression was filled in, and a shelfal setting is interpreted.

The whole basin region is strongly affected by large scale soft sediment deformation. Mobilization of sands took place where sandy formations were sealed by deep-water clay and ooze. Evacuation structures, pillow-like structures and injectites are found at several stratigraphic levels and were apparently triggered by deposition of turbidites or mass flows.

ORAL

Aeolian silt transport processes as fingerprinted by dynamic image analysis of the grain size and shape characteristics of Chinese loess and Red Clay deposits

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This study applied dynamic image analysis (DIA) to characterize the grain size and shape of Chinese aeolian sediments in order to fingerprint their transportation processes. We selected four well-studied Quaternary loess-palaeosol sequences along a north-south transect across the Chinese Loess Plateau and compared their grain size distribution obtained by DIA with that yielded by laser diffraction(LD) particle size analysis. The results demonstrated that DIA is able to characterize clearly spatiotemporal variations in the grain size records of loess-palaeosol sequences formed during the last two glacial and interglacial periods. This is consistent with grain size results obtained using LD. DIA is also able to characterize spatial variations in the more fine-grained aeolian Red Clay deposits and to allow the quantification of the fluvial contribution to Red Clay sequences. DIA of the grain shapes characteristics in loess-palaeosol and Red Clay deposits revealed a systematic pattern, whereby the aspect ratio decreased with increasing grain size, indicating systematic shape sorting occurred during the aeolian transportation of these dust particles. Also evident from our DIA data was a subtle but systematic downwind decrease in the aspect ratio of the particles in the loess units. This observation suggests that elongated and/or flat particles (with a low aspect ratio) were transported further downwind than more symmetrically shaped particles (with a high aspect ratio). This study indicates that DIA of grain size and shape characteristics can be an additional powerful tool for fingerprinting grain size and shape sorting trends and reconstructing the transportation pathways of silt-sized aeolian sediments.

ORAL

A new observation of a biosiliceous opal bearing sequence in the Miocene Lark Formation in the Danish North Sea.

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The Paleogene – Lower Neogene Lark Formation of the Danish North Sea consists of a biosiliceous, opal-bearing sequence of sediments which extend into the German, Norwegian and UK sectors of the North Sea. The uppermost 50-100 m part of the Lark Formation is characterized by abundant biogenic silica in the form of diatoms, radiolarians, Bolboforma and sponge spicules. This biosiliceous-rich section is of Early to Mid-Miocene age and formed during a period of climatic optimum. The interval can contain up to 40% biosiliceous material, together with detrital clay and quartz. Carbonate stringers and pyrite occur in minor amounts. The content of organic matter can be significant with TOC's of up to 8%. In the lower parts of Lark (Early Miocene), diagenesis has transformed the biogenic silica from Opal A into Opal CT. No Opal has been observed in the Oligocene part of the Lark

Formation. This talk discusses the key characteristic of this biosiliceous section of the Lark Formation, and the regional controls on it's development.

ORAL

Across the Eocene-Oligocene Transition in inland Asia: Bio-, Litho-, and Magnetostratigrapy of Ulantatal, Inner Mongolia, China

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Coherent terrestrial sequences are critical in scrutinizing past environmental and climatic changes through successive fossil and sedimentary records. Central Asia has been an exquisite locality for past and ongoing paleontological investigations for Eocene to Oligocene aged mammalian faunas. Transition from Eocene to Oligocene (EOT) at ~34 Ma signified considerable changes in climate, flora, and fauna, externalized by the decrease of mean annual temperature and the change in vegetation from Eocene forests to more bare lands of the Oligocene. The faunal transition in inland Asia was characterized by replacement of Eocene perissodactyl-dominant faunas to the Oligocene rodent-lagomorph-dominant faunas.

Ulantatal is a renowned Oligocene mammalian fossil locality in Inner Mongolia, China. Although the area has produced a significant collection of vertebrate faunas, knowledge of the stratigraphy, ages and depositional environments have remained poor or nearly non-existent. Litho- and magnetostratigraphic context, and correlation of the Ulantatal area sediments with the Geologic Time Scale (GTS) is presented, thus providing age estimations for th e fossil-bearing horizons.

Landscape of the Ulantatal formation is characterized by flat lined topography with low uplands and small gullies. Outcrops of the area show a uniform pattern predominated by fine-grained massive sediments occasionally interbedded with coarser grained horizons. The sequence produces fossils along most of the section, with the richest fossil occurrences in the lower half of the sequence. Our magnetic section suggests a correlation in magnetozones C15n to C9n, with an age range of about 35-27 Ma, and places the lowermost fossil site in Ulantatal in the latest Eocene.

3.3. Composition of siliciclastic rocks

ORAL

How can provenance and sorting effects be differentiated from detrital zircon data? Example from the German Triassic Buntsandstein Group

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This study stresses how sorting and provenance effects can be differentiated by combining zircon-grain length and U-Pb-ages for individual detrital grains. We exemplify this by a provenance study for continental deposits of the Lower Triassic, continental Buntsandstein Group in central Germany. The study is based on > 1000 zircon grains from 12 sandstone beds. The unbroken grains in seven of the zircon separates have mean lengths of 190-220 µm and five are composed 100-140 µm long grains in average. All have a main population of 340-320 Ma ages, representative of granitoid from the Variscan Orogen of the Massif Central and the Bohemian Massif. This detritus was mixed with abraded grains from Ediacaran to Palaeozoic (meta)sedimentary units feeding the basin with 610-460 Ma (Ediacaran to Ordovician) and 2 Ga age grains. The 610-460 Ma age population is common only in five samples with mean grain lengths of 100-140 µm. Those grains mainly are < 130 µm in the east, but equally common in all grain sizes in the west. This indicates that the east-west age difference is a provenance effect but that internal differences in the east is a sorting effect. The western group was fed from the Massif Central and the eastern group from the Bohemian Massif. We conclude that interpretation of detrital zircon ages preferably are separately for different size classes, because zircon studies performed on broad grain-size intervals without considering possible size-age correlations may disguise sorting effects that potentially can lead to a misleading source-area interpretation.

ORAL

Middle Triassic siliciclastic deposits of Svalbard as a part of source to sink framework of the Arctic

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Sandy facies of the Bravaisberget Formation (Middle Triassic) exposed at the southernmost part of Spitsbergen (Svalbard archipelago) represent an uplifted part of the northwestern corner of the Barents Sea shelf. The deposits are interpreted as an effect of shallow marine and deltaic sedimentation and their facial equivalents in the Barents Sea are considered as good reservoir rocks for hydrocarbon accumulation.

The aim of this study was to characterise and recognise potential source areas for the Middle Triassic siliciclastics based on petrological and geochemical methods. Standard quantitative petrographical analysis of thin sections and bulk rock geochemistry technics have been supplemented by U-Pb and Lu-Hf zircon analysis.

The studied deposits have quartz-dominated framework composition, with minor content of feldspars and lithoclasts therefore they have been classified as quartz arenites, subfeldsarenites, sublitharenites. Concentrations of major, trace elements and REE point to silicic source rocks

composition. Distribution of zircon ages shows domination of Paleo- and Mesoproterozoic ages with significant content of Archean ages, minor Caledonian zircons and lack of Uralian grains. This provenance signature has been compared with data from other areas of the Arctic region.

The area analysed in this study represents only small part of the whole Arctic sediment routing system existed in the Mesozoic time and the investigated deposits have provenance signature which is consistent with the Triassic provenance signatures from Canadian Arctic and Greenland and linking their proto-sources to Laurentia, but the deposits components were recycled from older sedimentary rocks, likely from Devonian strata.

ORAL

Quartz cementation and diagenetic effects in sandstone – an analog study of Cambrian quartz arenite from Scandinavia

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Lower Cambrian quartz arenitic deposits have a world-wide occurrence. Nevertheless, diagenetic effects are rarely taken into consideration to explain the existence of these mature, shallow marine deposits. In this study, petrographic, geochemical and mineralogical analyses were carried out on core and outcrop samples from the quartz-rich Ringsaker Member from Southern Norway and the corresponding Hardeberga Formation from Bornholm in Denmark and Scania in Sweden. The sandstone units have been examined in a state of complete quartz cementation in order to study the diagenetic history and the effects leading to destruction of porosity and permeability. Quartz cementation was estimated by comparing the amount of cement present to the modelled amount of quartz cement based on its time-temperature history. The quartz arenite from Southern Norway has an intergranular volume of ca. 20%, and close to 100% of the initial porosity has been replaced by quartz cement. For most samples, other authigenic cement minerals, together with detrital phyllosilicates, represent < 5% of the present-day composition. Preliminary petrological investigation on the Hardeberga Formation points to similar quartz-dominated chemical diagenesis. This indicates that the sediment composition was extremely quartz-rich already during deposition throughout Scandinavia, as is supported by the high SiO_2 content averaging at 95.6%. Sediment reworking by waves, and subsequent removal of early authigenic components produced from subsurface leaching of unstable grains are likely to have influenced the composition severely. The findings contribute to an increased understanding of the formation of both quartz-rich sediment and the end products of cementation processes.

ORAL

IMPACT OF METEORIC-WATER DIAGENESIS ON RESERVOIR QUALITY IN PALEOCENE TURBDITIC SANDSTONES, UK CENTRAL GRABEN, NORTH SEA

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This petrographic and stable isotopes study on the distribution of diagenetic alterations and of their impact on reservoir-quality evolution of Paleocene marine turbidite successions (Andrews Formation, UK Central Graben, North Sea) revealed the important roles of tectonic setting, depositional facies, and changes in the relative sea level. Diagenetic modifications include dissolution and kaolinitization of framework silicates, cementation by carbonates and quartz, mechanical compaction of sedimentary rock fragments, and chemical

compaction of detrital quartz. Despite tens of km distance from the paleoshore line, kaolinitization is attributed to meteoric-water flux during major fall in the relative sea level. The wide range of $\delta^{13}C_{V\text{-}PDB}$ values of calcite cement (about -18‰ to +22‰) is attributed to the input of dissolved carbon from microbial methanogenesis and methane oxidation. The wide range of $\delta^{18}O$ values (about -17‰ to -1‰) of this cement might reflect the involvement of various fluids including marine, meteoric, and evolved formation waters) and wide range of precipitation temperatures. Preservation of porosity and permeability in sandstones from the passive margin basins (up to 30% and 1 Darcy, respectively) is attributed to the presence of abundant rigid quartz and feldspar grains and to dissolution of carbonate cement as well as mica and feldspars.

ORAL

Factors influencing stylolite development and quartz cementation in the Jurassic Stø Formation sandstone, Tromsø Basin, SW Barents Sea

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Stylolites are common diagenetic structures in quartz cemented sandstones and provide records of extensive chemical compaction. As documented and modelled in the diagenesis literature, the development of stylolite seams in sandstone involves dissolution of quartz grains as well as "re"-precipitation of the dissolved silica as quartz cement. This study compares microstructures of stylolite and quartz cement in strongly cemented Jurassic sandstones from a well in the southwestern-most part of the Barents Sea to interpret diagenesis and deformation structures. The impact of sedimentary fabric and bioturbation in development of stylolites is emphasized based on comparison of sandstone cores of different degrees of bioturbation. The stylolite forming processes involved differential compaction in several stages of diagenesis: 1) Initial mechanical compaction inducing folding of softer clay-rich lamina. 2) In deeper burial chemical diagenesis with enhanced grain dissolution at clay contacts accompanied with quartz cementation and 3) continued stylolite growth involving also dissolution of earlier precipitated quartz cement. Micro shear-zones along stylolite fold limbs are interpreted in terms of dissolution-enhanced differential compaction. Deformation accompanying quartz cementation is evidenced by a frequent distribution of dauphine twins at adjacent cement – cement contacts, revealed by use of SEM-backscattered electron diffraction techniques. The latest stage of diagenesis involved abundant pyrite crystallization, in particular along stylolites, questioning if stylolites could have acted as conduits for fluid migration. Further research is suggested to examine regional tectonic and thermal influences on the distributions of extensive quartz cementation in some of the westernmost areas of the Barents Shelf.

ORAL

Stiffening effect from temperature and stress on sandstones from the deep North Sea Basin

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We investigate effects of temperature, stress and stress symmetry on the dynamic stiffness of two sandstones from depths of approximately 5 km in the North Sea Basin. The studied temperature range was 25-170°C, whereas the studied stress range was 2.5-15 MPa. Two stress symmetries were compared: 1) hydrostatic stress and 2) uniaxial stress with constant confining stress. We derived dynamic compressional and shear moduli from density and ultrasonic P- and S-wave velocities and show that the stiffness can increase with up to 20% and 100% for respectively

increase in temperature and stress. We link the increased stiffness to two physically different mechanisms, both resulting in closure of ruptured grain contacts created by equilibrating sample material to atmospheric conditions. Eventually, the increase is hence recovery stiffness by mechanisms of: 1) frame deformation due to increase in stress and 2) thermal expansion due to increase in temperature. That contact ruptures (micro-cracks) can full or partially close by 1) is an accepted mechanism for partial recovery of in-situ stiffness. We show that stiffness recovery by 1) or 2) have different magnitude, but that both are most pronounced for sandstones with a low degree of cementation. This is probably because cementation hinders progression of micro-cracks during deloading and cooling. The results demonstrate the significance at testing samples at their natural stress and temperature.

ORAL

The diagenetic impact on reservoir sandstones of the Heno Formation in the Ravn-3 well, Danish Central Graben, Denmark

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The Upper Jurassic Heno Formation in the Ravn-3 well is the deepest producing sandstone reservoir in the Danish North Sea. A combined approach including petrography, geochemistry, porosity and permeability analysis and core description have been achieved to investigate variations in diagenesis up through the formation and how post-depositional changes impacts the sandstone reservoirs. Three depositional environments characterize the reservoir sandstones: lower shoreface, middle shoreface and foreshore. Results show that the reservoir potential of the sandstones predominantly depend on occurring digenetic phases and not depositional environment. The dominating diagenetic phases are eogenetic microcrystalline quartz, mesogenetic precipitation of illite, extensive mesogenetic quartz overgrowth and extensive Fe-dolomite and ankerite cementation. The different diagenetic phases are present in all three depositional environments. Diagenesis had a major impact on either preserving or destroying porosity, but did in all cases highly reduce the permeability. The different diagenetic phases can be recognized in the Ravn-1 well and in less degree in the Ravn-2 well.

ORAL

Terrestrial paleoweathering and the presence of deep biosphere in fractured granites, Utsira High, Norwegian North Sea

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Whereas the global stratigraphic record is dominantly marine, deeply buried paleoregolith profiles are rare and important remnants of the terrestrial paleoenvironment. On the Utsira High, Norwegian North Sea, the crystalline basement was probably close to the surface from the Permo-Triassic until the early Cretaceous (Ksienzyk et al., 2016). Recent K-Ar ages of illite clays from weathered granites in the area suggested commencement of regolith/paleosol formation in mid-Triassic (Fredin et al., 2017). Drill cores from well 16/1-25S in the Rolvsnes discovery include ~21 m of fractured and weathered granite below Cretaceous cover. In the studied regolith, two intensely weathered, clay-rich intervals were identified in the upper part of the profile. They contain randomly interstratified mixed-layer illite-smectite and poorly crystalline

kaolinite clays, pseudomorphically kaolinitized biotite, and dendritic aggregates of fine-grained hematite. Although quartz is preserved, feldspars are affected by chemical weathering with plagioclase nearly completely removed. The fracture network facilitated deep percolation of meteoric water and in samples more than 20 m below the basement-sediment contact weathering is evidenced by minor amounts of well-crystallized kaolinite and moderately altered feldspars. Estimates of MAP and MAT using the Paleosol-Paleoclimate Model (PPM1.1) (Stinchcomb et al., 2016) from the clay-rich intervals indicate formation under subhumid and temperate conditions. Use of geochemical proxies is complicated because of heterogeneous protolith composition, truncation of the original paleosol, and the likelihood of multiple alteration episodes. Mycorrhizal fungal hyphae have been observed down to about 20 m below the basement-sediment contact, indicating the presence of deep biosphere.

POSTER

Impact of electrostatic forces on sediment porosity

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In this paper, we assess the impact of electrical double layer related forces on sediment porosity using low field Nuclear Magnetic Resonance Spectrometry. Samples of Calcite, Quartz or Kaolinite powder were saturated with brines containing ions found in seawater (Na^+, Ca^{2+}, Mg^{2+}, Cl^- and SO_4^{2-}) at varying ionic strengths and as a non-polar reference, with ethylene glycol. The difference in porosity between a sample saturated with ethylene glycol and a sample saturated with a given brine reflects the repulsive pressure resulting from the electrostatic forces.

We found that for calcite samples, saturation with solutions containing divalent cations (Ca^{2+} and Mg^{2+}) lead to higher repulsive forces between the grains, while adsorption of SO_4^{2-} counteracts the initially positive surface charge, leading to a decrease of the repulsive forces. For kaolinite, differences in potential between the silica and alumina faces as well as the edges can either lead to repulsion between particles or to flocculation depending on ionic strength and ionic species of the fluid. For quartz, relatively high porosity for powders saturated with sodium chloride brine indicates that Na^+ is a potential determining ion for the quartz surface. The repulsive pressure inferred from the experiments could be correlated to zeta potential measurements available in the literature.

4. Tectonics and structural geology

4.1. Trans-Atlantic correlation of Proterozoic collisional belts and Paleoproterozoic Metallogeny of the Arctic

ORAL

The Amitsoq Plutonic Suite – a newly discovered suite in the Ketilidian Orogen, South Greenland

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The study area is situated in the ca. 1855-1735 Ma Ketilidian Orogen of South Greenland. Six fine- to medium-grained felsic rocks from the northeast coast of Amitsoq Island were dated by LA-ICPMS (U/Pb zircon). Observations from fieldwork show show complex mixing and mingling structures of feldspar-phyric monzonite and leucogranite. Both rocks have an intrusive contact with granodiorite, which itself intrudes a metasedimentary rock. North of the metasedimentary rocks, a banded, porphyroclastic felsic gneiss occurs.

The gneiss yields an age of 1784±7 Ma, that is interpreted as the intrusion age of a felsic precursor. This age overlaps with regional peak metamorphism (1790-1770 Ma) and the late stage of the Julianehåb Igneous Complex (1781-1807 Ma). The fine-grained metasedimentary rock gives a spread of concordant ages from ca. 1800-2800 Ma, supporting its sedimentary origin. The feldspar-phyric monzonite has an intrusion age of 1680±8 Ma, which is indistinguishable from the 1704±11 Ma intrusion age of the granodiorite. Homogeneous monzonite from the same site yields an intrusion age of 1735±6 Ma. This ca. 45 Ma older age falls in the range of the Illua Plutonic Suite (1755-1728 Ma).

The Amitsoq Island is underlain by a complex set of igneous and metamorphic rocks with intrusive ages (ca. 1700 Ma) never reported for the Ketilidian Orogen before. The new data indicate that its geology is more complex than previously thought, which highlights the need for remapping and reinterpretation, to improve our understanding of the geological history and economic potential for gold deposits.

ORAL

A new configuration of crustal-scale shear zones controlling copper-gold mineralization in northern Sweden

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Northern Sweden is a well-mineralized area in Europe and contains three major metallogenic belts; namely, the Gold Line, Skellefte and Northern Norrbotten ore districts. Gold and/or copper deposits occur in all three belts as orogenic Au, Au-rich VMS and IOCG-style mineralization. Regardless of mineralization style, however, most deposits appear to be spatially controlled by a set of crustal-scale Paleoproterozoic shear zones, which share similar structural characteristics and deformation histories.

Reappraisal of regional geological and geophysical data, coupled with structural mapping, suggests crustal-scale shear zones form continuous, c. N-S-trending zones extending from the Gold Line in the south to Northern Norrbotten. An example from Norrbotten is a zone that extends SSW from Karesuando in the

north towards Svappavaara. While this zone has traditionally been inferred to continue SW towards Arjeplog (i.e. the KADZ, Karesuando-Arjeplog deformation zone, Bergman et al. 2001), we favour its deflection SSE into the Nautanen-Aitik trend, which mimics the configuration of analogous zones to the east and west. Furthermore, we tentatively suggest splays of this major zone continue south through the Laver area and terminate in the Skellefte district close to Björkdal and Boliden.

Crustal-scale shear zones show a long-lived deformation history with several reactivation-hydrothermal events. The most important ore forming events along these zones can be assigned to an early phase of crustal extension at c. 1.90 Ga (Skyttä et al. 2012), and two phases of crustal shortening at around 1.87 and 1.80 Ga, coinciding with major Svecofennian-cycle tectonothermal events (c.f. Bauer et al. 2016, 2017).

ORAL

Paleoproterozoic volcanogenic massive sulfide mineralization, Karrat Group, Central Kangiusap Kuua, West Greenland

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The Karrat Group of Central West Greenland is composed of the Qeqertarssuaq (Lower Karrat Group), Qaarsukassak, Mârmorilik, Kangilleq, and Nûkavsak formations (Upper Karrat Group). All volcanic rocks of the Karrat Group are placed in the Kangilleq formation (informal), which is defined as a package of meta-volcanic (greenschist) rocks that unconformably overlie meta-sedimentary rocks of the Qeqertarssuaq Formation and are conformably overlain by meta-sedimentary rocks of the Nûkavsak Formation. The Kangilleq formation shows dominantly within-plate, alkali basalt geochemical signatures.

A unique sequence of meta-volcanic rocks (~100 m) occurs in the Central Kangiusap Kuua. These rocks differ from all other rocks of the Kangilleq formation in that they: 1) show tholeiitic arc-like affinities; 2) contain felsic volcanic rocks; and 3) contain VMS-type sulfide mineralization. The basal ~60 m consist of pillow basalt lava containing flow top breccias and hyaloclastite indicating subaqueous eruption. Overlying the pillows is an ~30 m sequence of mafic volcaniclastic rocks where normal to reverse grading, massive to crudely bedded, and channel/scour structures suggest emplacement by mass debris flows. The mafic volcaniclastic beds are overlain by a rhyolite breccia ~5 m), which is capped by a strongly silicified rock (~2 m). The felsic breccia hosts stringer to massive sulfide (pyrite, pyrrhotite ± sphalerite, chalcopyrite).

Our work documents the first occurrence of a tholeiitic, bi-modal volcanic sequence with arc-like signature, and VMS-type mineralization within the Karrat Group. Thus, it has important implications for mineral exploration, and the interpretation of the geodynamic setting of the Kangilleq formation.

ORAL

A new reef-type PGE-enriched zone in the early Paleoproterozoic Näränkävaara Layered Intrusion, northeastern Finland

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The 2.44 Ga Näränkävaara layered intrusion is located 100 km south of the Arctic Circle. It belongs to a belt of 2.45-2.43 Ga mafic layered intrusions formed during continental extension (Lauri et al. 2012). These intrusions contain

contact-, reef- and offset-type PGE deposits (Rasilainen et al. 2010).

The intrusion is 25 km long and 5 km wide. Geophysical modelling infers a triangular keel extending up to a depth of 10 km. Wall rocks are Archean TTG, migmatites, gneisses and metavolcanic rocks (Alapieti 1982). The intrusion consists of four principal units (stratigraphic thickness in parentheses): a basal dunite (2 km), a peridotitic-pyroxenitic unit (700 m), a gabbroic unit (400 m), and a quartz-dioritic unit (200 m). Parental magma has boninitic or siliceous high magnesium basalt affinities except for the basal dunite, which is komatiitic.

Five drill holes intersect a 10–25 meter thick PGE-enriched zone located at the border zone between the pyroxenitic and gabbroic units (Lahtinen 2005). Average intersection is 15 meters with 0.25 ppm Pt+Pd+Au. Highest assay is 0.39 ppm Pt+Pd+Au in a 1 meter long sample. The Pd/Pt is 2.5–8.7. Sulfides are rare (highest analyzed S at 2440 ppm and Cu at 262 ppm). The PGE-enriched zone is continuous along strike for at least 5 km.

This type of PGE-enriched zone has not been found in similar stratigraphic position from other Finnish 2.43-2.45 Ga layered intrusions (e.g. Iljina et al. 2015). Lithologically it resembles the PGE mineralization in the Munni Munni Complex (Barnes & Hoatson 1994).

ORAL

Linking the Umivik and Scourie dyke swarms tighter into a pre-Iapetus plate configuration

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The mafic Umivik dyke swarm in SE Greenland (64˚10-30'N) was sampled during the GEUS 2012 'SEGMENT' expedition and mapped in Google Earth for structural and petrological investigations. This approximately 40-km-wide exposed part of a much more extensive igneous province is made up of more than 160 roughly E-W trending dykes, which constitute 5-15 % of the outcrop. Within Umivik we recognize at least two slightly oblique cross cutting sub-swarms with similar geochemical signatures. Their compositions are comparable to those of the Scourie dyke swarm, across the conjugate rifted margin in Scotland (Myers, 1987), which may all have been derived from the same metasomatised sub-continental lithospheric mantle source (Hughes et al., 2014). According to Nilsson et al (2013) and Davies & Heaman (2014), these dykes were emplaced between 2.42-2.36 Ga, during the break-up of the Superia supercontinent. Subsequently, dykes were variably deformed through a combination of conjugate shear and thrust zones during the Nagssugtoqidian/Laxfordian orogeny, with the southernmost extent of this orogen's deformation front coinciding with the Umivik area. With the exception of a few less deformed 'crustal enclaves', mafic intrusions become progressively more deformed and metamorphosed across this nearly 150 km wide deformation front, exemplified by four case study areas up along the coast. The Atlantic Ocean eventually separated the Greenlandic and Scottish part from each other and our primarily aim is to use both structural and petrological evidence provided by mafic intrusions to bring these two craton fragments tighter together within their post-Nagssugtoqidian and pre-Atlantic configuration.

ORAL

Architecture of the Rinkian Orogen between Svartenhuk and Holm Ø, western Greenland

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The Paleoproterozoic Rinkian Orogen extends from Nuussuaq to north of Holm Ø along the Greenlandic western coast. It has recently been interpreted as northern extension of the Nagssugtoqidian Orogen that continues west in the Trans-Hudson Orogen of Canada. We concentrate on the high-grade metamorphic northern part of the Rinkian Orogen.

The rocks are characterized by Archean orthogneiss, ultramafic rocks, amphibolite, Paleoproterozoic paragneiss, charnockite of the 1.90-1.87 Ga Prøven Igneous Complex (PIC), and ca. 1.82 Ga granite. The PIC has a diameter of ~100 km, with increasing foliation intensity towards the outer contact. In the south, rocks of the PIC are thrust E on top of Paleoproterozoic paragneiss, which records peak metamorphic conditions at 750-800°C and < 4 kbar. In the north, contact relationships between the igneous rocks of the PIC and paragneiss are complex. The near-vertical, several km wide Tussaaq shear zone marks the boundary between the PIC and Paleoproterozoic paragneiss. From this shear zone to the N, the fabrics flatten progressively, turning into a NW-vergent fold-and-thrust structure. Leucosomes are ubiquitous, most abundant around the Tussaaq shear zone and form syn-deformational structures, indicating high temperature metamorphism. These leucosomes coalesce into pegmatites and plutons, which are dated at 1.82 Ga. Similar ages for peak metamorphism indicate a tectonothermal event some 50 m.y. after emplacement of the PIC, exhuming rocks of the middle crust. The fact that the youngest of the ca. 1.82 Ga granites crosscut the high-T fabrics, indicates that exhumation was a fast tectonic process and not driven by erosion.

ORAL

Sniffs of 'IOCG-style(?)' chalcopyrite mineralisation in northwestern Greenland

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The Nutaarmiut Complex was identified during a 2016 field campaign in the Paleoproterozoic Rinkian Orogen. It is notable for: 1) blebby chalcopyrite and extensive malachite staining, and 2) being low grade and undeformed compared to the adjacent strongly deformed and granulite-facies lithologies. Field mapping defined locally chalcopyrite mineralized, gabbro and syenite layers. Further petrologic, geochronological, geochemical, and isotopic investigation has since demonstrated that these lithologies rather form locally mineralized metasomatic rocks.

The 'felsic' layers comprise sericitised orthoclase and albite. At least two generations of assemblages are observable in the 'mafic' layers: 1) quartz+albite+epidote+biotite+chlorite+sericite, and 2) an overprinting assemblage of hematite+ilmenite+chalcopyrite+apatite+monazite+zircon. The second assemblage contains abundant iron oxides that are intimately associated with blebs and stringers of chalcopyrite. Sulfur isotope measurements of chalcopyrite yield $\delta 34S$ of +10‰, indicating sourcing of sulfur from an oxidised fluid. A'felsic' layer yielded metamict uraniferous (up to 8000 ppm) zircon. The zircon with the lowest uranium content (<2000 ppm) are used to constrain a 207Pb/206Pb age of ca. 1783 Ma. Regionally, this hydrothermal event follows peak high-T

metamorphism by about 40 m.y., coinciding with the timing of metamorphic titantite and resetting of hornblende Ar-Ar ages. In the Churchill Province, this age corresponds to magmatism of the post-orogenic Nueltin Suite, which is sourced from lower crustal and mantle melts. Petrological observations, geochronology, sulfur isotopes and mineralisation style define a package of metasomatic rocks that is consistent with fluids that, in other areas, form IOCG-style mineralisation. This remote area of northwestern Greenland could be prospective for IOCG mineralisation.

ORAL

Structural inheritance and basement-cover linkages within the Palaeoproterozoic Peräpohja Belt, Northern Finland

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Correlation of regional-scale bedrock structure and stratigraphy within the Peräpohja Belt (PB), Northern Finland, shows that the evolution of the Palaeoproterozoic cover sequences have an intimate relationship with the underlying Archaean basement. By recognizing the basement control the heterogeneous nature of the contractional structural overprint within PB may be explained by one progressive south-verging thrusting event instead of several compressional events with highly contrasting palaeostress orientations. Compressional deformation was additionally controlled by strain localization into a basin-wide basal detachment zone accommodated by a mechanically weak unit. Hard linkages between the basement and the cover is shown by exposure of the deepest parts of the PB stratigraphy in the hanging walls of reverse faults, which consequently must continue down to the basement and represent reactivated basement structures. By contrast, soft linkages are shown by deviations from the typical thrust-and-fold belt fold patterns, such as abrupt fold terminations. The recognized major basement structures comprise fault-bound, approximately E-W trending horsts and an orthogonally cross-cutting central graben. The basement structures were generated under synchronous extension in both NE-SW and NW-SE orientations, which we attribute to development of a pull-apart basin with pre-existing basement weakness zones, at an overstepping zone between two major N-S deformation zones. This indicates that the N-S structures experienced lateral slip during the break-up of the Archaean continent at around 2.45 Ga, and the inferred setting explains why PB did never progress into a proper rift. Recognition of the major basement structures significantly improves targeting of mineral exploration in PB.

ORAL

Linking orogenesis across the North-Atlantic; the Grenvillian and Sveconorwegian orogens, different in style, but geodynamically coupled

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The Sveconorwegian orogeny in SW Fennoscandia comprised a series of geographically and tectonically discrete events between 1140 and 920 Ma (Slagstad et al., 2017). Thrusting and high-grade metamorphism at 1140–1080 Ma in central parts of the orogen were followed by long-lived arc magmatism and ultra-high-temperature metamorphism at 1070–920 Ma in the westernmost part of the orogen. In the eastern part of the orogen, crustal thickening and high-pressure metamorphism took place at 1050 in one domain and at 980 Ma in another. These discrete tectonothermal events are best explained as series of accretionary events of fragmented and attenuated crustal blocks of the SW Fennoscandian margin behind an evolving

continental-margin arc. In contrast, the coeval Grenvillian orogeny is ascribed to long-lived collision with Amazonia. We argue that roughly coeval, but tectonically different events in the Sveconorwegian and Grenville orogens may be linked through the behaviour of the Amazonia plate. Subduction of Amazonian oceanic crust, and consequent slab pull, beneath the Sveconorwegian may have driven long-lived collision in the Grenville. Conversely, the development of a major orogenic plateau in the Grenville may have slowed convergence, thereby affecting the rate of oceanic subduction and thus orogenic evolution in the Sveconorwegian. Our model shows how contrasting but coeval orogenic behaviour can be linked through geodynamic coupling along and across tectonic plates, and cautions against comparing and correlating orogenic belts mainly based on geochronological data.

ORAL

Paleoproterozic volcanism of the Karrat Group

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Exceptionally well exposed and preserved meta-volcanic rocks of the Paleoproterozoic Kangilleq formation (informal), Upper Karrat Group. are found throughout the Karrat region. This allows us to characterize the Kangilleq formation and the volcanic environment prior to- and during the early formational stages of the Nukavsak Formation that comprises the bulk of the Paleoproterozoic stratigraphy.

Through field-observations and 3D-mapping we document that the stratigraphy of the Kangilleq formation varies from one dominated by mafic tuff breccias with subordinate pillow and massive basalt lavas to one dominated by alternating, thin (1 – 10 m) pillow and massive basalt lava flows with lesser mafic volcaniclastic rocks. This suggest a dynamic subaqueous environment for the emplacement of the Kangilleq formation volcanic rocks, one in which active, synvolcanic faulting caused the formation of one or more basins restricting both the deposition of volcaniclastic debris, and the distribution of lava flows.

The meta-volcanic rocks of Kangilleq formation are greenschist facies consisting of amphibole and chlorite with variable proportions of carbonate, quartz, feldspar, titanite, apatite, Fe-oxides +- biotite. Immobile element lithogeochemistry characterize these rocks as alkali basalt, with minor tholeiitic basalt, that display significant light REE enrichment and high field-strength element concentrations suggestive of within-plate basalts. Volcanic lithofacies and structures, combined with lithogeochemistry suggest the Kangilleq formation erupted in a localized intracratonic rift, possibly associated with mantle plume activity.

ORAL

Indicator minerals obtained by gold sluicing in Lapland, a clue to possible deposit types in the area

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Lapland gold rush started 150 years ago, when visible gold was panned at Ivalojoki in September 1868. A wide spectrum of ore minerals has been obtained since then as byproduct of gold sluicing. Astonishingly, only few studies have been made to use this material as exploration tool in the area. The reason for this might be, that the claims are usually small and many times run by manpower. There are also societal and nature conservation reasons that possibly repulse explorers interest in the region. Also, the Lapland Granulite Belt (LGB) bedrock is quite monotonous. The indicator minerals may be grouped to PGMs and associated minerals as chromian magnetite; Fe-Ti-oxides together with some silicates; different types of corundum; tantalite, columbite, ferberite and related minerals; different gold nuggets sometimes together with pieces of parent rock;

REE minerals, especially abundant monazite; and objects with possibly extraterrestrial origin.

A variety of PGMs has been found but the study has mostly targeted to new species rather than using the mineral compositions and assemblages to identify the parent deposit type(s). Isoferroplatinum is the most common of the PGMs. The inclusions indicate enrichment of Ru, Ir and Os which is usual to chromitite associated deposits. This is reinforced by the occurrence of chromian magnetite and chromite in the concentrate. Some mineral associations as kashinite-laurite-cooperite could indicate Alaskan-type intrusion parent.

Tantalite-columbite etc. and possibly monazite, could be derived from the marginal zone of the LGB, which is characterized by anomalous REE concentration.

ORAL

Drone-borne mineral exploration in Central-West Greenland: New insights from the Paleoproterozoic Karrat group

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During the last two field seasons, two different types of Unmanned Aerial Systems were tested and evaluated for mineral mapping in central West Greenland. A fixed-wing system turned out to be more suitable as large areas can be covered faster and more efficiently.

In 2017, a sensefly ebeePlus fixed-wing system with a 4 channel multispectral Sequoia camera (4 channels in VIS-NIR with 1.2 MP and an additional 16 MP RGB camera) was deployed. Flight altitude was set to achieve 11cm ground sampling distance (GSD). Processing followed in-house routines using Structure-from-Motion photogrammetry to get Digital Surface Models (DSM) and geometrically corrected orthomosaics. In total 6.4 km^2 of the VMS showings in Kangiusap Kuua at Svartenhuk were covered. The VMS showings are hosted in the Nûkavsak Formation of the Paleoproterozoic Karrat Group. In certain stratigraphic horizons within the meta-turbidites, meta-basalt with associated sulfide-rich sea-floor alteration occurs. Flight plans were set to cover both alteration and host rock. A validation dataset includes sampling and spectral characterisation of selected hand specimens.

Gossan and associated alteration of host rock is easily mappable by integrated morphological and spectral analysis as they form ridges with a distinct iron feature. Moreover, traces of fractures and faults, their spatial distribution and relation to the altered horizon are retrieved.

This further highlights the capability of drone-borne application for high-resolution reconnaissance mapping within short turn-around times. Intermediate insights from the project Multi-sensor drones for geological mapping (MULSEDRO) will facilitate the application of drones under unfavourable conditions.

POSTER

New U-Pb geochronology for the Archean basement, Karrat Group cover sequence and later intrusions of the Ray Province, West Greenland.

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The Ray Province of West Greenland comprises Archean orthogneisses and overlying Paleoproterozoic supracrustal rocks, the Karrat Group. The Karrat Group is traditionally divided into a lower Qeqertarssuaq Formation that is overlain by the Nukavsak Formation [1]. The Archean basement and the Karrat Group are intruded by the Prøven Igneous Complex at 1.90-1.87 Ga and all were reworked to varying extents

and metamorphic grades during the Paleoproterozoic [1,2,3].

New U-Pb data from the Archean orthogneisses yield ages of ca 3.1-3.0 Ga in the central Rae Province of West Greenland, which give way to younger ages of ca. 2.7 Ga to the north. This apparent progressive younging either reflects a different terrain to the north or northward growth of the craton.

The Qeqertarssuaq and Nukavsak formations yield distinctly different detritus patterns. The Qeqertarssuaq Formation is dominated by ages corresponding to the underlying Archean basement, whereas the Nukavsak Formation yields detritus pattern dominated by Palaeoproterozoic ages, typically with a significant mode at ca. 2.00-1.95 Ga [3].

Metamorphic monazite ages from the Nukavsak Formation reveal multiple metamorphic events, the earliest being coeval with the intrusion of the Prøven Igneous Complex at 1.90-1.87 Ga. A later metamorphic event ranges in age from ca. 1.83-1.80 Ga. Granitic intrusions of similar age are also present in the northern part of the Province. The young ages may be related to convergence and eventual collision of the Superior and Rae provinces.

4.2. Caledonian orogenic cycle: the Greenland-Svalbard-Scandinavia connection

ORAL

Chemistry, age and tectonic evolution of the western Trondheim Nappe Complex in the Oppdal area, Central Norway

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The evolution of, and along-strike correlations within the Iapetus-derived western Trondheim Nappe Complex (TNC) have been debated for almost a century. The area close to Trondheim is best studied. It consists of the Løkken, Vassfjellet and Bymarka (LVB) ophiolitic fragments in the NW, and the Støren s.s. greenstones in the SE, which both are unconformably overlain by Mid-Ordovician to Silurian volcanic and sedimentary rocks of the Hovin and Horg successions. Until recently, the TNC in the Oppdal area to the south has been less studied, but metabasaltic and metasedimentary rocks have been correlated with the LVB/Støren, Hovin and Horg units, and a large-scale tectonic inversion has been inferred. Here we present new lithological and structural field observations, geochemical data, and detrital and magmatic zircon ages from the Oppdal area, and suggest a new tectonic model for this southern part of the TNC. Our results indicate that the area consists of four different units: (1) a ~480-472 Ma volcanic and sedimentary succession comprising submarine basaltic and minor rhyolitic flows, (2) a ~472-469 Ma volcanic unit dominated by intermediate to rhyolitic pyroclastic deposits, (3) a <450 Ma sedimentary and volcanic succession, and (4) an unconformably overlying <430 Ma sandstone and volcanic succession. The rocks in the area record the change from marginal basin or ocean floor spreading to subduction-related and continental

volcanism. The study has consequences for along-strike correlations within the TNC and offers further insight to the complexity of the Iapetus Ocean closure preserved in this part of the Scandinavian Caledonides.

ORAL

The Seve subduction system in the Scandes

David G. Gee[1], Per-Gunnar Andreasson[2], Håkan Austrheim[3], Christoph Hieronymus[1], Iwona Klonowska[1], Jaroslaw Majka[1] and Remi Vachon
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The Seve Nappe Complex (SNC) in the Scandinavian Caledonides provides some of the best exposed evidence on land for the character of a highly attenuated, magma-intruded, outer margin of a continent (including the continent-ocean transition zone). The last forty years of research has shown that this Baltoscandian margin of continent Baltica was initially rifted and locally intruded during the late Tonian and Cryogenian and subsequently extensively injected by mafic magma during break-up and separation of Baltica from Laurentia in the early Ediacaran at c 600Ma. Partial eclogitization of the SNC was recognized in the late 1960s and more recent studies of the metamorphic history have shown that Ordovican UHP metamorphism, with microdiamonds in garnets, is widespread in the host metasediments of the SNC over a vast area, apparently related to subduction beneath outboard volcanic arcs during closure of the Iapetus Ocean (now preserved in the overlying Köli Nappe Complex). It is suggested here that the increase in density related to eclogitization of the mafic magma-rich margin, promoted the subduction process. The SNC is dominated by upper crustal components – psammitic and pelitic metasediments, hosting the dolerites and gabbros; most of the underlying attenuated, magma-intruded, lower crustal "basement" was apparently eclogitized and lost into the mantle. Our preferred hypothesis is that most of this subducted basement was of Sveconorwegian age and included a substantial, granulite facies component.

ORAL

The North Atlantic Caledonides - from Scandinavia and Greenland to Svalbard and the high Arctic

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The type area of the Caledonides in the UK and Ireland is disrupted by major late- to post-orogenic, orogen-parallel faults. Western Scandinavia provides a more coherent section through the orogen and, together with complementary parts of northeastern Greenland, comprise an excellent laboratory for understanding this collisional orogen. The southernmost Scandes also suffer from similar problems to those in Scotland, with the Oslo rift disrupting the Caledonian foreland basin. Nevertheless, the whole 1700 km long Scandian mountain belt provides an amazingly coherent eastern flank of the Orogen, with well-preserved Ordovician and Silurian foreland basin successions, abundant evidence of Ordovician HP/UHP subduction of the outermost Baltoscandian margin during accretion of Iapetus-related terranes, and culminating Siluro-Devonian, Scandian underthrusting of Laurentia by Baltica, involving vast lateral displacement of allochthons. Northeastern Greenland, providing the complementary western flank of the Orogen, is also dominated by major thrust systems, all comprising parts of the Laurentian margin, emplaced at least 200 km westwards onto the platform.

In the deep hinterland of both the Scandinavian and Greenlandian Caledonides there is abundant evidence of late-orogenic, early Devonian axial extension, superimposed on the nappe pile; also, hinterland-vergent extension. Both these phenomena are prominent in the Svalbard Caledonides, where the rock units and tectonic history of deposition and thrusting is so similar to northeast Greenland; only in southwestern

Spitsbergen, in the domain of the Cenozoic fold-and-thrust belt, is there a Caledonian terrane with affinities to northernmost Greenland, Pearya and the Timanides, providing key evidence for understanding Caledonian orogeny in the Arctic.

ORAL

Remnants of the pre-Caledonian Baltica rifted margin preserved in a lithologically mixed unit between Bergen and Tynset, Scandinavian Caledonides, South and Central Norway

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Remnants of the magma-poor and magma-rich pre-Caledonian rifted margin of Baltica are preserved in the allochthons of the Scandinavian Caledonides. The transition from magma-poor to the magma-rich domain corresponds to the northern termination of the Jotun Nappe Complex. Solitary metaperidotite bodies abound in the magma-poor segment and the transition zone.

The metaperidotite bodies display a characteristic early flattening fabric. The flattening fabric is well-developed in the ultramafic bodies enclosed in the metasedimentary units structurally below the large crystalline basement nappes of Southern Norway including the Jotun, Lindås, and upper Bergsdalen nappe complexes, but can also be found in the metaperidotite lenses between Vågåmo and Tynset. Pre-Scandian contact relationships between those deformed metaperidotites and the metasediments have been obliterated during the Scandian Orogeny. However, well-recrystallised, pre-Scandian, extensional and sedimentary "ghost structures" within the metaperidotite bodies are locally preserved and can be found on favourably weathered surfaces.

The interpretation of the lithologically mixed unit between Bergen and Tynset is challenging, because, no geochronological evidence of the early rift stages from within the unit have yet been reported. Moreover, the unit may have been reworked between the latest Cambrian and early Mid-Ordovician (Jakob et al. 2017). However, an original lithostratigraphic succession of the ancient Baltica rifted margin may be preserved in a thrust nappe north of Lesja (Jakob et al. this volume) and may help to shed light on the origin and pre-Scandian history of the mixed unit between Bergen and Tynset.

ORAL

Subduction and thrust emplacement of the Lower Seve Nappe in the Scandinavian Caledonides: Pressure-Temperature-Deformation constraints along the COSC-1 borehole in Åre

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The Scandinavian Caledonides comprise thrust sheets transported onto the Paleozoic platform successions of the Baltoscandian margin. These thrust sheets are subdivided into the Lower, Middle, Upper and Uppermost allochthons. The tectonostratigraphically highest part of the Middle Allochthon is the Seve Nappe Complex, the target for the Collisional Orogeny in the Scandinavian Caledonides (COSC-1) scientific drilling project. A continuous ~2.4 km long drill core through the metamorphic Lower Seve

Nappe (LSN) has been retrieved. The Seve nappes are considered to have been still hot when emplaced and, consequently, the COSC-1 profile provides a unique opportunity to relate the pressure-temperature-deformation (P-T-D) history of this critical allochthon to the tectonic structures that formed during emplacement under mid-crustal condition. Moreover, this research will endeavor to establish a coherent model of mid-Palaeozoic (Scandian) mountain building. Our research focuses on deciphering the complete P-T-D evolution of the LSN based on a combination of established and innovative methodologies of P-T estimates (QuiG barometry and TitaniQ thermometry). The finite ductile strain pattern of the LSN results from the superposition of two major tectono-metamorphic events M1-D1 and M2-D2. M1-D1 features are interpreted as the consequence of the LSN subduction, and M2-D2 event corresponds to the final exhumation and thrusting of the LSN above the underlying allochthons.

ORAL

A new tectonic model for the Seve Nappe Complex in Norrland, Sweden

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The Seve Nappe Complex (SNC) in Norrbotten, Sweden has classically been mapped as a series of nappes formed by the telescoping of the rifted margin of Baltica. Typically, the SNC is sub-divided into the lower, middle and upper nappe-series. The lower Seve generally constitutes slivers of basement and are overlain by meta-sedimentary and meta-igneous rocks representing both the middle and upper Seve nappes. The peak metamorphism varies considerably within the Seve from local eclogite facies to a more regional amphibolite facies and domains where original pre-Caledonian contact metamorphism related to dolerite intrusions are preserved. This has led to the norm of subdividing the SNC in different thrust nappes. We propose, however, a model where the Seve in Norrbotten represents a more continuous section through the magma-rich, attenuated margin of Baltica and that the metamorphic overprint, rather than representing decoupling and re-stacking, represent differential reactivity of individual lithologies with different reaction potential. High strain zones are present throughout Seve but the need for large internal thrusts juxtaposing older rocks on top of younger is not present internally in the Seve. This has dramatic consequences for, not only the understanding of the mountain building in the Caledonides, but may also open a new interest for the Seve as a place to study the deep processes of magma-rich passive margins, which are often lost in subduction and in general difficult to study in seismic lines due to masking of high velocity mafic intrusive and extrusive rocks.

ORAL

UHP metamorphism in the Seve Nappe Complex in the Scandinavian Caledonides

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Evidence for ultrahigh-pressure metamorphism (UHPM) and deep subduction of the Baltican outer margin in provided by diamond-bearing gneisses in three localities, on Tväråklumparna and Åreskutan in west-central Jämtland and near Saxnäs in southern Västerbotten. These UHP gneisses are found within the Middle Seve Nappe.

Microdiamonds are identified by microRaman spectroscopy and are found as inclusions in garnet as well as in zircon. The UHPM within this rocks is also confirmed by the phase equilibrium modelling. The peak pressure conditions of the Åreskutan gneiss are estimated to 4.1-4.2 GPa and 830-840ºC, whereas of the Marsfjället gneiss (Saxnäs) to ~3.6 GPa and 750ºC. Monazites from

all three localities were chemically dated and they yielded Ordovician ages of migmatization (post-UHP stage). The dating for Åreskutan and Tväråklumparna gneisses shows that the diamond-bearing gneisses underwent partial melting between 445 and 435 Ma, whereas the post-UHPM in Marsfället gneiss is older (ca. 470Ma). The timing of the UHPM and diamond formation still remains to be resolved, however the recent studies provide important information about the tectonometamorphic evolution of the Seve Nappe Complex in the Swedish Caledonides.

ORAL

A review of magmatic and metamorphic events recorded by crystalline basement of Southwestern Svalbard

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Svalbard's Southwestern Basement Province (SBP) consists of numerous tectonic units juxtaposed by major strike-slip faults and thrust zones of early Paleozoic (perhaps also Neoproterozoic) to Cenozoic age. Felsic and mafic igneous rocks of various affinities are of Ectasian-Stenian, Tonian and Cryogenian-Ediacaran age. Sedimentary successions were deposited during Mesoproterozoic, Neoproterozoic and early Paleozoic. Majority of both igneous and metamorphic rocks have been affected by at least one metamorphic event. Metamorphic events were associated with the Torellian (c. 640 Ma), Caledonian and Ellesmerian (c. 360 Ma) orogenies. The grade of metmorphism varied from greenschist and amphibolite to blueschist and eclogite facies. The SBP is definitely a composite terrane assembled piece by piece during the aforementioned orogenic events as well as the Eurekan orogeny that shaped final tectonic framework observed nowadays. Comprehensive recognition of the geological complexity of the SBP is a key for understanding of whole Svalbard together with adjacent area.

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ORAL

Syn-collisional Scandian extension and magmatism on the Orkney Islands, Scotland

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The Orkney Islands, NW Scotland, are dominated by sedimentary rocks of the Devonian Orcadian basin. The sparsely outcropping basement has received less attention than its cover, but is typically interpreted as Grampian or Scandian granites intruding Neoproterozoic Moine schist. New structural, TIMS age and geochemical data demonstrate that a grey and a pink granite intruded metasedimentary gneiss at 432 ± 0.5 Ma and 430 ± 1 Ma, respectively, to form the Orkney granite complex during the Scandian phase of the Caledonian orogeny. Inherited zircons in the granites give ages typical of Moine schist. Both granites display geochemical characteristics of the Scandian high Ba-Sr granite suite in the northern British Isles. Both the granites and the gneiss are cut be previously undocumented extensional mylonite zones, which are overprinted by similarly oriented extensional phyllonites, and in one case by similarly oriented extensional brittle faults. Three such deformation zones are observed: in the north, the Yesnaby shear zone display top-to-north extensional shear sense and in the south the Stromness and the Graemsay shear zones display top-to-south extensional shear sense. Successive emplacement of granite, pegmatite and aplite into the shear zones, cross-cutting some structures while being deformed by others, allow dating of the deformation. We propose that the ductile to

brittle evolution of the shear zones reflect deformation during emplacement and cooling of the granite complex at a relatively shallow crustal depth. The N-S extension on Orkney during Scandian overall NW-SE directed collision likely reflects transcurrent faulting associated with the nearby Great Glen Fault.

ORAL

Are Southwestern Svalbard and the Pearya Terrane counterparts?

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Svalbard's Southwestern Basement Province (SBP) and the Pearya Terrane of northern Ellesmere Island are thought to be possible counterparts dismembered by long-distance strike-slip faults. Both terranes indeed share some similarities including Mesoproterozoic to Neoproterozoic igneous rocks and associated sedimentary successions locally intruded by younger mafic dykes as well as thick Neoproterozoic sedimentary successions that include horizons of diamictites of possible glacial origin. However, there are also dissimilarities between the two terranes. The SBP bears a record of the Torellian orogeny (c. 640 Ma), which is hitherto lacking in Pearya. Also, clearly subduction related Caledonian blueschist facies rocks are known only from the SBP. On the other hand the Pearya Terrane comprises a vestige of the Ordovician island arc, which could have been a part of the same subduction system. The Pearya Terrane also hosts Devonian intrusives which do not occur in the SBP. Despite these dissimilarities, it can be stated that both the SBP and the Pearya Terrane form a coherent system of tectonically juxtaposed sub-terranes, but much more comprehensive tectonic, petrological and geochronological research in both terranes is needed to decide whether they are true counterparts or not.

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ORAL

Integration of palaeomagnetic, isotopic and structural data to understand Svalbard Caledonian Terranes assemblage

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During the PALMAG project (2012-2016) a total number of 828 palaeomagnetic specimens of metacarbonates and metabasites from 46 sites representing all three of Svalbard's Caledonide Terranes were demagnetized in the Laboratory of Palaeomagnetism (Institute of Geophysics Polish Academy of Sciences) to recognize their NRM patterns. Simultaneously, 13 samples of mica schists and amphibolites from the Western and Eastern Terranes and mylonites from the Kongsfiord, Billefiord and Eolussletta Fault Zones were subjected to in situ laser ablation 40Ar/39Ar age determinations at the CEPSAR (The Open University, UK). Integration of palaeomagnetic and isotopic experiments accompanied by detailed structural observations lead to the following palaeogeographic and tectonic conclusions: (a) the results confirm the complete remagnetization of the investigated metamorphic complexes of Spitsbergen (West of Hinlopenstretet) during Caledonian tectono-genesis (Burzyński et al. 2017); they also confirm the amalgamation of Svalbard with Baltica in Late Silurian time (Michalski et al. 2012, 2014); (b) the results indicate a significant reorganization of the geometry of the sampled sectors of the West Spitsbergen basement by listric faulting related to the opening of the North Atlantic-Arctic Ocean Basins (Michalski et al. 2017); (c) In

Nordaustlandet (East of Hinlopenstretet), relicts of a pre-Caledonian (primary?) magnetization appears to have survived; (d) analyses of the palaeolatitudes derived from the Murchisonfiord (Nordaustlandet) samples do not confirm the positioning of Eastern Svalbard near to Eastern Greenland in Neoproterozoic time, the results suggest, rather, that Eastern Svalbard constituted a separate microplate or could have been located near the N. Greenland/Pearya blocks. (manuscript in revision).

ORAL

The Siljan Ring; A Lower Paleozoic petroleum system with kitchens in a Telychian rift basin, disrupted by meteor impact and rejuvenated by biological and Quaternary glacial processes

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The oils in Siljan are thought to have formed by Frasnian impact heating of the Katian Fjäcka shale (Vlierboom et al., 1986). However, oil remains are not unique to the Siljan crater and occur throughout the subsurface of central Sweden (Sandström et al., 2006). By reexamining published seismics (Juhlin et al., 2012; Muhamad 2017), well descriptions (Lehnert et al., 2012; Muhamad et al., 2015) together with our own source rock observations, we demonstrate that the oil formed in kitchens in a Telychian rift basin prior to the impact. We see no evidence of NW-SE oriented Ordovician facies belts (Lehnert et al., 2013), and imaged major normal faults and the Mora structural high are Telychian rather than impact related. The major unconformity seen in the Mora 1 well (Lehnert et al., 2012) is the base of a 200m+ deep NNW-SSE oriented 600m+ wide incised valley, triggered by associated normal faulting. We suggest the rift basin formed due to extension over the flexural bend in front of the Caledonian orogeny. We also observe younger incised valleys, possibly related to the Sheinwoodian glacially triggered regression. We explain the post-Ordovician deformation as a combination of the Telychian extension, and the meteor impact. The gas produced in the Siljan Ring is biogenic and likely from biodegradation of residual oils (Rouchon et al., 2015). The gas seeping activity however, is likely due to the decompression (around 200 bar) from the withdrawal of the Weichselian ice cap and the associated subglacial basement water flow patterns.

ORAL

Timing of collision initiation and location of the orogenic suture in the Scandinavian Caledonides

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The Scandinavian Caledonides formed during Baltica–Laurentia continent-continent collision in the late Silurian. We propose that initial contact along continental-margin promontories led to a drop in convergence rate, resulting in increased slab roll-back along parts of the margin still undergoing oceanic subduction. Slab roll-back caused extension of the overlying lithosphere with orogen-wide emplacement of mafic layered intrusions, ophiolite formation and bimodal magmatism at 438–434 Ma, in what immediately thereafter became the upper plate (Laurentia) in the Scandian collision. Initial collision at promontories may be challenging to identify due the metamorphic effects of full-fledged collision shortly thereafter. However, rapid deposition of sediments from eroding orogenic highs just prior to or during the 438–434 Ma period may represent a tell-tale sign of early collision. An example of such early Silurian deposits may be present on Magerøya, in the northernmost Scandianavian Caledonides (Corfu et al., 2006), where the sediments appear penecontemporaneous with mafic intrusive units likely formed in a back-arc setting. This model

provides a tight constraint on the timing of collision initiation, and provides a framework by which some tectonic units comprising the Scandinavian Caledonides can be assigned a Baltican or more exotic heritage, where other methods, such as detrital zircon (DZ) chronology cannot, as proved by DZ statistical similarity right across the entire North Atlantic region (e.g., Slagstad & Kirkland, in press). Tracking the suture through the intrusive model highlights that many units conventionally ascribed a Baltican heritage are in fact much more far travelled.

POSTER

The age of metagabbro from the Bangenhuk unit, Atomfjella Complex, Ny-Friesland, Svalbard

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The Bangenhuk unit is a part of the Atomfjella Complex and belongs to the Svalbard's Eastern Basement Province. Whole Complex has been metamorphosed in amphibolite facies during the Caledonian Orogeny (Witt-Nilsson et al. 1998). The rocks of the Atomfjella Complex crop out in western Ny-Friesland and form north-south trending antiform, which includes metagranitic basement covered by younger metasediment (Gee & Tebenkov, 2004).

The Bangenhuk unit of the Nordbreen Nappe is composed mainly of granitic gneisses whose age was estimated to c. 1750 Ma (Johansson et al. 1995, Bazarnik et al. 2017). However, older (c. 2709 Ma) quartz-monzonite has also been found (Hellman et al. 2001). Both gneisses and metasedimentary covers are intruded by mafic dykes of unknown age.

A sample of metamorphosed gabbro was collected from the southern coast of Mosselbukta, near a small cottage on the Bangenhuken peninsula, during the CASE 18 Expedition in 2015. It forms a dyke cutting thorough gneisses and striking approximately north-south. The gabbro is composed mainly of plagioclase, pyroxene, amphibole and garnet with minor amount of apatite, ilmenite, quartz and zircon.

U-Pb zircon dating was performed in the Micro-Analyses Laboratory in Polish Geological Institute in Warszawa using SHRIMP IIe/MC. About 40 fragments of euhedral zircon grains with oscillatory zoning have been analyzed. The obtained result ca. 1382 Ma has not been recorded in the Ny Friesland area before. Similar ages were noticed in Zig-Zag Dal Formation in eastern North Greenland (Upton et al. 2005).

POSTER

Detrital zircon signatures of the metasedimentary rocks of the Lower Seve Nappe in the COSC-1 drillhole, Åre, Sweden.

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The ICDP- "Collisional Orogeny in the Scandinavian Caledonides" (COSC) drilling project, targeted the Lower Seve Nappe, located in the footwall of the microdiamond-bearing Åreskutan Nappe of the Seve Nappe Complex (SNC) in western Jämtland; it penetrated 2500m of mainly psammitic metasediments,

amphibolites and a few felsic, usually pegmatitic intrusions. U-Pb dating by LA-ICPMS of zircons in these lithologies provides evidence of a mainly Mesoproterozoic provenance of the metasedimentary rocks and it also confirms evidence of mid Ordovician felsic magmatism (Li et al. 2014). The age of the mafic rocks is difficult to constrain because they have all been subject to a complex metamorphic history (Jeanerette et al, this volume). Over twenty samples of the psammitic schists and gneisses have been analysed. As in previous investigations of the SNC (Gee et al 2014) and underlying Särv Nappes (Be´eri-Schlevin et al 2011) in central Jämtland, and farther north near the border to Västerbotten (Kirkland et al 2011) and also southern Norrbotten (Gee et al 2015), the zircon populations are nearly all dominated by Sveconorwegian signatures; many also by a strong late Palaeoproterozoic component. At the base of the hole, there is a significant late Archean zircon population. Along with the data from the Kalak Nappe Complex correlatives of the SNC and Särv Nappes in northernmost Norway (Kirkland et al 2007), the new data emphasize the common character of the provenance of the sediments in all these nappes, derived from the outer margin of Baltica.

4.3. Evolution of the North Atlantic margin: from Mesozoic rifting to Cenozoic inversion

ORAL

Deltaic growth-faults of the Triassic Barents Shelf; structural style and deformation mechanisms controlling basin configuration

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Deltas represent major sedimentary accumulation zones with distinct subaqueous, sigmoidal geometry and principal deposition concentrated near the top, which are inherently prone to instability that leads to mass wasting and/or structural collapse. We compare tectonic and collapse-related faults associated with delta progradation of the upper Triassic succession of Edgeøya (SE Svalbard), to collapse structures in a more "typical" Last Chance Delta (Utah). Common for both investigated delta systems is that faults have listric geometries instigated by linkage of variously oriented segments above well defined detachment zones. Hanging walls form rollover folds, locating accommodation in the half-grabens towards faults. Infill is characterized by wedge-shaped, sand prone bodies that attest to rapid slip increments on faults contemporaneous to mild erosion along the crests of fault blocks. In the footwall (underneath) of listric faults, mud pillows or triangle-zones are developed. Related smaller structures attest to a transition from hydroplastic shear to brittle, frictional flow deformation along with diagenesis and cementation.

Edgeøya half-grabens arrested high amounts of sand in the prodelta realm, whereas the Last

Change delta records deposition mainly in the deltatop. The trigger and driving mechanism for delta collapse by faulting is the localized, differential loading of the sand bodies of channels/mouth bars and fault-controlled basins. Faults move material towards the free surface of the delta-front. Complementary, compaction of prodelta muds offers localized and gradual mechanical decoupling from overlying denser sand. Further, the compaction front below deltas can trigger faulting in the prodelta realm, with land-ward dipping faults facing the prograding delta-front.

ORAL

The Mesozoic basin of Ramså in Northern Norway: Characteristics, Development and regional impact

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The Ramså Basin on Andøya, Northern Norway gives a unique insight into the Mesozoic sedimentary strata onshore the mainland of Norway. It experienced a great deal of attention since the 19th century and was studied geologically several times. However, extensive geophysical mapping was missing and the tectonic development of the basin itself is still disputed.

Moreover, the basin is part of the well developed strandflat of eastern Andøya where remains of deeply weathered basement around and underneath the sedimentary strata indicate a history of repeated uplift and erosion which makes it to a key location to understand the development of this remarkable landscape widely observed along the Norwegian coast. In a cooperation project of NGU and the University of Bergen we carried out extensive geophysical and geological profiling including seismic and potential field measurements to investigate the characteristics and settings of the Ramså Basin. Specimens were analyzed sedimentologically, petrologically/mineralogically and geochemically. Four new boreholes were core-drilled and are currently subject to further analyses.

This integrated study provides an enhanced understanding of the geometry and tectonic settings of the Ramså Basin as a set of a NE-SW oriented normal faulted half-graben, which developed in the latest stage of the opening of the Andfjorden Basin. Our results indicate weathering in a tropical to sub-tropical climate, and K/Ar dating reveals Late Triassic age. Two newly found Mesozoic sub-basins south of the Ramså Basin confirm repeated erosion and transgression phases with a burial depth of the sediments not exceeding more than 2 km.

ORAL

Correlation of the Oligocene – Pliocene succession in Norway, Denmark & UK

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The almost complete, mainly deltaic, upper Paleogene-Neogene succession from Jylland, Denmark was investigated for Sr-isotopes, micro-fossils, and palynology in order to make a robust stratigraphic framework for the North Sea area. The investigation shows that the Danish succession correlate readily with lithological units, in the Norwegian North Sea, the Norwegian Sea shelf and the East Shetland Platform. In particular, Bolboforma and dinocyst correlations show that the upper part of the Danish Gram Formation correlates with the base of the Molo Formation in it's southern part, and that this part of the Molo Formation corresponds to the

middle/upper part of the Kai Formation (Norwegian Sea shelf). The new robust correlation between the North Sea and North Atlantic realm is fundamental in the understanding the palaeogeography during the late Paleogene and Neogene. For instance, The Bolboforma assemblages have their origin in the Norwegian Sea and therefore, due to the presence in the Danish area, confirm that it was an open strait in the northern North Sea (the only seaway passage into the North Sea Basin during the Miocene). The glauconitic Utsira Formation (approximately 5.7-5 Ma), in the threshold area close to the opening to the Norwegian Sea, overlie erosional unconformities comprising 21 and 13 my. We believe that this unconformity was partly related to the activity of strong currents in the narrow strait between Norway and the Shetland platform and partly related to the Messinian glacio-eustatic level drop.

ORAL

Late Cretaceous basin inversion in the Kattegat – Skagerrak segment, Sorgenfrei – Tornquist Zone, Denmark, and Mesozoic – Cenozoic crustal tectonics of the eastern North Sea Basin

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The Sorgenfrei – Tornquist Zone is a NW-SE trending, 50-100 km wide fault zone that cut off the East North Sea Block (ENSB), i.e. the Mesozoic basement of the Eastern North Sea Basin, from the Baltica Palaeozoic platform. The break was established in the Triassic, where the ENSB was established as the hangingwall block in the Kattegat area; by contrast, the Baltica platform develloped as the hangingwall block in the Fjerritslev halfgraben to the northwest (1).

In the Kattegat area, the Triassic faulting established a staircase fault block trajectory with downfaulting towards the southwest into the Danish Basin. In the Jurassic – Early Cretaceous, the Kattegat segment changed into an asymmetric, northeast dipping graben, the Kattegat Graben. In the Late Cretaceous, maximum subsidence returned to the southwest into the Danish Basin, while the Kattegat Graben was inverted during backward tilt of the graben block.

The ENSB formed the northeast flank of the Central North Sea Dome (2). The Jurassic – Cenozoic structural evolution of the ENSB was governed by the rise and fall of the Central Graben rift dome: 1) synrift rise in the Jurassic – Early Cretaceous, 2) Late Cretaceous transition phase with collapse of the Central Graben rift, 3) Cenozoic postrift subsidence (3). A model of the Mesozoic crustal tectonics associated with the ENSB illustrates the interrelationship between the evolution of the Kattegat – Skagerrak segment and the Central Graben Dome across the eastern North Sea Basin (4).

ORAL

Mesozoic basin inversion governed by crustal extension in the Bornholm area, Sorgenfrei-Tornquist Zone, Denmark

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Basin inversion describes the deformation of asymmetric grabens characterized by folding and thrusting, i.e. horizontal shortening, associated with uplift of the sedimentary graben fill above regional (1). The compressive stress field has been interpreted in a plate tectonic concept as a result of continent-continent collision that established a compressive stress field in the orogenic foreland (2, 3).

However, structural analysis of basin inversion in the Sorgenfrei – Tornquist Zone illustrates, that basin inversion was the result of superposition of asymmetric extensional fault basins dipping in opposite directions. The evolution of the graben

basins, took place during successive extensional tectonic regimes separated by stillstand intervals. During subsidence of the superposed, extensional basin, the primary basin was tilted backward, and the basin was inverted during local compression between the primary footwall blocks.

The Mesozoic fault block pattern of the Bornholm area illustrates, that the NW-SE trending Sorgenfrei – Tornquist Zone was extended in two directions: The main extension was in a NE-SW direction across the strike of the fault zone, and a secondary NW-SE extension along the fault zone trend.

Based on the changing graben activity, the Mesozoic has been divided into Triassic, Jurassic – Early Cretaceous and Late Cretaceous extensional tectonic regimes. Graben subsidence started in the Triassic, and basin inversion was active in the Jurassic – Early Cretaceous and again in the Late Cretaceous (4, 5). The tectonic regimes were separated by turnover intervals characterized by only minor tectonic activity in the late Late Triassic and the early Late Cretaceous.

ORAL

Evidence of post-breakup tectonism on the Northeast Greenland shelf: Implications for "passive" margin conditions

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The break-up between the Eurasian and North American plates during the Paleogene is well constrained by geophysical data. The structural history of Northeast Greenland following the breakup is on the other hand still very much an area of discussion. Here, analysis of seismic data offshore Northeast Greenland constrains the timing of the post-breakup tectonic events by correlation with the well-dated magmatic intrusions in the region and their associated thermal uplift and venting of gasses. Previous studies have mapped large-scale faulting along the western margin of the Thetys Basin where extensional faulting with an offset exceeding 1s TWT on the seismic profiles is observed. This is often associated with dramatic failure of the uplifted footwall where vast quantities of sediment slid into the Thetys Basin, apparently instantly, which suggests relatively fast propagation of the fault system. The time of breakup is constrained in the seismic data by magmatic intrusions dated to peak in the earliest Eocene. Both a southwards deepening erosional incision, as well as several vents associated with the de-gassing of intruded magma coincides with the continental breakup. This seismic marker is clearly truncated by the failure of the footwall as well as offset by the fault, which shows that the faulting occurred in post-breakup times, during a tectonic phase where no faulting on the "passive" margin is expected. Significant progradation associated with tilting and erosion superseded the observed faulting. This indicates that active tectonism may explain the exhumation and progradation observed on the Northeast Greenland margin during the Neogene.

ORAL

The late Cenozoic evolution of the mid Norwegian Margin

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Even though North Atlantic post break-up sediments are well recorded on the structural rather simple mid Norwegian passive margin, the unconstrained ages and uncertain paleo-geographic reconstructions has led to debate. The aim of this paper is to constrain the late Cenozoic geological evolution with focus on vertical movements of the inner margin and positions of coast-lines. The database consists of regional 2D and 3D seismic and well data.

Prior to the Miocene compression phase, Eocene to lower Miocene coastlines were located landward of the subcrop with an unresolved eastward extent. The mid to late Miocene compression phase, which formed inversion

structures more than 1000m high and 300km long, also caused dramatic shifts in base levels along the inner passive margin. The base level fell 100's of meter at onset of compression and the coastline shifted ocean-ward. The Mid Miocene Unconformity developed and the syn-tectonic Kai Formation was deposited. Upon termination of the compression phase the base level rose in the order of 500m. Sediments from the following transgression (lower Molo Formation) is documented for the first time. The younger coast-parallel 600km long upper Molo Formation shelf delta is overlain by the Quaternary glacio-marine Naust Formation. The inner shelf was tilted 0.5° westward during the glacial period due to isotatic adjustments from onshore erosion and offshore deposition.

The observed vertical base level fall and subsequent rise of the inner passive margin occurred with the onset and termination of the compression phase. Similar shifts may occur along any passive margin.

ORAL

Palaeostress analysis and hydrocarbon leakage potential of disparate fault sets within the Swaen Graben

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The Swaen Graben represents one of the Cretaceous structural elements of the SW Barents Sea whose growth and development remains poorly described in the literature. Majority of the previous works undertaken in the study area proposed a close connection between the Swaen Graben and the Eastern Loppa High with the likelihood of a strike-slip tectonics being the dominant process for fault growth on the western section of the graben. In this work, we assessed the palaeostress and slip tendencies of five fault types in the Swaen Graben. These faults were selected based on the assumption that they are strike-slip faults, flower structures, riedel shears, isolated-erosionally decoupled faults, and small-scale transfer faults. The principal palaeostress tensor associated to the faults, was determined based on the relationship between the slip tendency values and the measured displacement. Our model shows a sub-vertically oriented σ_1 plunging 76.9º along a N246.4º azimuth for all the five fault types. The orientations of σ_2 and σ_3 are sub-horizontal. Slip tendency values for the faults varies from 0 to 1. Most of the Type 1 faults show slip tendency values 0 to 0.67. Type 3 and 5 faults have the highest slip tendency values. Hydrocarbon leakage factor ranges from 0.16 to 1 and is highest within the Type 3 and 5 faults. We show that these faults are extensional with the Type 5 faults acting as transfer faults connecting two disparate fault systems. The studied faults are analogous to modern day examples in the East African Rift Systems.

ORAL

Influence of late Cenozoic erosion and deposition on temperature distribution beneath the north-eastern part of the Mid-Norwegian continental margin (the Lofoten-Vesterålen area)

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A 3D thermal pattern beneath the north-eastern part of the Mid-Norwegian continental margin (the Lofoten-Vesterålen area) and adjacent areas of the continent has been investigated to understand the thermal effect of relatively high erosional and depositional rates observed during the Pleistocene.

A lithosphere-scale 3D structural model of the Lofoten-Vesterålen area from Maystrenko et al. (2017) has been used as a realistic approximation

of the geometries of the sedimentary infill, crystalline crust and lithospheric mantle during a 3D thermal modelling. The 3D thermal modelling has been performed by use of the commercial software package COMSOL Multiphysics. The Earth's surface and sea floor have been taken as an upper thermal boundary condition with taking into account palaeoclimatic changes during the Cenozoic. The lithosphere-asthenosphere boundary has been used as a lower thermal boundary. The erosion and deposition have been also included in the 3D thermal calculations.

The modelled thermal influence of the late Cenozoic erosion within the Lofoten-Vesterålen margin segment is reflected by a positive thermal anomaly within the areas where sedimentary and/or crystalline rocks were eroded. A negative thermal effect has been modelled in the areas affected by deposition of sedimentary rocks. The erosion-induced, positive, temperature anomaly is up to +27 ^{o}C at depths of 17-22 km beneath the eastern part of the Vestfjorden Basin. Two deposition-induced, negative, temperature anomalies have minimal values of around -70 ^{o}C at 17-20 km depth and -48 ^{o}C at 12-14 km depth beneath the oceanic Lofoten Basin and the north-eastern part of the Vøring Basin, respectively.

ORAL

Extensional detachments, breakaway complexes and supradetachment basins in rifted margin formation: examples from offshore Mid Norway

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The large-magnitude faults that control crustal thinning and excision at rifted margins combine into laterally persistent structural boundaries that separate margin domains of contrasting morphology and structure. We term them breakaway complexes. At the Norwegian rifted margin, the constituent faults operated on the crustal scale, cut large thicknesses of heterogeneously layered lithosphere and facilitated fundamental margin processes such as post-orogenic equilibration, deformation coupling and eventual excision or near excision of continental crust. Many of them can be classified as extensional detachment faults, and they performed different types of work on the lithosphere and occupy different locations in the margin architecture. The array of associated synrift basins thus record the changing state of the continental lithosphere as the crystalline crust was nearly or wholly excised in a series of major deformation stages. The association of synrift supradetachment basins with fundamental modes of crustal thinning explains the particular locations of distinct basin styles in the margin architecture and provides the basis for a broad classification. Supradetachment basins appear to dominate the population of synrift basins on the margin scale. They were draped by a basin that post-dated local block rotation but pre-dated breakup, and that was still strongly affected by a subsidence pattern that much reflected the earlier large-magnitude faulting.

ORAL

The source area of the Miocene Ribe Group, Eastern North Sea basin: the control of climate and tectonism.

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The sediment provenance was investigated by comparing radiometric age dating of the sink area to the comprehensive data available from the source area. The basement in southern Norway and southwestern Sweden, and possibly its derived sediments, is the primary source of the Miocene sand. However, smaller age populations show that the rivers had a larger catchment area. Overall, it is the same type of sediment that was

fed from source to sink during the early Miocene, but heavy mineral analyses show that the maturity of the sediment varies, presumably in response to changes in the erosion rate. The study of the source area encompasses investigations of clay minerals, flora, and fission track data, in order to unravel the climate and uplift history. The initial topography of the source area (Fennoscandian Shield) was relatively low, less than 500 m in the earliest early Miocene when a pronounced phase of uplift and erosion in this region began according to interpretation of apatite fission-track data. The elevation of the source area during the early Miocene is coincidence with a major reorganisation of sediment routing systems in the eastern North Sea region. This occurred during a period of climatic stability and thus most likely an indication of tectonic activity in the source area. An increased relief of the hinterland is revealed from steadily higher contents of mountain elements in the pollenflora and by the end of the early Miocene, at app. 15 Ma, the highest peaks in the source area likely exceeded 1500 m.

ORAL

Deep crustal structures in the northern North Sea rift: observations from new 3-D seismic reflection data

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Pre-existing basement structures can affect the nucleation, growth and linkage of normal faults in rifts and rift systems. The northern North Sea rift developed on top of an extremely heterogeneous crust containing structures from the Caledonian orogeny to Devonian extension. Our understanding of these structures has long been limited by poor imaging of the basement with conventional 2-D seismic reflection data. New broadband 3-D seismic reflection data allow us to study the extent, geometry and orientation of these deep crustal structures in unprecedented detail. The data contain a wide range of frequencies (2.5-155 Hz) and provides high-resolution, three-dimensional images of deep crustal reflectors. The improved imaging allows us to map a high-amplitude lower crustal reflection package over an area of more than 4000 km^2. The package varies in depth from 20 to 30 km with elevations coinciding with footwalls of major N-S trending normal faults.

Deep crustal reflectivity observed in the northern North Sea has been explained by eclogized continental crust using a combination of 2-D seismic, gravity and magnetic data. This study explores alternatives to this explanation. More precisely, we examine the role that igneous intrusions, Caledonian thrusts and Devonian extensional shear zones could have played in the generation of the observed reflection package. Moreover, we examine the timing and interaction between these structures and subsequent tectonic faults.

POSTER

Pliocene Pockmarks in the eastern Danish Central Graben, North Sea - Formation and Significance

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[1]Student, [2]Supervisor

In this study, we describe abundant Pliocene circular depressions from the Danish Central Graben, mapped using 3D-seismic data which are courtesy of Maersk Oil, Operator of DUC. We interpret the depressions as buried pockmarks formed due to focused fluid-venting to the seafloor during the Pliocene. The origin of the fluids and the significance of the fluid-venting are not fully understood. Our preliminary analyses show that the majority of the pockmarks occur on one distinct surface suggesting a very confined timing of formation. The distinct pockmarked surface is comprised within a westward prograding set of clinoforms suggesting that the

pockmarks may have formed in response to sea-level changes and/or climatic fluctuations. The pockmarks furthermore occur spatially clustered in a large pockmark field, which could be controlled by lithology variations along the clinoforms. Alternatively, deeper structural elements vertically below the pockmark field such as the Coffee Soil Fault, which marks the eastern edge of the Danish Central Graben, could have focused migration of deep thermogenic fluids and controlled the spatial distribution of the pockmarks. Hence, our seismic observations point towards a combined control of pockmark formation from both deep structures and depositional environment. Our further analysis of the pockmarks will include borehole data and will focus on constraining the timing and the controlling factors in more detail. We will investigate the origin of the escaped fluids and the possible relations with regional events in the Late Neogene-Quaternary such as climatic fluctuations and maturation of thermogenic source rocks in the Central Graben.

POSTER

Origin and sediment budget of an early Neogene - early Quaternary contourite drift system on the SW Barents Sea margin

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Alongslope ocean currents distribute sediments across continental slopes surrounding ocean basins, making contourite drifts deposited from such currents important paleoceanographic archives. Furthermore, on high-latitude margins submarine failures often relate to contourites, as they may act as weak layers due to their lithological character and/or physical properties. Although identified several places along the Norwegian-Barents Sea-Svalbard margin, contourites are not described from the SW Barents Sea. Using 2D-seismic data, we here describe a contourite drift covering a substantial part (~20,000 km^2) of the SW Barents Sea slope, located mainly beneath the Bear Island Trough Mouth Fan. From correlation to commercial well data, this mounded drift covers a time span from early Neogene to early Quaternary. This drift therefore likely started to form at the onset of alongslope flow similar to the present circulation following the opening of the Fram Strait gateway and the subsidence of the Scotland – Faroe – Iceland – Greenland ridge. It continued to accumulate sediments following the onset of the northern hemisphere glaciations in late Neogene until glacigenic deposits completely dominated this part of the slope. Parts of the drift has been remobilized, thus it has influenced on the stability of the continental slope, most likely because of stress exerted by up-flank accumulation of glacigenic sediments causing the drift deposits to fail. We will discuss the onset of drift growth and its implications for the evolution of the margin, and – for the first time, present sedimentation rates and sediment volume for a high-latitude contourite drift.

4.4. Vertical movements, changes in plate motion and mantle dynamics: observations and models in the north-east Atlantic domain

ORAL

An undereexplored method for determination of paleotemperature and burial depth.

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A number of methods are used to estimate palaeotemperatures. Fluid inclusions studies give a direct measure of the palaeo temperature. Other methods are based on changes in mineralogy, e.g. Quartz cementation at 70°C. Clay transformation from smectite to potassium rich illite happens in several stages with increasing temperatures. Fission track analysis is based on formation of damage trails formed by radioactive decay in apatite and subsequent annealing as a

function of temperature. Methods based on blocking temperatures are based on diffusion of a gas out of the crystal lattice at certain temperatures.

Other methods are based on the combined effect of temperature and the time of exposure to this temperature. One such method is a hitherto underdeveloped method based on the magnetisation of a sediment or rock. If the magnetic grain size is favourable, the rock may acquire and preserve a magnetisation which will be added to the already present magnetisation. If a rock changes position by folding at a certain point in time, this new magnetisation will have a different direction and may be easily defined. Knowing the temperature, the duration of the rock being in its present position may be calculated. Knowing the time period, the temperature may be calculated. In addition, the age of the component may be calculated from the palaeopole to which the magnetic component points. Examples were determination of burial depth (approx. 5km) during Carboniferous of a suevite from the Ritland impact crater, Norway, and determination of palaeotemperatures of sediments in the Barents Sea.

ORAL

Early postglacial rebound tectonics within the Tjörnes Fracture Zone, North-Iceland.

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The multi-branched plate boundary across Iceland is made up of divergent and oblique rifts, and transform zones, characterized by complex tectonics. The Tjörnes Fracture Zone (TFZ) links the northern rift zone (NVZ) on land with the Kolbeinsey Ridge off shore. The TFZ lacks the clear topographic expression typical of oceanic fracture zones and consists of broad zone of deformation roughly 150 km wide (E-W) by 50-75 km long (N-S), involving a complex array of oblique-slip faults bounding (NS) rifts and right-lateral (WNW) strike-slip faults, active throughout Holocence. The magma-starved southern extension of the KR, the ~80 km NS and 15-20 EW Eyjafjarðaráll rift (ER), is made up of dominantly extensional faults merging southwards a system of right-lateral strike-slip faults with vertical displacement up to 15 m.within the Húsavík Flatey Fault Zone (HFFZ). A 500-700 m deep asymmetric rift, with 20-25 m vertical displacement on normal faults characterizes the northern ER whereas transform along the HFFZ has created a NW- striking pull-apart basin with frequent earthquake swarms. We present the tectonic framework of the ER and Skjálfandadjúp (SK) basins multibeam bathymetry, high-resolution seismic reflection data (Chirp) and seismicity. Both basins contain post-glacial sediments of variable thickness.

Correlation of Chirp reflection data and tephrachronology from a sediment core within the SK basin reveal major rifting episodes between 10-12.1 kyrs BP activating both basins, followed by smaller-scale fault movements throughout Holocene. These vertical fault movements reflect increased tectonic activity during early postglacial time coinciding with isostatic rebound enhancing volcanism within Iceland.

ORAL

The surface below ca 900 m altitude in southern Norway was probably buried by late Mesozoic sediments and re-exposed by Neogene uplift and erosion

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[1]Geological Survey of Denmark and Greenland

Analysis of the ASTER DEM over southern Norway confirms that the landscape of southern Norway above an altitude of about 900 m consists of 3 sub-horizontal surfaces separated by steeper slopes and incised by deep glacial valleys (Lidmar-Bergstöm et al., 2000). The surface of the Pre-Cambrian basement rocks below 900 m in southwest and south Norway consists of a uniform rough slope dipping to sea-level or to the strandflat, also incised by deep glacial valleys. Field work shows that the landforms below 900 m asl and between the deep glacial erosion consist of "hilly relief" and "joint valleys" as interpreted onshore in southern Sweden where they were buried below Late Cretaceous limestone (Lidmar-Bergstöm, 1994). Similar structures observed on seismic sections offshore western Norway and south-west Sweden have been buried by Late Jurassic and Cretaceous rocks respectively. Hilly relief and joint valleys formed during warm wet climates during the Late Mesozoic by weathering of feldspars in fractures to produce kaolin. Subsequent erosion of the kaolin produces joint valleys where the fractures are aligned and hilly relief where there are intersecting sets of fractures. Burial and later erosion are required to preserve these landscapes. Norway south of Hardangervidda must therefore have been buried below Mesozoic sediments that have subsequently been removed. No kaolinitic weathering of the Pre-Cambrian rocks of Hardangervidda took place because they were covered during the Mesozoic by Caledonian metamorphic rocks.

ORAL

Burial and exhumation history of the Upper Jurassic sediments on Andøya, northern Norway based on AFTA and VR data

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[1]GEUS, [2]Geotrack International, [3]Geovisiona

Outliers of Middle–Upper Jurassic sediments occur onshore and in the coastal zone of Norway near Bergen, Trondheim and in the Lofoten archipelago (Bøe et al. 2010). But only on the island of Andøya (Lofoten) do they crop out; here a coal-bearing Jurassic–Cretaceous succession of 900 m occurs in a small, partly fault-bounded area on the eastern part of the island. We have measured vitrinite reflectance (VR) on samples from Norminoil well B (courtesy of the Norwegian Petroleum Directorate) that penetrated the entire Jurassic sequence on Andøya (Petersen et al. 2013); the mean VR value is 0.48% for 6 samples from depths between 218 and 520 m. This value corresponds to a palaeotemperature of 78°C, and for any reasonable palaeogeothermal gradient this implies that a km-thick cover of Jurassic and younger sediments must have covered the Jurassic–Cretaceous sediments exposed on Andøya; e.g. around 2 km for 25°C/km and a palaeo-surface temperature of 20°C. New apatite fission-track analysis (AFTA) data from samples of Jurassic sediments and basement from the Lofoten region provide results that are consistent with the interpretation of the VR and provide information about when cooling (exhumation) from maximum palaeotemperatures (burial)

began. Our results thus suggest that thermal subsidence following rift climax in the late Middle Jurassic (Hansen et al. 2012) led to burial of Lofoten and the adjacent region by a thickness of sedimentary cover equivalent to the altitude of the highest peaks in the present-day landscape.

ORAL

Neotectonics in Norway

Odleiv Olesen[1], John Dehls[1], Sofie Gradmann[1], Yuriy Maystrenko[1], Lars Olsen[1], Conrad Lindholm[2], Ilma Janutyte[2], Halfdan Kierulf[3], Jan Michalek[4], Lars Ottemöller[4], Dag Ottesen[1], Lei Rise[1], Maria Ask[5], Tom Rune Lauknes[6] and Fridtjof Riis[7]

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We summarize results of the 2013-2017 NEONOR2 project (Neotectonics in Nordland – implications for petroleum exploration) and compare it to previous research projects (e.g. NEONOR project 1997-2000) and other recent relevant discoveries. The NEONOR2 project is a collaboration project between NGU, Kartverket, NORSAR, Norut, NPD and the universities in Bergen and Luleå. The project is sponsored by the Norwegian Research Council and ten petroleum companies. The project investigates neotectonic phenomena onshore and offshore through a multidisciplinary approach including geological, seismological and geodetic studies combined with rock mechanics, applied geophysics and numerical modeling.

Within this project, a 26 seismograph network monitored the seismicity within a 2.5 year period. More than 1000 earthquakes were registered and 123 focal mechanisms have been derived. An updated compilation of all geodetic stations in Norway and Fennoscandia were analyzed for regional and local present-day strain patterns. Numerical modelling of the present-day stress field evaluated the effect of ridge push, sediment loading/unloading, glacial isostasy and topography. The effect of the Pleistocene sediment redistribution on the subsurface temperature has also been modelled. The occurrence of earthquake swarms is to some degree correlating with high mountains located along the wide Nordland strandflat.

Two presumably postglacial faults (Stuoragurra F. and Nordmannvikdalen F.) have been subject to more detailed studies such as trenching, ground penetrating radar and resistivity profiling. The Stuoragurra F. in Finnmark and the Grønna F. in Nordland are seismically active faults in Norway. These results are entering an updated neotectonic map of Norway.

4.5. Open Session: Structural Geology and Tectonic

ORAL

Coupling of the ductile and brittle structures of the bedrock in Hyvinkää, Southern Finland

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There is a general difficulty in understanding the attitudes of the inherently discontinuous fractures of the bedrock in contrast to the continuous ductile structures. This study aims at linking the ductile and brittle features and, consequently, getting a better control over the fracture occurrence and orientation within the poorly-exposed bedrock. This study relates to studying the relationship between the bedrock and the overlying glacifluvial aquifers of the First Salpausselkä formation in Hyvinkää, Southern Finland. The results provide input data for the ongoing implicit modelling, and bedrock DEM interpolation development in the future. Based on existing geological and geophysical data, and new mapping observations, three principal, structurally homogeneous domains were defined. Brittle and ductile data from two of the domains correlate with the E-W main branches and NE-SW splays of the regional-scale shear zone, whereas fracturing within the third domain is more irregular, controlled dominantly by a regional scale, upright fold and secondarily by N-S structural trends. On individual outcrops, mutually parallel fractures were assigned into fracture sets. The sets were then correlated with the regionally dominant fracture and foliation orientations, and reassigned into representative sets within the respective structural domains. Fracturing is dominantly of cubic type with the main fracture set (R1) orientation strongly controlled by the foliation. The second most abundant set (R2) tends to be approximately at a right angle to R1 and the third group (R3) consists of horizontal to sub-horizontal fractures. Deviations from this pattern are attributed to fracturing caused by non-coaxial deformation along shear zones.

ORAL

Sand tectonics - sand mobility linked to faulting and the influence on depositional systems

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Mobility of sand by fluidisation, so-called sand tectonics, can drive surface movements and implicity have a significant impact on sediment distribution and sand body geometries. Although similarities between sand- and salt tectonic-related structures exist, substantial differences in deformation style and geometries occur. We adress the understanding of sand tectonic processes. Three outcrops in the Upper Jurassic Entrada Sandstone and Curtis Formation in Utah (USA) have been used to characterise the structural and sedimentary response to the underlying mobilisation of sand. Key observations are assembled from mapping of sag-upwarp and fault geometries, as well as from logging and description of growth succession. The latter deposits attest to channelised sub- to inter-tidal depositional environments. Data show that mild sand mobilisation results in meter-scale gentle sag and upwarps (sand pillows). Increased sand mobility leads to progressively higher and steeper relief between upwarps and sags, which links to nucleation of faults and thereby development of small fault-bound grabens. During fault activity, growth sequences attest to repeated fault movement events, demonstrating the strong structural control on the basin fill. After graben formation, many of the faults in higher positions of the grabens are truncated and removed by erosion. Subsequent lenticular-shaped basin fill reflects a wider channelized depositional body than that of the grabens. However, the grabens seem important in locating

these channels. The result from our analysis may provide important input applicable to both CO_2 storage operations and the petroleum industry.

ORAL

Brittle fault systems of deep geological nuclear waste repository at Olkiluoto, SW Finland

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Olkiluoto Island has been selected as the site for deep geological repository for high-level nuclear waste. This study aims to improve the characterisation of the brittle structures intersecting the repository. The objective is to gain a better understanding of the structural evolution of the site, with the ultimate goal of enhancing the understanding of the reactivation potential of different fault systems and associated seismic hazard.

The structural complex of Olkiluoto is composed of ductile and brittle structural systems, which both have a long and complex history. The ductile systems comprise ductile structures, formed during several different phases of Paleoproterozoic ductile deformation. The ductile deformation has affected the bedrock properties, resulting in prominent anisotropy and manifested by ductile structures such as foliation, folding and ductile shear zones, which all form planes of weakness in the bedrock. These type of structures have also played an important role in the localisation and development, of the brittle structures in Olkiluoto. The brittle structural system is composed of brittle structures such as joints, veins, single plane faults and fault zones. The faults were in this study classified into fault systems, with each system being composed of fault zones with similar tectonic history and structural properties. The classification can be employed in the assessment of the reactivation potential of the faults at the site, as the faults in each fault system are considered to have similar properties and thus, a similar chance for reactivation in either current or future stress states.

ORAL

Target-rock weakening mechanisms during peak-ring formation of the Chicxulub impact crater inferred from IODP-ICDP Expedition 364

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The floors of large impact craters are largely flat and contain one or more morphological rings. The formation of the innermost ring, the so-called peak ring, and the causes of target rock weakening leading to the observed flat crater floors are not well understood. Constraining these mechanisms is the prime structural geological objective of Expedition 364 “Drilling the K-Pg Impact Crater”, using the Chicxulub crater, Mexico, as a terrestrial analogue for the formation of planetary impact basins. The target rocks of the crater are replete with cratering-induced, microscopic to mesoscopic deformation structures including: (1) pervasive grain-scale fractures, (2) centimeter-thick cataclasite zones, (3) striated shear faults, (4) crenulated mineral foliations, and (5) ductile band structures. Structural overprinting criteria point to a relative age for these structures. Specifically, cataclasite zones cut grain-scale fractures displaying jigsaw geometry and are consistently displaced by shear faults. Impact melt was emplaced in zones of dilation, often localized by shear faults. These observations indicate that pervasive fragmentation was respectively followed by localized cataclastic deformation, shear faulting, and emplacement of melt into dilation zones. This

succession of deformation mechanisms is corroborated by the observation that melt bodies are devoid of shear faults. As melt bodies were viscous during formation of ductile band structures, these structures formed after the shear faults. Based on the overprinting relationships, we relate the deformation structures to cratering stages known from impact mechanics.

POSTER

3D model of the lithotectonic units and regional deformation zones in the bedrock of Sweden

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A three-dimensional model has been created representing the lithotectonic units and their bounding regional deformation zones in the bedrock of Sweden. The model, including a brief description and basis for modelling of each modelled deformation zone and lithotectonic unit, is a development of the existing lithotectonic subdivision included in the bedrock map of Sweden at the scale 1:1 million (Bergman et al. 2012). The aim is to visualize the interpretation of the overall geometrical relationships between the various lithotectonic units on a national scale and provide a basic framework and background for more detailed regional and local scale models. The aim is to link the model to general geological descriptive texts aimed at schools and other interested parties as well as scientific presentations.

POSTER

East Greenland 72-74° N Inland to Coast Thermo-tectonic Evolution

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Fission track analysis of eight samples from East Greenland yields information of the exhumation history. Modelling the thermal evolution of the samples indicates that essential elements of the recent landscape were established before 250 Ma. Thus, altitude variations of 2-3 km at that time are like present values. From before 350 Ma to before 200 Ma, starting form SW, deep valleys were incised into a plateau being more than 3 km above the present landscape. After about 200 Ma the exhumation rate of the overall area was moderated, however with an increase especially in the valleys after 50 Ma.

Our interpretation is based on a simulation of temperature history through time intervals derived from the track length distribution. We use signal analysis theory to enhance the resolution of the time-temperature information of the fission tracks. Statistical noise and biases such as track annealing anisotropy are taken care of. We calculate the thermal history backwards in time and analyse the results as erosion/burial depths, which leads to our interpretation of the gradual inland erosion.

All measurements are performed in transmitted light on prismatic faces, however, horizontal track lengths are measured without angle to the c-axis.

POSTER

Modelling the fracture characteristics of crystalline bedrock for the purposes of bedrock surface interpolations

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The purpose of the study is to characterize the bedrock fracturing and its spatial variability which may be subsequently used in interpolating the digital elevation models (DEMs) of the glacially eroded bedrock surface. The work focusses at testing and developing the implicit modelling approach and tools, validating the results by using explicit models and compared to fracture networks defined with the Discrete Fracture Network modelling tool (DFN). The used implicit modelling approach, by contrast to the conventional explicit approach, allows generation of more objective, time-efficient and repeatable 3D-models.

This study is conducted in the Hyvinkää area, southern Finland, under an umbrella of a broader Salpausselkä project investigating the relationship between the bedrock structures and the overlying glacifluvial aquifers. The principal input data of this study are fractures, correlated with foliation data and regrouped into sets as determined within a parallel ongoing study.

As a central tool, a new functionality "Local Anisotropy Interpolator" of SURFE plug-in for GOCAD has been developed. With this tool, we are able to generate a grid with an interpolated fracture plane at each grid cell displaying the local variations within the anisotropy of the bedrock across the study area. The resulting anisotropy will provide improved control over the fracture orientations, and the results of the DFN models will provide constraints on the fracture densities. These together may be used to evaluate the existing DEMs of unexposed bedrock surfaces based on sparse data, and as input data in future development of the DEM interpolation tools.

POSTER

Mechanical separation of crust from slabs subducted below the transition zone

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As oceanic crust subducts into the mantle, it eclogitizes and becomes negatively buoyant relative to the peridotitic upper mantle. However, experimental studies indicate that, at depths between 660 km to 800 km, below the mantle transition zone, MORB compositions are positively buoyant at certain conditions. This has raised the possibility that oceanic crust can become mechanically separated during subduction below the 660 km discontinuity. Several conceptual and simple physical models have been proposed for such crustal segregation. Here we present a 2D thermomechanical model that employs recent experimental constraints that indicate that majoritic garnet is relatively weak at transition zone conditions. We show that channel-like upward flow within oceanic crust can occur in the density-inversion window between 650 and 750 km depth. Depending on geometric and thermal boundary conditions, this flow is sufficient to cause runaway instabilities, episodic mechanical separation of crust from the downgoing slab and thus the formation of stable crustal patches at the lower-upper mantle boundary. Our results have far-reaching implications for our understanding of the compositional stratification of the mantle, its convective circulation and the seismic velocity structure near the mantle transition zone.

5. Mineralogy

5.1. Mineralogy and its applications

ORAL

Occurrence of indium with late-stage intrusions in the Kymi granite stock, Southern Finland

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The Kymi granite stock contains hydrothermal greisen and quartz vein type F––Sn and Zn–– Pb––Cu sulphide mineralization. These intrusions are enriched in indium and rare earth elements, roquesite (CuInS2) being a major indium-carrier. The accessory minerals are fluorite, zircon, apatite, cassiterite and different sulphides, such as sphalerite, chalcopyrite and galena. The indium and REE-bearing mineral assemblages were studied by a combination of optical and field emission scanning electron microscopy (FE-SEM) and electron probe micro-analyzer (EPMA) techniques. Roquesite occurs as microscopic grains (10–40 micron) in galena. EPMA analyses of these grains yield an average composition of 26.16% S, 0.02% Fe, 25.06% Cu, 0.03% Zn, 1.06% As, 0.31% Sb and 47.14% In. Indium incorporation into the galena structure probably occurred according to the relation $Pb^{2+}S^{2-} \leftrightarrow Cu^{+}In^{3+}S^{2-}$, whereas zinc present in the galena was probably replaced by indium. Therefore coupled substitution $2(Pb^{2+}\ Zn^{+}) = Cu^{+}In^{3+}$ may also have occurred.

ORAL

The fumarolic minerals of the Fimmvörduhals 2010 eruption

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The eruption at Fimmvörduhals, Iceland, lasted from March to April 2010 followed by the well-known Eyjafjallajökul explosion. It formed two craters, Magni and Móði and expelled a substantial amount of volcanic gasses.

The samples of fumarolic minerals were collected in three campaigns in 2010, followed by two in subsequent years. The locality temperatures ranged from around 50 to almost 800°C.

The mineral parageneses can be divided in five main types:

1) Aluminofluorides and silicofluorides of Na, Mg and Ca, including two recently described new minerals characteristic for Icelandic fumaroles, plus two new minerals under investigation. They are characteristic for sites with lower formation temperature (<200°C) found south from craters, outer rim of Magni and north from Móði crater.

2) Halite-dominated associations. They include both low-temperature associations (<100°C) with hydrous sulfates found south of craters, and occurrences at high-temperature fumaroles (>500°C) in the northern part of Magni crater.

3) Anhydrous and hydrous sulfates characteristic for low to medium-temperature fumaroles (<300°C) occurring south of craters and on Móði. They are represented by various Na-K-Mg-Ca-Al phases, two of them new species.

4) High-temperature Na-K sulfates found at temperatures >600°C on the rim of the Magni crater and in one crevice south from crater.

5) Other high-temperature Na, K, Mg and Ca sulfates forming at similar temperature conditions as 4) and also found on the rim of Magni crater.

Exceptional for Fimmvörduhals fumaroles is that the high-temperature sites contain acidic K and Na hydrogen sulfates mercalite ($KHSO_4$) and a new mineral with composition $Na_3H(SO_4)_2$.

ORAL

Element mobility and new paragenses of the Ivigtut cryolite deposit, South Greenland

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The Ivittuut, formerly Ivigtut, cryolite deposit has been known since the late 18th century as a source of unique minerals in particular fluorides of which cryolite was mined for almost 100 years. The majority of scientific publications about Ivittuut have focused on the formation of the deposits, the fluorides or the sulphides. However, little is known about the alteration mineralogy and consequently element mobility in this unique fluorine-rich environment.

A fieldtrip to Ivittuut in the summer 2016 specifically targeted various paragenesis showing signs of alteration. Consequently, we have discovered 11 minerals new for Ivittuut including a series of alteration stages of primary sulphides and the first Rare Earth Element (REE) paragenesis.

Galena is one of the main sulphide minerals and to date only cerussite ($PbCO_3$) and wulfenite ($PbMoO_4$) are known secondary Pb-minerals at ivigtut. However, new types of galena alteration have been observed consisting of Pb-chlorides and carbonates (cotunnite, $PbCl_2$, and phosgenite, $Pb_2CO_3Cl_2$) and sulphates (anglesite, $PbSO_4$, and linarite, $PbCu(SO_4)(OH)_2$) and at places native sulphur. The source of chlorine is likely to be the Arsuk fjord, bordering the deposit. The presence of S in three oxidations states reveals a progressive oxidation event at places, but also subtle variations in secondary mineralogy within the same sample. A similar oxidation situation has been observed for S and As in arsenopyrite (FeAsS), which is being replaced by kaňkite ($FeAsO_4 \cdot 3.5H_2O$) and native sulphur.

ORAL

Nanoscale observations of 'invisible gold' from the Olympias mine, Greece

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In some gold deposits, gold exists as invisible form in pyrite or arsenopyrite. Such gold is not recovered readily from ore materials. The identification of the gold form and distribution may provide some insight into the recovery of gold. Here, we use electron microscopy, NanoSIMS and high energy resolution fluorescence detection X-ray absorption spectroscopy (HERFD-XAS) to investigate 'invisible gold' from the Olympias Au-Ag-Pb-Zn polymetallic carbonate replacement deposit, northern Greece.

Bulk analyses show that given ore samples contain gold up to ~30 ppmw and gold has positive relationships with arsenopyrite and probably As-containing pyrite. The arsenopyrite and pyrite make up 15% and 19% of the samples, respectively. Assuming that all the gold is accumulated in arsenopyrite, each arsenopyrite grain would contain ~200 ppmw. NanoSIMS

suggests that gold is present primarily in arsenopyrite and is distributed with large variations along the growth direction. Pyrite also contains some gold but the concentration is even lower than that in arsenopyrite. TEM was used to examine the near-surface of arsenopyrite, where gold is usually concentrated. However, no gold precipitates were observed, which might suggest that gold is present in the form of ions in either the crystal lattice or interstitial position. This result is also supported from the HERFD-XAS study, in which gold is likely present as a higher oxidation state (e.g., Au^{3+}) occurring as a chemically bound form in the structure. Thus, gold may have been incorporated into arsenopyrite and pyrite during relatively rapid growth of them.

ORAL

Plasticite, (Plas-TI-Kite) an ore mineralization from the late Anthropocine

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The Late Anthropocine has caused a noticeable shift in the ability for new minerals to form via human mechanisms. One such mineral, plasticite, is a relatively abundant mineral at Earth's surface deriving from plastic. The general chemical formula for plasticite and all plasticite like minerals (with a plastic provinance) are

(Contact author for better formatting)

\centerline{$(C_{2}H_{4})_{n}\pm(F^{-},Cl^{-},Br^{-},I^{-})\pm(Pb,Sn)$}

The discussions in the last chapter details a proposal for mineralis, a new mineral category taking into account the prospect of anthropogenic minerals having a class of their own to accommodate for the potentials of the rapidly increasing carbon mineral category.

(note: this can also be considered under the "Other category" but I won't double submit until the committee allows me, I can also explain the concept in more detail, I am working with Dr. Eero Hanski of Oulu University and Dr. Richard Wunderman, former Smithsonian institution, on the concept. This serves as a discussion for the anthropocine's impact on geology of the future.)

POSTER

Prediction of swelling potential using the Atterberg limits

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Expansive soils are known to cause numerous problems on surface and underground constructions. In the oil and gas industry, they may cause operational problems during drilling and completion, workover, production, and stimulation procedures. The use of water-based mud during drilling operations can cause clay swelling and consequently wellbore instabilities that, in extreme cases, could lead to complete well abandonment. Moreover, swelling clays can affect the quality of the reservoir and lead to problems during the conventional hydrocarbon production, or Enhanced Oil Recovery (EOR). Therefore, to avoid serious complications and excessive operational costs in the case of hydrocarbon operations, it is of high importance to fully understand the behaviour of swelling clay and quantify the volume change, linking it to the mineralogy.

Throughout the years, several researchers studied the correlation between the Atterberg limits and the swelling potential or swelling pressure of soils providing numerous empirical correlations. During this study, data acquired from 12 different publications were examined to determine whether there is a correlation between the Plasticity Index (PI) and the Swelling potential (SP) for varying samples and methodologies. A linear correlation between the SI and PI was found, with a coefficient of determination (R2) = 0.731, which is rather satisfactory given the different methodologies and soil conditions used. The influence of the

mineralogy was assessed using the Casagrande chart and it was found that the montmorillonitic samples resulted in a significantly higher coefficient of determination.

POSTER

A new single-crystal XRD for mineral sciences in Scandinavia

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The natural history museum in Oslo has purchased a state of the art single-crystal XRD, which is dedicated to mineral sciences. The instrument is a Rigaku Synergy-S dual-beam instrument equipped with Mo and Cu μ-sources and a HyPix-6000HE hybrid photon counting area detector. The instrument comes with various options for Gandolfi movement making it ideal for mineral identification of minute grains and aggregates as well as powders. The Gandolfi data can be exported in various file-formats making it importable into a range of other software used for traditional powder XRD search and match functions.

The high-intensity μ-sources combined with the fast detector read-out time makes it possible to collect data rapidly. The Cu-source is more intense than the Mo-source, which is particularly beneficial for data collection of low absorbent materials and the Gandolfi methodology. The software controlling the instrument (CrysAlis Pro) is combined with on-site license of AutoChem, which makes it possible to solve structures while data is collecting. This function combined with the high-intensity sources and fast detector enables rapid screening of crystals to identify the best suitable for full data collection. The software handles up to eight twins or intergrowth domains for full structure determination. The software for data reduction and face indexing can be downloaded for free and consequently all data processing can be carried out off-site.

The instrument should be installed in spring 2018 and we invite users from the mineralogy community in Scandinavia to come to Oslo for their single-crystal diffraction work.

6. Paleaontology

6.1. Paleozoic and Mesozoic stratigraphy, paleoceanography and paleoclimate

ORAL

At the boundary between the middle Albian hoplitinid and gastroplitinid ammonite provinces: linking the Arctic with northwest Europe with ammonites in North Greenland .

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The Albian is characterized by pronounced provincialism, and within the Boreal Realm endemic faunas form defines separate faunal provinces with only limited faunal communication. Palaeobiogeographic subdivision of the Albian in the Boreal Realm includes a Boreal-Atlantic Subrealm, an Arctic Subrealm and a Boreal Pacific Subrealm (Lehmann et al 2015). During the middle Albian the Boreal-Atlantic is characterized by hoplitinids and corresponds to the European or hoplitinid province of Owen (1979, 1996, 2007). Hoplitinids were dispersed widely in the European shelf seas but also towards the north, where impoverished faunas are recorded in Greenland and Svalbard. The ammonite zonation based on the hoplitinids form a standard for the European Province. In the neighbouring Arctic or gastroplitinid province to the north hoplitinids are totally absent and the issue of accurately dating the gastroplitinids of the Arctic from correlation to the hoplitinid zonation has been a long-lasting problem and commonly discussed in the literature. North-East Greenland (Donovan 1957) and Svalbard (Yershova 1983; Nagy 1970), where faunas are reported to overlap, have, however, no localities were hoplitinids and gastroplitinids are found together in assemblages, or at precisely defined levels within a faunal succession. Recently, an ammonite-rich horizon was discovered in an otherwise rather unfossiliferous Albian succession in Kilen, North Greenland. It contains an assemblage with both gastroplitinid representatives of the Arctic Province and hoplitinid representatives of the European Province. The ammonites thus represent a rare and unique occurrence record of a mixed hoplitinid-gastroplitinid assemblage.

ORAL

The secret wonders of the middle Danian

Bodil Wesenberg Lauridsen[1], Kasper Blinkenberg[1], Trine Edvardsen[1] and Lars Stemmerik[1]
[1]Natural History Museum, Denmark

The Danian is named after and known for the imposing bryozoan mounds of Stevns Klint and the cold-water coral mounds of Faxe. Less attention has been on the middle Danian chalk localities in the northwestern part of the Danish Basin. Here the chalk is soft, with a low diversity benthic fauna and a relatively high degree of unevenly distributed flint. The fauna composed mostly of irregular echinoids, bryozoans and crinoids. However, a detailed look into the Danian chalk in Dalbyover, northern Jutland, reveals a much more vivid ecosystem. Echinoids (both regular and irregular), bryozoans, brachiopods, bivalves, serpulids, sponges, asterozoans and crinoids were thriving in this relatively deep and nutrient poor setting. The species all show special adaptations to survival in the environment and many are Mesozoic survivors from the Late Cretaceous chalk sea. One of the dominating species, the irregular echinoid Echinocorys sulcatus appears to be crucial for the ecosystem and is a true wonder of the middle Danian.

ORAL

Triassic biostratigraphy (ammonoids and palynology) and organic $\delta^{13}C$-isotope record of the Wandel Sea Basin, North Greenland

Sofie Lindström[1], Peter Alsen[1], Morten Bjerager[1] and Jussi Hovikoski[1]
[1]GEUS

The presence of Triassic sedimentary rocks in North Greenland was first reported from the Danish Peary Land Expedition 1948-49 by Troelsen (1950). The first descriptions of Triassic fossils, mainly ammonoids, were made by Kummel (1953), and later by Peel et al. (1974). During the Triassic the Wandel Sea Basin (WSB) constituted a continuation of basins in the southern part of the Barents Sea to the east, and of the Danmarkshavn Basin offshore Northeast Greenland to the south. The Triassic succession of the WSB was deposited unconformably on Upper Permian sediments and succeeded by Upper Jurassic – Lower Cretaceous deposits (Håkansson et al. 1991). During recent field campaigns (2012–2013) several outcrop sections and a cored drilling were sampled for palynology, macrofossils, and organic $\delta^{13}C$-isotope analysis. The integrated ammonoid faunas and spore-pollen biostratigraphy shows that the exposed Triassic succession of the WSB encompasses a near complete Induan (Dienerian) – Norian succession. The ammonoid faunas are correlated with the established zonation for Arctic Canada (Tozer, 1994), and spore-pollen assemblages correlate well with those of Svalbard and the Barents Sea (Vigran et al. 2014). An especially detailed organic $\delta^{13}C$-isotope record is registered for the Smithian–Spathian interval, which can be correlated with previously reported records globally (e.g. Galfetti et al., 2007, Grasby et al., 2013).

ORAL

Biostratigraphic correlation of the Cretaceous to Neogene succession of the western and eastern margins of the Labrador – Baffin Seaway.

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New analyses of the palynological assemblages in 13 offshore wells on the Canadian margin and six on the West Greenland Margin, in conjunction with onshore data, have led to a new biostratigraphic framework for the Cretaceous–Cenozoic strata of the Labrador Sea – Davis Strait – Baffin Bay (Labrador–Baffin Seaway) region and the first broad biostratigraphic correlation of the Canadian and Greenland margins. This framework is based on 167 last occurrences and 18 local or regional, peak- or common-occurrence events for dinocysts (which include three new genera and 16 new species), acritarchs (including one new species), miospores (including one new species), fungal spores and massulae of the fresh-water fern Azolla. Our findings delineate several local and regional hiatuses on both sides of the seaway. The palynomorph assemblages show that most Aptian to Albian sediments were deposited in generally non-marine to marginal marine settings, interrupted by a short-lived shallow-marine episode in the Aptian. A marine transgression commenced in the Cenomanian–Turonian and led to the most open-marine, oceanic conditions in the Campanian–Lutetian. Subsequent shallowing probably began in the late Lutetian and continued into the Rupelian, when inner neritic and marginal marine palaeoenvironments predominated. Throughout the rest of the Cenozoic, inner neritic palaeoenvironments alternated with marginal marine conditions on the margins of the Labrador–Baffin Seaway. Our findings broadly

reflect the tectonic evolution of the seaway, with rift conditions prevailing from Aptian to Danian times, followed by drift through much of the Paleocene and Eocene, and post-drift from Oligocene to the present.

ORAL

Biodiversity, climate and time – resolving the scale, tempo and drivers behind the Great Ordovician Biodiversification Event

Christian M. Ø. Rasmussen[1]
[1]*Natural History Museum of Denmark*

The early Palaeozoic witnessed two significant pulses in biodiversity increase and a catastrophic mass extinction. All are fundamental events and notably the two radiations had a lasting impact on Phanerozoic ecosystems. The early Palaeozoic has traditionally been considered a super-greenhouse period. This interpretation was primarily based on two lines of evidence: modelling scenarios suggesting CO_2 levels 15–20 times PAL, and a general perception of warmer climate due to what was likely a Phanerozoic sea level maximum during the early Late Ordovician. The interpretation of early Palaeozoic climate, however, is currently undergoing a paradigm shift. Increasing evidence is suggesting a cooler climate throughout most of the Ordovician Period, and the short-lived icehouse conditions traditionally linked to the end Ordovician mass extinctions now appear to continue well into the Silurian. In the midst of this paradigm shift lies the Great Ordovician Biodiversification Event (GOBE) – the greatest marine speciation event of the entire Phanerozoic. Thus, this event now seems to have been unfolding against a background of cooler climate instead of a super-greenhouse, but the exact onset of the GOBE is obscured by contradicting biodiversity estimates. The current talk presents ongoing efforts to unravel the speed and causes of the GOBE by combining three approaches: 1) the construction of a new, high-resolution biodiversity estimate for the early Palaeozoic, 2) an astronomically calibrated timescale through the GOBE, and 3) new abiotic climate proxies based on brachiopod ^{18}O data. Together, these three lines of evidence provides a highly interesting novel perspective on the event.

ORAL

Stratigraphic context and environmental changes in the Tuxen and Sola Formations (Barremian-Early Aptian, North Sea): new results from high-resolution carbon and oxygen stable isotopes, major and trace elements, sedimentology and calcareous nannofossils

Nicolas Thibault[1], *Kresten Anderskouv*[1], *Emma Sheldon*[2], *Jon Ineson*[2], *Anastasios Perdiou*[1] *and Mohammad J. Razmjooei*[1]
[1]*IGN, University of Copenhagen,* [2]*GEUS*

The Barremian to lower Aptian Tuxen and Sola Formations have been investigated in the North Jens-1 well (Danish Central Graben, North Sea) for environmental changes based on a revised calcareous nannofossil biostratigraphy, geochemical analysis of 316 samples (stable isotopes, hand-held XRF element analysis) and quantitative nannofossil abundance counts of 75 samples. Our results delineate the well-established Barremian rise in carbon isotopes as well as the typical excursions across the early Aptian Oceanic Anoxic Event (OAE) 1a characterized by two short and prominent negative excursions right below and at the base of the Fischschiefer laminated black shale horizon, followed by the long-lasting positive carbon isotope excursion of the lower to upper Aptian. Our new results also show significant cyclic changes in the Barremian carbon cycle with a number of new possible negative and positive excursions that could be defined and used for refinement of the stratigraphy of this stage. Oxygen isotopes and calcareous nannofossil assemblages highlight the coupling of significantly warm episodes associated to eutrophic conditions during deposition of the lower Barremian Munk marl and early Aptian

Fischschiefer laminated horizons whereas a significant cooling associated to oligotrophy triggered the deposition of nannoconid chalk in the upper Barremian. Major and trace elements suggest rather similar environmental contexts in bottom-waters for the deposition of the Munk marl and Fischschiefer and advocate for these levels but we denote a conflicting sequence stratigraphic context for the Munk Marl in the North Sea and the equivalent Hauptblätterton in the Lower Saxony Basin of North Germany.

ORAL

The Ordovician conodonts of the west Sørkapp Land (Southern Spitsbergen)

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[1]A.P. Karpinsky Russian Geological Research Institute, [2]Polar Marine Geosurvey Expedition

The Ordovician in the Sørkapp Land is known since the 50-ies, yet it is relatively poorly examined and its faunas are studied insufficiently. The western Sørkapp Land part between the Olsokbreen and Bungebreen was surveyed in 2013. Here the Ordovician (Sørkapp Land Gr - Hornsundtind and Nigerbreen Fms) and presumably Ordovician-Silurian (Arkfjellet Fm) have been found to form an NE-striking tectonostratigraphic antiform. The section is dominated by various limestones that range in color from almost black to light; layers of chert-bearing limestone also present. The antiform's SE limb contains two psammitic layers as well as layers of schists and conglomerate. The Early Paleozoic rocks are unconformably overlain by the Devonian red sandstones and/or Triassic.

Conodonts imply that the Hornsundtind and Nigerbreen Fms embrace the Floian to the Middle Darriwilian stratigraphic interval. The lower Floian part of the section yelded Wandelia guyi Smith, Paroistodus proteus Lindstrom, Colaptoconus quadraplicatus (Branson et Mehl), Oepikodus sp., Parapanderodus striatus (Graves et Ellison). The conodont assemblages are dominated by Wandelia guyi typical for the East and North Greenland. The Early Darriwilian is confirmed by Multioistodus sp., Drepanoistodus sp., Periodon sp. The youngest Middle-Upper Darriwilian ages of the section are based on findings of Belodina sp., Periodon sp., Panderodus sp., Drepanodus sp., Protopanderodus sp. The conodonts have Laurentian biogeographic affinity, supporting conclusions based on conodonts from Hornsund and Ny Friesland.

POSTER

The Silurian Lau event – testing plant weathering as driver for ocean anoxia and animal extinction

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The Silurian period witnessed several climatic events expressed as large positive carbon isotopic excursions in the carbonate rock record. One of these – the Ludfordian Lau event – is the greatest isotopic excursion in the Phanerozoic ($\delta^{13}C$ increases by ~9‰). Marine carbonates exposed on Gotland (Sweden) preserve this record. Here, we present new isotope data obtained from bulk carbonate rocks using Cavity Ring-Down Spectroscopy. Several extinction events are observed in conjunction with the isotope excursions. During the Lau event, marine animals from the pelagic zone to the benthos were affected in less than 200 kyr. We hypothesize that the Lau event reflects an organic carbon burial episode driven by the colonization of vascular plants on land. At this time, the first rooted plants appeared in the fossil record. They could have intensified weathering rates and sourced more of the biolimiting nutrient, phosphorus, into the oceans. This increased marine primary productivity and ultimately organic carbon burial – now recorded in higher $\delta^{13}C$ values in carbonate sediments. We test this relationship using uranium isotopes in the same samples to constrain the oxygenation state of the Silurian oceans. Uranium's long oceanic residence time (~400 kyr) and the preferential

incorporation of ^{238}U relative to ^{235}U into anoxic sediments makes $\delta^{238}U$ a powerful proxy for global marine anoxic sediment burial.

POSTER

Chemostratigraphy across the Toarcian Oceanic Anoxic Event in the Aubach section of SW Germany

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Early Jurassic strata, covering the Toarcian Oceanic Anoxic Event (T-OAE), are exposed in the Aubach section, Wutach area, SW Germany. The T-OAE is characterized by significant organic matter burial, numerous geochemical anomalies and one of the most significant negative carbon isotope excursions (CIE) in the Mesozoic (Jenkyns and Clayton, 1997; Küspert, 1982; Röhl et al., 2001). In the present study, we generated new organic and inorganic carbon isotope values as well as element concentrations (Mn, V, Mo), common organic geochemical data and biomarkers of bulk rock samples. The results are currently utilized to determine fluctuation in the carbon cycle, to evaluate bottom water redox conditions during sediment deposition, and to determine variation in the source of organic matter.

The first results show the well-known negative organic carbon isotope excursion from the semicelatum to exaratum Subzones and the organic geochemical characterization allow the preliminary interpretation that the organic matter source changed to a more marine source during the T-OAE. Fluctuation in the anoxia proxies Mo and V are asynchronous suggesting that the restricted conditions occurred in a larger basin and the reduced conditions prevailed throughout most of the falciferum Zone. Sea-level proxies (Rb/Zr, Zr/Al, Si/Al) suggest a sea level rise synchronous with the change to a more marine source of organic matter and the onset of the T-OAE.

POSTER

Seawater temperature change across the Pliensbachian–Toarcian transition – new isotope data from the Aubach section in SW Germany

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In the Wutach area of SW Germany, biostratigraphically well-defined Late Sinemurian to earliest Aalenian siliciclastic and carbonate sediments are exposed along the Aubach stream (Riegraf, 1980; Riegraf et al., 1984; Schlatter, 1997; Urlichs, 1997). The locality was sampled in high resolution during several field campaigns in the last years, and carbon, oxygen and strontium isotope datasets have been generated from Low-Mg-Calcite fossils (mainly belemnites) which were screened for diagenesis (see Ullmann and Korte, 2015). Known carbon isotope fluctuations for this period (e.g. Korte and Hesselbo, 2011; Peti et al., 2017) are expressed clearly in the Aubach data, including an about 2 ‰ negative excursion across the Sinemurian–Pliensbachian boundary, a positive excursion in the Late Pliensbachian margaritatus Zone, a negative excursion in the spinatum Zone (hawskerense Sz), a negative excursion of across the Pliensbachian–Toarcian boundary and relatively heavy values up to +4 ‰ in the falciferum Zone. The oxygen isotope values show an increase across the Sinemurian–Pliensbachian boundary, reaching heaviest values of ~ +1 ‰ (with periodic fluctuations) in the margaritatus and early spinatum zones (Late Pliensbachian Cool Mode; Korte et al., 2015). The values start to gradually decrease in the higher hawskerense

Subzone (with some heavy values in the semicelatum Subzone), lasting till the earliest Toarcian tenuicostatum Zone. The new data indicate that relatively cool temperatures have existed in the Swabo-Franconian Basin at palaeolatitudes below 40° for most of the Pliensbachian, and that the Toarcian warming may have preceded the negative carbon isotope excursion of the T-OAE.

POSTER

Orbital forcing of organic matter quality and quantity in a source-rock formation: the case of the Vaca Muerta Formation, Tithonian-Valanginian, Neuquén Basin, Argentina

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The Vaca Muerta Formation from the Neuquén Basin is an important petroleum source-rock formation in Argentina. A cyclostratigraphic study was conducted, based on a set of continuous data from four wells. The Total Organic Content (TOC) was measured using the LIPS method to investigate the control of orbital forcing on the variation of organic matter distribution. Moreover, the integration of the Rock Eval 6 Hydrogen Index (HI) and Oxygen Index (OI) were tested to understand the climatic conditions which favoured the deposition and preservation of organic matter.

Cyclic changes are attributed to astronomical forcing. The main driver of the oxygenation of the basin was the obliquity. HI, OI and TOC correlate with the precession and the eccentricity.

We attribute this link to changes in the sea level due to fluctuations in ice coverage during the late Jurassic – early Cretaceous and suggest that, with falling sea level, the connection between the Neuquén basin and the proto-Pacific got shallower, resulting in stratification of the basin with warm fresh water sealing off the deeper basin. With rising sea level, the connection to the ocean deepened and the stratifications weakened. Nutrients were mainly supplied by continental run-off from the south of the basin due to monsoonal activity during winter, which varied with the precessional cycle. Warm, hypersaline waters were synchronously formed in the south-east of the basin during summer. This led to the formation of a hypersaline lens in the deepest part of the basin and thus cutting it off from oxygen supply.

POSTER

The giant Lower Triassic sponge-microbial build-ups from Neotethys

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After the end-Permian mass extinction the upper Paleozoic skeletal carbonate factory was abruptly replaced by a non-skeletal carbonate factory and Permian-Triassic boundary microbialites (PTBMs) were flourishing. These PTBMs were abundant in low-latitude shallow-marine carbonate shelves in central Tethyan continents

and present during at least four events in the Lower Triassic.

The investigated PTBMs from three different sites in southern Armenia were formed in a distal open marine setting on a pelagic carbonate ramp. They grew during two microbial growth phases in Griesbachian times, whereas the microbialites from the first microbial growth phase co-occur with calcium carbonate crystal fans (CCFs). The microbes formed predominantly thrombolites that vary in size between 5 cm to 1.5 m. The biggest thrombolite has a cone-shaped build-up geometry and an asymmetrical growth, which indicates the influence of a steady bottom current. It consists of numerous thrombolite domes with a top head diameter of up to 8 m width and a total height of up to 12 m. The microbialites are surrounded by a bioclastic wackestone that mainly contains ostracods, foraminifers, microgastropods, thin-shelled bivalves.

Carbon isotope studies were performed on both the microbialites and the surrounding sediment. A comparison between the $\delta^{13}C_{sediment}$ and $\delta^{13}C_{microbialite}$ revealed that there is little difference (<0.4‰) between these values in the microbialites that formed during the second microbial growth phase. In contrast, the microbialites and CCFs from the first microbial growth phase show differences in the $\delta^{13}C$ values of up to 2.3‰, which could be due to microbial activity.

6.2. Open session in Palaeontology, palaeoecology and paleoenvironments

ORAL

Pushing research boundaries: Benefits of temperature ramped gas chromatography in EA-IRMS

Christopher Brodie[1], Oliver Kracht, Andreas Hilkert and Søren Dalby
[1]Dr.

The Thermo Scientific™ EA IsoLink™ IRMS System has fundamentally improved analysis by EA-IRMS using temperature ramped gas chromatography with a single GC column and a patented helium management system that reduces cost per analysis. These innovative features open doors to push research boundaries at new levels, especially for the analysis of very small concentrations and on very high C/N and C/S ratio samples.

This presentation will principally focus on the advantages of using temperature ramped gas chromatography. Traditionally, gas chromatography in EA-IRMS employed a GC column held at an isothermal temperature as the gases eluted. However, using temperature ramped gas chromatography in the EA IsoLink IRMS System, a feature common in GC-MS and GC-IRMS, the temperature of the GC column can be quickly changed as analyte gases are eluting, improving peak separation, peak fidelity, analysis of very small sample amounts and precision of replicate measurements.

We will discuss these improvements in peak separation, background determination, troubleshooting of the combustion, pyrolysis and chromatographic processes, blank determination and analysis of very small sample concentrations. Our improved GC technique is illustrated in Figure 1, which shows a chromatogram of a NCS analysis on wood (C/S ratio of 7900:1) from a single sample drop. Complete baseline separation

of each analyte is achieved with sound background correction and peak fidelity, including for very large (7000 µg C) and very small (11 µg N and 1 µg S) analyte amounts. For 5 replicate measurements on wood, $\delta^{13}C$ = -24.10±0.06‰; $\delta^{15}N$ = 3.20±0.23‰ and $\delta^{34}S$ = 5.92±0.26‰.

ORAL

Bryozoan biota as a proxy for the climatic changes in Cenozoic of West Antarctica

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Bryozoans in the marine and glacio-marine Cenozoic sedimentary sequences form a morphologically and taxonomically diversified biota in West Antarctica. During the late Early-late Eocene of the La Meseta Fm. they are dominated by hemispherical, multilamellar cyclostome cerioporines, cheilostome ascophoran lepraliellids and anascan microporoideans with a high number of a new taxa for the science, a great value for the austral biogeographical connections, as well as with considerable evolutionary interest, including the oldest stratigraphical records (Hara, 2001).

Bryozoans occur at least intermittently through the late Miocene-Pliocene glaciomarine Hobbs Glacier Formation of the James Ross Island group (Pirrie et al. 1997; Jonkers, 1998). The late Pliocene assemblage from the shallow-marine pectinid-rich biofacies preserved in the near-shore Pecten Conglomerate (= Cockburn Island Formation) of Cockburn Island in the James Ross Island area (NE Antarctic Peninsula) contains the abundance of the encrusting colonies.

The majority of the late Pliocene cheilostomes are known from the Mid-Late Cretaceous, the others are considered to have originated in the Paleogene (Eocene-Oligocene), evolving in the Antarctic region and becoming widespread through the Neogene to the Recent, along with one well-represented wholly Neogene Microporellidae family.

The distribution of the Recent bryozoans with a dominant ascophoran lepraliomorphs of Schizoporelloidea – the most richly represented superfamily as well as umbonulomorphs illustrate a dynamic evolution of the highly endemic Antarctic fauna. The bryozoan's colonial growth-form could be used as a potential tool in interpretation of the different Cenozoic ecosystems and climatic regimes ranging from greenhouse to icehouse.

ORAL

Elements of Eoarchean life trapped in mineral inclusions

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Metasedimentary rocks from Isua, West Greenland (> 3.7 billion year old) contain ^{13}C depleted carbonaceous compounds, with isotopic ratios consistent with a biogenic origin. Metamorphic garnet crystals in these rocks contain bands of carbonaceous material contiguous with carbon-rich sedimentary beds in the host rock, where carbon is fully graphitized. Here we studied carbonaceous inclusions armoured within garnet porphyroblasts by in-situ Infrared absorption on $\sim 10^{-21}$ m^3 domains within these inclusions. The absorption spectra are consistent with carbon bonding to N and O and likely to phosphate. C-H or O-H bonds could not be detected. These results are consistent with biogenic organic material isolated for billions of years and thermally matured at temperatures around 500 ^{o}C. They therefore provide spatial characterization for potentially the oldest biogenic carbon relics in Earth's geologic record.

ORAL

Sedimentology, stratigraphy and palaeoenvironments of the Miocene primate-bearing sequence in Inner Mongolia, China

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Central Inner Mongolia has been an area of great palaeontological interest since the beginning of the 20th century. Although the area has produced numerous diverse collections of Miocene faunas, fossil records from the early Miocene of Inner Mongolia are relatively rare.

Our field investigations in Damiao, Inner Mongolia have yielded more than 30 new fossiliferous localities, which have produced a rich mammalian fauna, including pliopithecid remains. We present a multidisciplinary study of the Damiao sequence, integrating sedimentological, stratigraphical, geochemical and diverse palaeontological data.

We have interpreted the Damiao sequence as the remains of a fluvio-lacustrine system comprising channels, subaerially exposed floodplains and ephemeral/marginal lacustrine environments. The bulk of the vertebrate fossils have been recovered from three main fossil horizons: The paleomagnetic results and faunal evidence suggest a correlation of lowermost fossil horizon producing relatively rich small mammal assemblage to the early Miocene, roughly in 20–21 Ma age range. The pliopithecid locality level represents latest middle Miocene and has an age estimate of about 12.1 Ma while the youngest localities with cervoids and abundant and diverse small mammal fauna represents the earliest late Miocene with an age estimate of about 11.6 Ma.

Hypsodonty, estimated mean annual precipitation, local sedimentology, and large mammal fossils suggest relatively humid and possibly more forested and wooded environments for the primate-bearing locality. This challenges the scenarios suggesting arid and highly seasonal conditions for Central Asia since Early Miocene.

ORAL

Sinemurian-Pliensbachian abundance and size changes in the calcareous nannofossil Schizosphaerella – relation to climatic and palaeoenvironmental change in the Paris Basin

Nicolas Thibault[1] and Peti
[1]Leonie

Abundance and size changes in the calcareous nannofossil Schizosphaerella have been investigated through the Early Jurassic (late Sinemurian to early Toarcian) of the Sancerre-Couy core (Paris Basin). Measurements are compared to variations in $CaCO_3$ content, total organic carbon (TOC) content, and isotopic trends in carbon and oxygen. Our results confirm that Schizosphaerella was better adapted to proximal areas than coccoliths as expressed by the stepwise rise in abundance of Schizosphaerella, followed by a rise in abundance of coccoliths during the major transgression of the Sinemurian. The results show that changes in the size of Schizosphaerella were mostly a response to Early Jurassic temperature variations (icehouse and coolhouse versus-greenhouse conditions) but comparison to belemnite oxygen isotope data show that temperature alone cannot explain all the patterns observed in size changes. Biometry statistics suggest the presence of 3 main morphotypes. The large morphotype is present mostly during proximal, cool environmental conditions of the upper Sinemurian. The medium morphotype was adapted to more distal conditions and cool surface waters whereas the small morphotype is associated with warm episodes an higher nutriency.

POSTER

The microstructure of Euselachian (Chondrichthyes) tooth and scales from Late Permian of Lithuania-Latvia Region

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The Late Permian palaeoichthyofauna of the Lithuanian-Latvian border Region is poorly known due to lack of the information and comparative isolated material from Southern Permian Basin. The studied region is located generally on the flat coastal zone of the northeastern shore of the Zechstein Sea (Dankina et al. 2017). The assemblages of the fish microremains such as teeth and scales of chondrichthyans and osteichthyans from Naujoji Akmenė Formation (northern Lithuania) and Alši, Kūmas, and Auce Formations (southern Latvia), Lopingian, Upper Permian were found.

Previous studies on tooth and scale enameloid microstructure provided a single crystallite enameoid (SCE) as a monolayer in the most primitive chondrichthyan taxa (Botella et al. 2009). However, the dental and dermal denticle microstructure of the Paleozoic ichthyofauna has yet to be investigated. We have studied the crushing tooth and some scales microstructure of the Late Permian chondrichthyans. As a result, the investigation with scanning electron microscope (SEM) has shown the presence of the crown and superficial cap of single crystallite enameloid of euselachian-type scales as well as tubular dentine on the Helodus sp. tooth.

POSTER

Palynological investigation of the late Pliocene to early Pleistocene proto-Gulf of Corinth, Greece

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Rift basins have proven economically significant as hydrocarbon provinces and, furthermore, record the structural, sedimentary and climatic evolution of the basins and associated catchment areas. The aim of this study is to utilize palynological methods to constrain rift basin evolution and provide insight into eastern Mediterranean late Pliocene climate development.

In this study, we take a closer look at the active Corinth rift, Greece, whose early syn-rift deposits are spectacularly exposed on the northern Peloponnese peninsula. So far, research and existing literature has focused on the western part of the onshore stratigraphy, whereas the central and eastern areas have received less attention. The study area is the northern Sythas Valley, where late Pliocene to early Pleistocene deep-water deposits of the Rethi-Dendro Formation (RDF) are exposed in extensive cliff sections.

The RDF has been mapped using traditional field methods combined with digital outcrop data (LiDAR). Furthermore, three drill cores that cover c. 750 m of stratigraphy are being retrieved. Palynological analysis suggests a strong sedimentary facies dependence of the palynomorph assemblage. The findings of marine dinoflagellate cysts suggests periods of connectivity between the proto-Gulf of Corinth and the Mediterranean at an earlier stage than previously reported. The results may prove vital for understanding the structural evolution of the basin as they imply that by Late Pliocene time the northern margin of the rift had already migrated close to its present location.

POSTER

Late Toarcian to Early Bajocian climate and environmental changes in Europe and East Greenland – geochemical records from calcite fossils and sediments

Jesper Allan Frederiksen[1], Suzanne Pultz[1], Gerd Dietl[2], Stéphane Bodin[3], Peter Alsen[4], Günther Schweigert[5], Clemens Vinzenz Ullmann[6] and Christoph Korte[1]

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This study becomes the first author's Master Thesis, and the aims are to use the isotope values from collected bulk rock samples and from pristine fossils to reconstruct climate and environmental fluctuations during the late Early and early Middle Jurassic (Late Toarcian–Bajocian) Middle European epicontinental Swabo-Franconian and Paris Basins, the French Subalpine Basin and the East Greenland Jameson Land Basin. Belemnite rostra and bulk rock samples were collected in SW Germany in Zell unter Aichelberg at the Pliensbach stream (upper Posidonienschiefer Fm., Jurensismergel Fm., lower Opalinuston Fm.), and in Balingen Zillhausen at the Wasserfall section (Opalinuston Fm.), and at the Roschbach section (Comptumbank, Eichberg Fm., and Subfurcatenoolith, Ostreenkalk Fm.) (see Quenstedt 1856-1858; Bloos et al., 2005). Coeval samples were taken from the La Baume section in SE France (Aalenian–Bajocian) (see De Baets et al., 2008), from different localities in Luxembourg, and from the Sortehat Fm. (only Aalenian) in Jameson Land, East Greenland (see Krabbe et al., 1994; Dam & Surlyk 1998; Koppelhus & Hansen 2003). All fossils were screened for diagenetic alteration (see Ullmann and Korte, 2015) using the Scanning Electron Microscope (SEM) and element ratios. Sr/Ca vary between 0.533 and 2.595 mmol/mol and Mn/Ca between 0.002 and 29.661 mmol/mol. Oxygen (vary between - 3.41 and 4.09 ‰ PDB) and the carbon isotope values (-11.11 and 1.90 ‰ PDB) were recently measured and altered data will be culled as the next research step. Organic carbon isotope measurements on bulk rock samples are currently in progress.

POSTER

Surface analyses of fossil leaves

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Recent studies show that the metallome and chemical composition of living plants depend on the geology as well as nutritional quality of the soils in which the plants grew (e.g. Husted et al. 2004; Laursen et al. 2011; Mie et al. 2014). Few studies, however, have examined the chemical makeup of fossil plant material. In this study, μXRF, ToF-SIMS, LA-ICP-MS and FTIR techniques are applied to a fossil conifer (Cupressaceae) from the Naujât Member, West Greenland in an attempt to identify and distinguish pristine organic matter preserved as well as the diagenetic history of the fossil. Moreover, the strengths and weaknesses of the various analytical techniques are compared. Organic matter within the fossil was identified, but it is uncertain whether it has a pristine or a bacterial origin. The Naujât conifer fossil is permineralized in calcite with small spots of iron sulphides present mainly where the fossil is thickest. The fossil is embedded in a siderite concretion formed in kaolinite-rich sediment. Based on the observations, a model for the fossilization of the plant is proposed.

POSTER

Carinodens – a new addition to the Late Cretaceous mosasaur fauna of Denmark

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The small durophagous mosasaurine mosasaur (Reptilia, Mosasauridae) genus Carinodens is exceedingly rare in north European chalk deposits, with published finds limited to a small number of shed tooth crowns and two partial dentaries from The Netherlands and Belgium, all assigned to Carinodens belgicus. A newly discovered isolated, shed tooth crown from the UNESCO world heritage site of Stevns Klint expands the known geographical distribution of another species, C. minalmamar, first described from Morocco, to Denmark. The specimen was found within the uppermost metres of the Maastrichtian chalk deposits, thereby placing it within the last 50.000 years of the Cretaceous. The new tooth crown represents the northernmost occurrence of the genus Carinodens. Previous finds of mosasaur dental and skeletal materials from Denmark have all been assigned to the hypercarnivorous mosasaurids Mosasaurus hoffmannii and Plioplatecarpus sp. Thus, the new specimen provides important new information on ecological niche partitioning amongst large marine reptiles during the latest Maastrichtian.

POSTER

Biostratigraphy and palaeoecology of calcareous nannofossils in the Lower Cretaceous Munk Marl Bed, Danish North Sea

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The Lower Cretaceous Munk Marl Bed of the Tuxen Formation (Danish Central Graben) marks a change in the depositional environment within a chalk unit. Here we investigate the calcareous nannofossils from this interval of the Danish Boje-2C well with emphasis on biostratigraphy and palaeoecology to better understand the pelagic environment at the time of deposition. A total of seventy-two samples were analysed from the well. The samples correlate to the upper Lower Barremian nannofossil zones BC14 and LK20B. An acme of nannoconid 'tops' is proposed as a new biostratigraphical event characterising the middle part of the Munk Marl Bed. High abundances of thermophile taxa suggest warm surface water conditions at the time of deposition. Indicators of increased fertility show particularly low abundances indicating a decrease in surface water fertility, presumably related to an increased detrital input. Correspondence analysis ordinates samples in relation to identified palaeoecological proxies and reflects palaeotrophic levels in the surface water within the section. The analysis shows that the calcareous nannofossils indicate a period of more oligotrophic surface water in the middle of the section.

POSTER

Middle Jurassic palaeoenvironmental events in Europe - evidence from palynology and carbon and oxygen isotopes

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During the early Middle Jurassic, several biotic and climatic changes took place. A major event occurred at the Aalenian to Bajocian transition, and is associated with a negative carbon isotope excursion in carbonate and organic matter (Bartolini et al., 1996; Hesselbo et al., 2003). This negative excursion is, in turn, succeeded in the Early Bajocian by a poorly understood positive carbon isotope excursion, associated with floral and faunal turnovers (Sucheras-Marx et al., 2015; Bodin et al., 2017). In contrast, dinoflagellates underwent a major evolution and radiation from the Late Aalenian to Early Bathonian, and changes in relative sea level are thought to have controlled the stratigraphic pattern of dinoflagellate cysts (Wiggan et al., 2017). These paleoenvironmental perturbations are also reflected in the carbon isotopes of terrestrial organic matter and marine carbonate, with lighter values in the marine palynofacies (Hesselbo et al., 2003). In the present study, currently in progress palynological and isotopic investigations of latest Toarcian to Bajocian samples from three different regions in Europe – (1) SE France (La Baume section), (2) SW Germany (sections in Zell unter Aichelberg at the Pliensbach stream, and Balingen Zillhausen at the Wasserfall and at the Roschbach), and (3) in S Sweden (Vilhelmsfält core) (Guy 1971) – are presented. The aim is to document the presence and abundance of marine and terrestrial palynomorphs as well as to identify carbon and oxygen isotopes trends in the investigated successions in order to replace them within the framework of Middle Jurassic climatic and environmental changes.

ORAL

Sable nickel isotopes measured in situ from fossilized microorganisms

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Precise in situ measurements of nickel isotopes in fossilized microorganisms holds great potential for differentiation between non-biologic and biologic microstructures in rocks. Stable nickel isotopes are well known to be fractionated by biological processes under laboratory conditions. Less is known, however, due to instrumental obstacles and alteration processes, if biologic signatures of Ni isotope fractionation are preserved in fossils in the geologic rock record. Using transition metal isotopes as biomarkers in microfossils has traditionally been difficult because of its usually low concentration preserved in the fossil. It has until now been technically impossible to reliably measure Ni isotopic fractionation pattern in situ in fossilized microorganisms, where the elemental concentration has sometimes been as low as 0.1wt%. Here we show both that biologic isotopic fractionation signatures are preserved in microfossils and that the instrumental development has reached a milestone in being able to measure such signals accurately. We also demonstrate that abiotic signatures are strongly deviated from the biological signatures, pointing out the eligibility of using stable nickel isotopes as biosignatures.

7. Climate

7.1. Climate from the Palaeogene to the Anthropocene - bridging timescales and approaches

ORAL

Miocene glacial events and their influence on lithology distribution within the Danish North Sea area

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During the Miocene, episodes of global cooling caused repeated, rapid, eustatic sea-level falls in the order of 25-50 m. In proximal settings within the North Sea Basin (onshore Denmark) these sea-level variations affected the distribution of lithologies with deposition of well-sorted delta sand or basin floor fans during the glacial events. These sand deposits form important subsurface aquifers in the western part of Denmark (Jylland).

Based on the dinocyst zonation of Dybkjær & Piasecki (2010) it has been possible to correlate three successive, prograding, fluvio-deltaic sand bodies with the early Miocene glacial events; Mi-1a, Mi-1b and Mi-2 of Miller et al. (1991). In more distal areas (offshore Denmark), the glacial events did not have any (significant) effect on the lithology, but can be recognised by increased abundances of freshwater algae and diatoms.

New data from the uppermost Miocene (upper Tortonian and Messinian) have led to the recognition of some of the climatic events known from this time-interval - and to related sand deposits. A Messinian glacial event, probably correlatable with the Mediterranean "Messinian salinity crisis", was recently recognised in the Nora-1 well. This event correlates with a prograding depositional system and incision, indicating a sea-level fall of 70-80m (Møller et al. 2009).

Identification and correlation of the Miocene glacial events are important for understanding lithology distribution and can be further used for prediction of potential reservoir sands.

ORAL

Eocene bryozoan biota vs climatic events (Seymour Island, West Antarctica)

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The earliest Antarctic late early Eocene bryozoans of the La Meseta Fm., Seymour Island are connected with the major phase of cheilostome evolution; clear preponderance of cerioporoidean cyclostomes along with numerous microporoideans. The internal moulds of the loose, small zooecia in the lowermost part of this formation, includes the cheilostomes of Beanidae, Catenicellidae, Savignyellidae, which nowdays are widely distributed in the tropical-warm, temperate latitudes in the shallow-water settings (Hara 2015). 90% of taxa reveal the multilamellar growth-form connected with a short-term episode in the lower part of Telm1, during their long in situ evolution. The bryozoans from the (Telm4-5) are the microporoideans and the first lunulitiform (free-living) bryozoans of Lunulites and Otionellina, ever reported from Antarctica. Their disc-shaped colonies are today indicative of tropics and subtropics but skeletal mineralogy is also important in view of the transition of such bryozoans from calcitic to bimineralic to aragonitic on the K/T boundary. Recent, free-living lunulitiforms occur in warm, shallow-shelf conditions, in temperatures of 10-29˚ C, on coarse, sandy to muddy bottom with low to moderate deposition in fairly high velocity currents. Contrary to that, the bryozoans recognized in the upper part of the formation

(Telm7) are composed of the impoverished bryozoan biota of scarse lepraliomorphs and fragmented cyclostomes, which are accompanied by the crinoids and brachiopods, gadiform fish remains, penguin bones and whales. The well-documented distribution of the bryozoans in the stratigraphical profile of the La Meseta Formation illustrates the climatic changes connected with the EECO, MECO as well as the EOT.

ORAL

Tracers of sea ice, primary production and meltwater inputs: distribution of biogenic proxies in a High Arctic fjord system, Northeast Greenland

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The coastal ecosystems of Northeast Greenland are vulnerable to the enhanced melt of continental and sea ice as a result climate warming, however little is known of past ecosystem changes in the region. We present the distribution of an array biogenic proxies (dinoflagellate cysts, pollen, diatoms, biogenic silica, C/N and their isotopes, IP25, HBI III) from a transect of 13 surface-sediment samples from Young Sound-Tyrolerfjord, NE Greenland (74°N), in order to assess their relevance as tracers of past changes in sea ice, primary production and terrigenous inputs. The Greenland Ecosystem Monitoring program provides a unique High Arctic time-series of hydrological, atmospheric and biological measurements from the fjord since the mid-1990s, against which the sediment signatures can be compared. The proxy data show an overall good agreement with the monitoring data. Organic carbon contents, diatom production, HBI III and heterotrophic dinoflagellate cyst abundance were higher in the outer fjord, where turbidity is lower, salinity higher and waters more nutrient-rich compared to the inner fjord. Conversely, in the inner fjord, these production proxies follow an opposite pattern. The seasonal sea-ice proxy IP25 and sea-ice-dwelling taxa are present in varying abundances, which reflects the seasonal character of the sea-ice cycle together with species-specific habitat preferences of these taxa. Our results support the notion that future warming and freshening will likely have a negative impact on primary productivity and organic matter sequestration. This implication may be assessed by reconstructing changes during past warm periods using the new sediment core records from the area.

ORAL

Investigating phase-relationships between ice margin instabilities and oceanographic conditions in Baffin Bay during the last deglaciation and early Holocene

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Freshwater forcing from Northern Hemisphere ice sheets during the last deglaciation likely played an important role in modulating deep-water formation, and thus global climate. The mechanisms of ice margin instabilities and its exact phase relationship with climatic change, such as paleoceanographic variation, are not fully understood.

Baffin Bay represents an important conduit for freshwater transported into the Labrador Sea, released from the Greenland, Innuitian and Laurentide ice sheets. We take advantage of two radiocarbon-dated marine sediment cores from central Baffin Bay that span the last deglaciation and early Holocene (ca. 17-10 kyr BP). These

archives provide co-registered records of detrital input from the surrounding ice sheets and sufficient biogenic carbonate for the reconstruction of paleoceanographic conditions.

Two distinct detrital carbonate-rich layers, originating from ice sheets surrounding northern Baffin Bay and dated at 14.2-13.7 kyr BP and 12.7-11 kyr BP, indicate that ice sheet retreat events occurred during both interstadial and stadial periods and were asynchronous with Heinrich events. Despite previous evidence for an oceanic trigger of these events, records here indicate change in deep water properties and stronger inflow of warmer Atlantic water via the West Greenland Current postdated the first event. The second event was not preceded by any major change in oceanographic conditions but likely a response to a combination of a consistently stronger West Greenland Current as well as climatic forcing. Results suggest that there were different mechanisms responsible for ice margin instability events in Baffin Bay during the last deglaciation and early Holocene.

ORAL

Paleoclimate and paleoceanography data based on isotope ^{13}C and ^{18}O measurements with the new measurement tool

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The contents of stable carbon and oxygen isotopes, 13C and 18O, in secondary precipitated carbonates and sediments can provide important information about paleoclimate conditions of the area. Environmental factors like temperature, concentration of atmospheric CO2, chemical composition of water, isotopic composition of water, CO2 and deposited are influence the isotopic composition. For many decades different instrumental methods involving generations of the isotope ratio mass spectrometers with different periphery units for sample preparation, have provided scientifically required high precision, and high throughput of samples for variety of different applications in paleoclimate reconstructions.

In this work we will present measurements of $\delta^{13}C$ and $\delta^{18}O$ from solid carbonate samples, DIC and $\delta^{18}O$ of water with new laser technology, with case study where Delta Ray was in the field (Karstic cave) performing for more than a year collecting high frequency data on $\delta^{13}C$ and $\delta^{18}O$.

We have demonstrated usage of a Thermo Scientific™ Delta Ray™ IRIS with URI Connect on certified reference materials and confirmed the high achievable accuracy and a precision better then <0.1‰ for both $\delta^{13}C$ and $\delta^{18}O$, in the laboratory or the field with same precision and throughput of samples. With equilibration method for determination of $\delta^{18}O$ in water samples, which we present in this work, achieved repeatability and accuracy are 0.12‰ and 0.68‰ respectively.

Applying new methods for measurement of the samples important for paleoclimate investigation one can come to the results already in the field.

ORAL

Deglacial – Holocene paleoceanography of Herald Canyon, Chukchi Sea

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The Herald Canyon is a local depression across the Chukchi Sea shelf, and acts as one of the main pathways for Pacific Water to the Arctic Ocean after entering through the Bering Strait. We analyzed sediment samples of two piston cores from Herald Canyon, collected during the 2014

SWERUS-C3 Arctic Ocean Expedition. Core 2-PC1 from the shallow (57 mwd) flank contains the late Holocene at high resolution (> 2m/kyr), while Core 4-PC1 from the central canyon (120 mwd) extends back in time to ~13 ka. The lower part of 4-PC1 contains an abrupt increase in biogenic silica and a carbon isotopic shift towards more marine values, which are interpreted as the signal of the Bering Land Bridge flooding and water exchange through the Bering Strait (Jakobsson et al., 2017). This major oceanic event is dated to ~11ka and thus occurs in the very early Holocene, contrary to most previous earlier estimates suggesting a Younger Dryas age for the opening of the gateway. The chronology of Core 2-PC1 is based on 17 radiocarbon dates and the 3.6 ka Aniakchak CFE II tephra, which is used as an absolute age marker to calculate the marine radiocarbon reservoir age (Pearce et al., 2017). Analysis of sea ice biomarkers and phytosterols indicate relatively stable sea ice conditions throughout the entire late Holocene, however ending with an abrupt increase of phytoplankton sterols in the very top of both sediment sequences which corresponds to the rapid ice retreat observed in recent decades.

ORAL

Sea ice, marine productivity, and human settlement dynamics in the North Water Polynya-Qaanaaq region (NW Greenland) during the late Holocene

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The North Water (NOW) is the largest polynya in the Arctic, a large extension of recurrent open waters surrounded by sea ice, in northern Baffin Bay. This polynya is the most productive ecosystem north of the polar circle, and its living resources have sustained human settlements in both Arctic Canada and Greenland for millennia. Within the framework of the ICE-ARC project: Ice, Climate and Economics - Arctic Research on Change (EU FP7, http://www.ice-arc.eu/), we aim to reconstruct changes in climate, sea ice, and marine resources in the NOW region using an integrated approach combining proxy records from marine sediment cores, remote sensing of sea ice, and historical data. We will present the latest results from a multi-proxy investigation of sediment core records from the high Arctic Inglefield fjord (Qaanaaq) and from a new 5,4 m high-resolution sediment core from the NOW, spanning the last ca. 3500 years. Our proxy results will be discussed in the light of historical and archaeological sources in order to identify possible links between past changes in climate and marine resource availability in this high arctic "oasis" with known cultural transitions in Greenland.

ORAL

Holocene temperature trends in the Northern Hemisphere high latitudes – model-data comparisons

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Regional differences in Holocene climate trends in the Northern Hemisphere high latitudes are primarily determined by orbital-scale insolation variations and melting ice sheets. Previous inter-model comparisons have revealed that multi-simulation consistencies vary spatially. We compared multiple model results with proxy-based reconstructions in Fennoscandia, Greenland, north Canada, Alaska and Siberia. Our model-data comparisons reveal that data and models generally agree in Fennoscandia, Greenland and Canada, with the early-Holocene warming and subsequent gradual decrease to 0

ka BP. In Fennoscandia, simulations and pollen data suggest a 2.0°C warming by 8 ka, but this is less expressed in chironomid data. In Canada, a strong early-Holocene warming is suggested by both the simulations and pollen results. In Greenland, the magnitude of early-Holocene warming ranges from 6.0°C in simulations to 8.0°C in $\delta^{18}O$-based temperature reconstructions. Simulated and reconstructed temperatures are mismatched in Alaska. Pollen data suggest a strong early-Holocene warming, while the simulations indicate constant Holocene cooling, and chironomid data show a stable trend. Meanwhile, a high frequency of Alaskan peatland initiation before 9 ka can reflect either high temperature, high soil moisture or large seasonality. In high-latitude Siberia, the simulations and proxy data depict high Holocene temperatures, but the signals are noisy owing to a large spread in the simulations and between pollen and chironomid results. On the whole, the Holocene climate trends in most regions (Fennoscandia, Greenland and Canada) are well established and understood, but important questions regarding the Holocene temperature change and mechanisms remain for Alaska and Siberia.

ORAL

An evaluation of IRD as a proxy for glacier change: results from Upernavik Isfjord.

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The sudden increase of mass loss of the Greenland ice sheet at the onset of this century has spurred investigations regarding ice-discharge at marine terminating glaciers, a process that is thought to contribute up to 50% of Greenland's total mass loss. To evaluate whether this recent increase of mass loss was an outstanding event or occurs, centennial or millennial timescales, sediment cores in fjords with marine-terminating glaciers can be investigated since they constitute high-resolution sedimentological records that reflect past changes in glacier stability.

In glacimarine fjords, sand-sized sediment is predominantly transported and deposited by melting of sediment-laden icebergs. Therefore, ice-rafting can be reconstructed by quantifying the downcore variations in sand content. Even though the interpretation of IRD as a proxy for glacier stability (iceberg production) is common, many glaciological and sedimentological complexities are involved in interpreting IRD records. A better understanding of those complexities can be achieved by investigating the relationship between IRD variability and recent observations of climatic and glaciological changes.

In this study, we quantify the IRD variability of four short cores (~2 m) from Upernavik Isfjord, West Greenland. Ice-rafting is reconstructed back to 1930 and compared to climatic measurements and a record of glacier terminus position changes, derived from historical expeditions and satellite imagery. We discuss spatial trends of ice-rafting and the different processes that modulate its variability. This information aids the general understanding and interpretation of IRD in paleoceanographic research.

ORAL

A 2000-year record of ocean influence on Jakobshavn Isbræ calving activity, based on marine sediment cores

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The Greenland Ice Sheet has experienced significant mass loss in recent years. A substantial component of this is attributable to the retreat of marine-terminating outlet glaciers, which lost mass through increased calving and meltwater discharge. Jakobshavn Isbræ is the most productive marine-terminating glacier in Greenland, yet relatively little is known about its history before the first instrumental observations of local climatic conditions ~140 years ago.

Three marine sediment cores were collected from locations north-west to the mouth of Jakobshavn Isfjord in Disko Bay. These cores were analyzed to reconstruct changes in glacier behavior in response to past climatic and oceanographic changes; this provides context against which to assess the significance of recent changes. The sediments deposited at this site reflect oceanographic and climatic changes as well as the discharge of ice rafted debris from Jakobshavn Isbræ.

Radiocarbon dates of plant material combined with a 210Pb profile indicates that the cores cover a time span of ~2000 years. X-Ray images and a high-resolution grain size analyses reveal clear changes in the sedimentation regimes over time. The influence of ocean water temperature derived from benthic foraminifera record as well as the impact of a floating glacier tongue on the sediment output of Jakobshavn Isbræ is discussed.

POSTER

Holocene oceanographic variability in coastal southeast Greenland

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The coastal waters of southeast Greenland are the interface between the Atlantic Ocean and the vast Greenland Ice Sheet. Oceanographic processes have been implicated in the recent loss of ice from marine-terminating glaciers across the region. Ocean processes here are also important as they modulate global thermohaline circulation; this occurs both through the influx of meltwater from the ice sheet, and through mixing of water masses on the continental shelf. Understanding how these processes have varied in the past is crucial for predicting future behavior.

We present two complementary sediment core records of oceanographic variability from the continental shelf of central southeast Greenland. Radiocarbon and lead-210 dating demonstrates that these cores cover the last 5000 and 9000 years respectively. We analysed benthic and planktonic foraminifera to reconstruct variability in water masses at both the surface and seabed. We use independent, but complimentary, measurements of sortable silt to reconstruct the strength of ocean circulation at the sea bed and build a holistic picture of oceanographic conditions from the mid-Holocene to the present.

Combining our new results with records from further north in the region yields a unique resource with which to assess the variability of

oceanic currents at a regional scale. We use this to examine the factors that have driven the oceanographic development of the region. We then identify how oceanographic changes in southeast Greenland have influenced oceanic and climatic conditions across the wider North Atlantic region.

POSTER

Late Holocene paleoclimatic and palaeoceanographic development of the eastern Baffin Bay area

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A 738 m long marine sediment core, AMD14-204 CasqC, was retrieved from the eastern Baffin Bay during a research cruise on board CCGS Amundsen in 2014. The study of benthic foraminiferal assemblages, XRF core scan data and CT-scans supported by radiocarbon dating of this core allows the reconstruction of the palaeoceanography and palaeoclimate of the eastern Baffin Bay during the last ~4800 cal. BP. Several major changes in oceanographic conditions and climate are reconstructed during this time interval in the eastern Baffin Bay area, which also influenced the nearby Upernavik Isstrøm glacier. Our study reveals that relatively warmer subsurface waters prevailed during the final phase of the warmer 'Holocene Thermal Maximum', linked to the entrainment of relatively warm Irminger Current (IC) water into the West Greenland Current (WGC). This relatively strong advection of IC may also have resulted in relatively strong melting of the Upernavik Isstrøm glacier, causing influx of meltwater to the area. However, at ~3100 cal. BP, the onset of the Neoglaciation, the area experienced an abrupt transition to dominantly agglutinated benthic species, indicating enhanced carbonate dissolution. This was likely in part caused by a reduction of the influx of IC water and increased entrainment of the East Greenland Current into the WGC. The reduction of IC water influx also allowed increased influx of the cold, corrosive Baffin Bay Deep Water. These cold subsurface water conditions persisted throughout the late Holocene, only interrupted by short-lived climate fluctuations superimposed on this cooling trend.

POSTER

Spatiotemporal differences in varve structure and preservation over the last 200 years in Lake Lehmilampi, Eastern Finland

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A wide variety of studies considering varved lake sediments as a climate proxy have been performed in Finnish lakes. Nevertheless, none of them is considering spatial distribution of varves within an entire lake, although it is essential to acquire data not only from the deepest point of a lake but also from more shallow areas. The distribution of varves within the entire lake has only been studied in a few lakes in Europe (Jenny et al. 2013).

In previous work the changes in the presence of varves within the whole lake during the past 200 years, arriving at a conclusion in changes in hypolimnetic hypoxia (2mg/l (Roberts et al. 2009)), were investigated. As a result the extent of hypolimnetic hypoxia has clearly changed during the past 200 years in the lake due to climate.

In this study the differences in sediment composition in varved and non-varved sections are studied with SEM (scanning electron microscopy), μXRF (X-ray fluorescence) and X-ray radiography to investigate the factors influencing varve formation in the lake. The aim of this study is to investigate spatiotemporal

differences in varve structure, formation and preservation within the whole lake.

8. Quaternary geology

8.1. Ice and climate history in the Arctic and subarctic

ORAL

A 200 ka glaciation history from NW Svalbard

Helena Alexanderson[1], Mona Henriksen[2], Heidi T. Ryen[3], Jon Y. Landvik[2] and Gustaf Peterson[4]
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Late Quaternary sedimentary units at Kongsfjordhallet, NW Svalbard, represent five cycles of glaciations and subsequent deglaciations during high relative sea levels. The high sea-level events are interpreted as glacioisostatically induced and imply preceding regional glaciations, which we constrain in time by luminescence and radiocarbon ages to just prior to ~195 ka, ~130 ka, ~85 ka, ~60 ka and ~14 ka. Combined with the stratigraphical record from nearby Leinstranda (Alexanderson et al. 2011) we identify six, possibly seven, major glacial advances during the last 200 ka in the Kongsfjorden region. Two of these occurred during the Saalian and at least four during the Weichselian.

The results are based on detailed sedimentological, stratigraphical and chronological investigations of the uppermost 15 m of the 40-m-high Kongsfjordhallet coastal sections. The succession is dominated by sediments of marine and littoral origin, representing partial shallowing-upward sequences due to isostatic rebound. Only one subglacial till was recognized. Interestingly, alluvial and periglacial deposits, not commonly recognized in this type of setting, occur in the sequence. These include weathered coarse alluvium, sandy channel fills as well as cryoturbated sediments and solifluction deposits. The sedimentary succession has been summarised in a facies model for an emergence cycle following deglaciation.

Our study encompasses only the upper 15 m of the coastal cliff sections at Kongsfjordhallet (succession A of Houmark-Nielsen and Funder 1999), and there is an additional ~20 m of sediments below our Unit 1, which is promising for future studies aiming to go further back in time.

ORAL

Reindeer kill dates record late Holocene glacier lake outburst floods in East Greenland

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In the summers of 2004 and 2005 a surprising find of the remains of several dead reindeers was done in East Greenland. The carcasses were melting out of a snowbank in a small valley next to the village Ittoqqortoormiit at the mouth of Scoresbysund fjord-system. The radio-carbon ages of the 30 animals showed a surprising spread with several episodes of reindeer-deposition within the last four thousand years. We argue that the only phenomena capable of killing and positioning the animals at the exact same location over multiple millennia are glacier lake outburst floods (GLOFs). In the catchment, glaciers and topography capable of creating

GLOFs are indeed present. Thus, our pile of dead reindeer became an unlikely proxy of glacial presence, and moved the onset of neo-glacial build-up in the region by a thousand years.

ORAL

Preliminary results based on 24 new ^{36}Cl exposure datings reveals asynchronous deglacial history of Tröllaskagi peninsula, central north Iceland

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At present the Tröllaskagi peninsula, located in central north Iceland hosts 150 cirque and valley glaciers. The landscape is characterised by steep narrow glacially carved valleys separated with up to 1500 m high peaks and ridges. The glacial history of Tröllaskagi suffer from lack of direct dating. Previous studies indicate Tröllaskagi peninsula was mostly ice covered during the last glacial maximum. Several lowland end moraines and raised beaches indicate recurrent glacial re-advances during the deglaciation , which was completed about 10 Ka ago. Most of the present glaciers are considered to have reached maximum Holocene conditions during the late Little Ice Age.

We sampled 24 rock samples from erratics and moraine boulders for ^{36}Cl exposure dating in order to improve the glacial history of the area. Preliminary results indicate asynchronous deglaciation pattern over the peninsula. Some mountain ridges and summits were deglaciated at least about 16 Ka ago. Furthermore, some highland valleys were deglaciated about 13-14 Ka ago while others probably remained glaciated at least until early Holocene. Finally we obtained average ages 2.66 Ka and 0.7 Ka from two moraines proximal to present glaciers which were suspected to relate to LIA fluctuations.

Our preliminary results support recent researches that suggest ^{36}Cl exposure dating method as plausible to improve significantly the deglacial history of Iceland, especially where presence of tephra and organic material for dating is limited.

ORAL

Advances in Deglaciation on Svalbard

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Despite warm regional fjords, a variety of data suggest extensive glacier advances on Svalbard during the Pleistocene-Holocene transition. We present the first well-constrained (in age) end moraine formed during the Lateglacial-early Holocene (LGEH) in Svalbard, De Geerbukta, NE Spitsbergen. The landform was deposited by an outlet glacier re-advancing into a fjord extending 4.4 km further than the late Holocene maximum. We compare the synchronicity of this glacier advance to paleoclimate records and 15 other proposed glacier advances from Svalbard. Furthermore, we introduce 35 additional LGEH glacier deposits identified through remote sensing were glaciers also advanced into a high relative sea level. Glacial deposits were wave-washed or cut by early Holocene raised marine shorelines, suggesting the landforms were deposited before or during high relative sea level stands, thus exhibiting a similar LGEH age.

Contrary to current understanding, our new evidence suggests that the LGEH glaciers were more dynamic, exhibited re-advances and extended well beyond the extensively studied late Holocene glacial expansion. Given the widespread occurrence of the LGEH deposits on Svalbard, we suggest that the culmination of the Neoglacial advances during the Little Ice Age does not mark the maximum extent of most Svalbard glaciers since deglaciation; it is just the most studied and most visible in the geological record.

ORAL

^{10}Be and ^{26}Al exposure and burial histories for ancient granite tors in arctic Finland.

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The ice-divide zone of northern Finland experienced low erosion beneath successive cold-based Fennoscandian ice sheets (Hall et al., 2015). One indicator of this are the many tors that occur on hill tops and flanks. Published ^{10}Be and ^{26}Al inventories for two tor summit surfaces near Vuotso indicate ~0.8 Myr of exposure and burial (Darmody et al., 2008). These samples came from tabular tors that may have lost granite sheets to glacial erosion. Schmidt Hammer values are high, indicating limited weathering of these rock surfaces despite apparently long exposure. Hence published data may relate to one or more phases of glacial erosion rather than to tor surface erosion. In contrast, nearby tors retain delicate superstructures and give low rock hardness values, features consistent with little or no glacial modification, more advanced weathering and longer exposure of the tor summit surfaces. We will present new ^{10}Be and ^{26}Al isotope results for these surfaces and use Monte Carlo simulations to derive Pleistocene exposure and burial histories. We expect bedrock erosion rates to be amongst the lowest reported for the northern Fennoscandian shield.

ORAL

Constraining the evolution of the last Eurasian ice sheets: progress towards DATED-2

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In 2016 we published an empirical reconstruction of the evolution of the extent of the last Eurasian ice sheets, that is fully documented, specified in time, and includes uncertainty estimates (DATED-1; Hughes et al. 2016). This was the culmination of a 10-year effort to compile and archive all published dates relating to the build-up and retreat of the British-Irish, Scandinavian and Svalbard-Barents-Kara Seas ice sheets. Over 5000 dates were assessed for reliability and used, together with published geomorphology-based ice-sheet margin positions, to reconstruct time-slice maps of ice extent for every 1000-years 25-10 ka and four periods between 40-27 ka. All uncertainties (both quantitative and qualitative e.g. precision and accuracy of numerical dates, correlation of moraines, stratigraphic interpretations) were combined based on our best glaciological-geological assessment and expressed in terms of distance as a 'fuzzy' margin. Since the DATED-1 census (1 January 2013), the volume of new information (from both dates and mapped glacial geomorphology) has grown significantly (e.g. 32% increase in the number of dates), although the spatial distribution of information remains similar. Here, we present work towards an updated version of results, DATED-2 (census: 1 January 2017), that attempts to further reduce and explicitly report all uncertainties inherent in the ice sheet reconstructions, and discuss the implications of the revised margins.

ORAL

Local ice caps response to Holocene climate variability in Kobbefjord, West Greenland

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The sensitivity of glaciers and ice caps (GICs) in Greenland to prolonged warm periods is poorly constrained and geological records documenting the long-term glacial history are needed to put recent observations into a broader perspective. Here we report the results from three proglacial lakes where fluctuations in local glaciers located at different altitudes in Kobbefjord, southwest Greenland have been recorded. Our results show that the lakes received meltwater from the initial deglaciation of the area ~9.2 cal. ka BP until ~8.7-7.9 cal. ka BP when the meltwater input ceased as the glaciers most likely disappeared. Regrowth of glaciers began again at ~5.5 cal. ka BP at ~1,370 m a.s.l., ~3.6 cal. ka at ~1,170 m a.s.l., and ~1.6 cal. ka BP at ~1,000 m a.s.l., clearly reflecting strong altitudinal control of the GIC response to Neoglacial cooling. Our results highlight that GICs in Kobbefjord, southwest Greenland are primarily influenced by changes in summer air temperatures and winter precipitation and that they are facing a rapid decay that most likely will result in their disappearance within the next centuries as a consequence of global warming.

ORAL

Deglaciation patterns of the Lake District Ice Lobe of the Scandinavian Ice Sheet in SE Finland during the Younger Dryas

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The deglaciation pattern of the Lake District Ice Lobe (LDIL) of the former Scandinavian Ice Sheet (SIS) in the Salpausselkä zone, southern Finland were studied. Glaciofluvial landforms (i.e. eskers, glaciofluvial deltas and subaquatic fans and sandurs) were mapped using Digital Elevation Model (DEM) data with 10 metre-resolution and Light Dedection And Ranging (LiDAR) data with 2 metre-resolution. Hillshading was used to make a DEM-generated 3D-landscape in order to help the recognition of landforms and their surface deformation. Based on these observations ice lobe re-advance and retreat phases, and their extent across the Salpausselkä zone were defined.

The results indicate that the LDIL of the SIS retreated as far as 40 kilometres north of the proximal side of the present Second Salpausselkä ridge most likely prior to the Younger Dryas. This retreat phase was followed by a re-advance and the deposition of the First Salpausselkä in front of the LDIL ice margin. Subsequently, ice retreated further north and the Second Salapusselkä in front of the LDIL margin was formed. Optically stimulated luminescence dates indicate that the Second Salpausselkä was deposited during the Younger Dryas.

compared with our reconstruction when ice sheets, or ice sheets and meltwater, are included in the models (Zhang et al. 2016).

ORAL

Molluscs show an early and exceptional warm Holocene Thermal Maximum around Svalbard, which is not found in climate models

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Several species of shallow-water marine molluscs that cannot presently live around Svalbard due to the cold-climate occur frequently in raised Early Holocene deposits. The most warmth demanding of these species, Zirfaea crispata, currently has a northern limit 1000 km farther south. Based on radiocarbon ages of this species we conclude that the August temperatures on Svalbard were as much as 6 °C warmer than today during the period 10,200 to 9,200 calendar years ago (Mangerud & Svendsen 2017). The blue mussel, Mytilus edulis, re-appeared on Svalbard in 2004, in response to the recent warming of the Arctic. This happened almost 4000 years after Mytilus disappeared from the shores of Svalbard, excluding a short re-appearance during the Medieval Warm Period 900 years ago. After the last Ice age, Mytilus arrived for the first time in Svalbard as early as 11,000 years ago, indicating that the climate was then as least as warm as today.

If we, as an example, postulate that the winter precipitation pattern during the period 10,200 – 9,2000 years ago was similar to the present pattern, then a summer warming of 6 °C would have raised the equilibrium line altitude (ELA) on glaciers by about 900 meters, and all glaciers on Svalbard would have melted away.

We also note that climate models simulate a much later and not-so-warm Thermal Maximum

ORAL

Local or distant centre of uplift, a case study from Northwest Iceland

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Contemporary studies of glacio-isostatic uplift at the Vatnajökull glacier in Iceland have revealed a more or less instantaneous accelerating rates of uplift as high as 35 $mm \cdot a^{-1}$ due to negative glacier mass-balance. During the late Weichselian deglaciation of Iceland, uplift rates exceeded 160 $mm \cdot a^{-1}$ when relative sea-level regressed from the marine limit in West Iceland some 14.7 cal ka BP.

Glacial striae in Northwest Iceland are arranged in an apparent radial pattern with the striae orientated towards the outer coasts of NW-Iceland implying that the striae were formed by actively eroding glaciers retreating towards the centre of the peninsula. Numerical modelling of the Weichselian retreat of the Icelandic Ice Sheet (IIS) has returned local ice-caps in NW Iceland when the IIS reached a temporary minimum in Bølling-Allerød times. Thus, the existence of independent late Weichselian ice-caps in NW Iceland seems plausible and also that they influenced glacio-isostatic uplift in the area, especially when considering temporal and spatial isostatic equilibrium during deglaciation.

Raised shoreline features are found throughout lowland areas of NW Iceland from present sea-level and up to or slightly above 80 m a.s.l. The aim of this paper is to examine if altitudes of raised shorelines can be used to decide if glacio-isostatic uplift of the NW Iceland was controlled by reduced crustal load (uplift) of a local ice cap

or if, and then to what extent, the uplift was influenced by the wastage of the IIS in central Iceland.

ORAL

Younger Dryas ice margin retreat triggered by warming of the ocean surface in central-eastern Baffin Bay

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The Greenland Ice Sheet stability is linked to fast-flowing ice streams that are strongly influenced by sea surface temperatures (SSTs) at their front (Holland et al. 2008; Nick et al. 2013). As the ice mass loss from the Greenland Ice Sheet is accelerating (Shepherd et al. 2012), there is a need for high-resolution marine proxy data to understand interactions between the ocean and the ice sheet. Here we present the first diatom-based high-resolution quantitative reconstruction of sea surface conditions from central-eastern Baffin Bay covering the period from 14.0 to 10.2 kyr BP. Our reconstruction reveals warmer sea surface conditions from 13.4 kyr BP to the end of the Younger Dryas (YD) period (11.7 kyr BP) and strong interaction between the ocean and the West Greenland ice margin. These warmer ocean conditions were caused by an enhancement of Atlantic-sourced water inflow together with increased insolation and amplified seasonality. Our sediment record shows that warmer ocean conditions played key part in the retreat of Jakobshavn Isbræ, one of the largest ice streams in West Greenland, which has been shown to have collapsed at 12.2 kyr BP (Rinterknecht et al. 2014). Our results show that ice retreat occurred mainly by calving during the YD period while surface/subsurface melt dominated during a warmer climate before and after the YD. Our results emphasize the ocean`s significant role for ice sheet stability under the current climate change.

ORAL

Marine environmental changes in front of the Scandinavian Ice Sheet during the last deglaciation

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The Kattegat-Baltic Sea region shows evidence of strong coupling with North Atlantic climate over recent glacial-interglacial cycles, but insufficient long, high-resolution Baltic area climate records have limited evaluating such links. New ultra-high-resolution sediment cores collected during IODP Expedition 347 can provide such records, including foraminiferal and mollusc geochemistry records reflecting seawater environmental changes directly adjacent to the Scandinavian Ice Sheet (SIS) during the most recent deglaciation.

We present benthic foraminiferal stable isotope ($\delta^{18}O$ and $d^{13}C$) and trace element (Ba/Ca, Mn/Ca and Mg/Ca) records as well as mollusc Sr isotope data from IODP Site M0060 (located between Sweden and Denmark in the southern Kattegat) to constrain bottom water salinity, temperature and oxygenation changes from ~18-13ka. Because of the large salinity changes (fresh to marine) during the past 20ka in this region, we

interpret $\delta^{18}O$ as reflecting salinity changes more than temperature here, while $d^{13}C$ reflects ventilation, productivity, and salinity. Ba/Ca, Mn/Ca, and Mg/Ca may indicate salinity, oxygenation, and temperature variations, although these proxies are less straightforward to interpret in this setting.

Stable isotope results suggest fjord-like, poorly ventilated conditions during early deglaciation, with three clear phases: 1) an initial rapid, large freshening event; 2) subsequent slower, step-wise freshening (likely linked to the decay of the SIS); 3) more marine, ventilated, saline conditions after ~15.6ka. These events may be linked to regional and global climate changes during this period of global climate changes, and may help us evaluate the interplay between the SIS and climate in the North Atlantic and beyond.

ORAL

New insights into the glacial and climate history of the Polar Urals, Arctic Russia

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Here we present new results and discoveries from several field campaigns in the Polar Urals of Arctic Russia. This talk focus on the late Weichselian and Holocene glacial and climate history as inferred from a 24 m long, partly varved, high resolution and exceptionally well dated sediment core from a deep lake (Bolshoye Schuchye) located in the interior of the mountain chain. The core, that is spanning the last 24,000 years, provide a unique high resolution record of the climate and environmental changes since the Last Glacial Maximum (LGM). Our results infer glacial influence on lake sedimentation including annual rhythmites, i.e. varves, through the LGM until about 19 ka when the continuous sequence of varves successively disappear and the sedimentation rate decrease. We conclude that all local glaciers within the catchment had melted away by 15 ka and there are no indications that a regrowth of glaciers took place during the Younger Dryas. A significant warmer climate prevailed during the Holocene period. The combination of AMS ^{14}C- and varve chronology in this study has provided a valuable contribution to constrain the age model for ongoing palynological-, paleomagnetic, DNA- and compound specific isotope ($\delta^{2}H$, $\delta^{18}O$) analyses also conducted within the framework of the CHASE- (Climate History of the Arctic Seaboard of Eurasia) project. Put together, this continuous and unprecedented high resolution record effectively supplement previous attempts to reconstruct pre-Holocene environmental changes based on fragmentary data from moraines and exposed strata along river banks and coastal cliffs around the Russian Arctic.

ORAL

Relative sea-level data as a constraint of Holocene ice sheet history in Finderup Land, NE Greenland

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Here, we present a new relative sea level (RSL) reconstruction for Finderup Land, NE Greenland, based on isolation basins to obtain more knowledge about the Lateglacial and Holocene glaciation history. Existing RSL data is in general sparse in NE Greenland and the RSL curves produced at nearby locations are based on very limited data[1,2]. It is imperative to understand how the large ice sheets responded to a warming climate in the past, in order to make accurate predictions of future sea level change. Reconstructions of past relative sea level changes is a key parameter in modeling global sea level fluctuations under past climate changes[1,3,4,5].

We present a new dataset of isolation lakes covering elevations from 8-62 m a.s.l. in which we identify the marine to lacustrine environmental transition. We date this transition using radiocarbon ages from foraminifera combined with paleomagnetic age correlation. Our new dataset will allow us to construct a RSL curve for Finderup Land, which in turn reflects the Lateglacial and Holocene ice marginal fluctuations in NE Greenland. Furthermore, we compare our results with existing predictions of past RSL in the area produced by the Huy2 (ref. 6) and Huy3 (ref. 1) ice sheet models and discuss possible improvements of the ice sheet models by incorporating our new data set.

ORAL

Deglaciation history of western Norway inferred from ^{10}Be- dating of erratics and ^{14}C-dates from sediment cores

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We report new results from an ongoing field campaign in southern Norway aiming at reconstructing the glacial and climate history since the Last Glacial Maximum (LGM). The inferred ice sheet history is based on a large number of cosmogenic nuclide exposure ages (^{10}Be) from glacially transported boulders as well as sediment records from lake basins. We find that all coastal mountains in the studied area were ice covered during the LGM, at which time the Scandinavian Ice Sheet was flowing westward, independent of the underlying topography. Later, the fast flow of the Norwegian Channel Ice Stream led to a lowering of the ice surface. The highest mountain peaks along the Hardangerfjorden became ice free as early as ~20 ka. Following the collapse of the Norwegian Channel Ice Stream, the ice margin stabilized just outside the outermost coast. A major withdrawal took place ~15 ka, possibly in response to the Bølling warming (Gump et al. 2017, Mangerud et al. 2017). The retreat was later interrupted by two re-advances that culminated ~14 ka (Older Dryas) and during the end of Younger Dryas. We find ^{10}Be- dating a very useful tool for making three-dimensional ice sheet reconstructions. The front of the ice sheet seems to have been surprisingly steep. In the Bergen area the ice surface appears to have reached an elevation of more than 700 m only some 15 km inside the front. However, in low-lying areas radiocarbon dating of basal lacustrine sediments provides more precise and accurate dates of the deglaciation.

ORAL

The Mineral Assemblage of Gas-charged sediments from Vestnesa Ridge, NW Svalbard – a tale of crystallization and dissolution

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We present a full-pattern quantitative phase analysis of x-ray diffraction data (QXRD, Vogt et al., 2002) from sediments taken within the active methane seep sites of Vestnesa Ridge, NW Svalbard. The 4 coring positions were controlled by remotely operating vehicle (ÆGIR 6000) with three sites within the active seep sites and one reference site outside the main activity. Hence, a clear differentiation between active and inactive with respect to methane gas flux can be shown. While the reference core can be related to well know sedimentary events in the vicinity of the W Spitsbergen shelf and Yermak Plateau – which are related to warm Atlantic water influx and/or deglaciation of the Svalbard ice sheets - gas-hydrate influenced cores contain particular carbonate mineral phases. Mg-rich calcites and

aragonites have been freshly precipitated in the vicinity of a sulfide methane transition zone (SMTZ) triggered by anaerobic methane oxidation (AOM) and sulfate reduction due to high methane flux through the sediments.

The QXRD allows also for the investigation of Fe-, Mn-oxides and –sulfides probably precipitated in the transition zones under changing redox-conditions. Combined with sediment and pore water geochemistry, the authigenic mineral assemblage indicative for a gas-hydrate influenced sediment can be described in much detail. While geochemical processes can be quantitatively viewed, the high resolution determination of authigenic minerals also helps to understand the past history of methane emissions in this Arctic gas hydrate system. .

POSTER

From fjord to land – Holocene climate of the Femmilsjøen area, NE Spitsbergen

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The overall aim of the project is to reconstruct the Holocene climate and glacial history of northeast Spitsbergen, based on a holistic approach including collection and integration of marine, terrestrial and lacustrine data. The area of main interest is the 8 km long lake Femmilsjøen in NE Spitsbergen, as well as its surroundings and the adjacent part of northern Wijdefjorden. Marine sediment cores and swath bathymetry data were collected just off Femmilsjøen in the summer of 2017. Lacustrine cores are to be collected in 2018. We expect that data series from different archives with restricted spatial distribution will reflect the various feedback mechanisms (e.g. the interaction between ocean-atmosphere, atmosphere-sea-ice, precipitation-ice-masses, increased runoff from glaciers and solar forcing) of the different elements in the climate system in that particular area. This will help to solve questions as whether the Late Pleistocene-Early Holocene fjord temperatures increased first and subsequently the glaciers on land retreated - or vice versa. Furthermore, we aim to identify if the same climatic signals occur in both archives synchronously. Preliminary results from the project will be presented.

POSTER

Sea-ice in the Iceland-Norwegian Sea during the last 50-60000 years: first results from the IS-4C marine core

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Sea ice coverage in the North Atlantic plays an important role in the Arctic climate system.

The aim of the study presented here is to reconstruct and time sea ice coverage in the Iceland-Norwegian sea during the Weichselian with the purpose of increasing our understanding of climate and oceanographic changes. The area is highly affected by the cold southward flowing East Greenland current and a branch of the warmer north-westward flowing Norwegian current, creating a complex zone of temperate and cold waters.

A 430 cm long marine sediment core, IS-4C, retrieved from 1598 m water depth in the Iceland-Norwegian sea, northeast of Iceland has been investigated with regard to quantity and source of ice rafted debris (IRD) as well as the abundance of planktonic foraminifera. These proxies have been counted at every 2-3 cm throughout the core. Radiocarbon dating indicate that the upper 251 cm of the core represent the

last 42000 years and the Vedde Ash is present in the uppermost 30 cm. More precise chronology with radiocarbon dating, tephrochronology and correlation of oxygen isotopic records from Greenland ice cores and the North Atlantic deep sea is in progress.

IRD has been identified to three main components; crystals, rock fragments and ash/tephra. Planktonic foraminifera have been counted and identified to species. These proxies display high amplitude variations throughout the core indicating variable sea ice flux. A low sea ice flux is recorded between 184 cm (39500 yr. BP) and 294 cm indicating an interglacial period. The investigation is ongoing.

POSTER

A new relative sea level curve from Mestersvig, NE Greenland based on isolation basins

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Our ability to model the past response of the Greenland ice sheet to climate change is fundamentally dependent on the quality and distribution of geological observations of ice margin history and relative sea level (RSL) observations. In Greenland, the extensive ice-free corridor provides an excellent opportunity to develop a network of well constrained RSL observations that can provide powerful glacio-isostatic adjustment (GIA) constraints over the post-glacial period. In southern Greenland, the RSL observations are in many places well constrained in contrast to northern Greenland where the data quality and spatial resolution is poorer. In this study, we present a new RSL curve from Mestersvig, Northeast Greenland. We used sediment cores from seven isolation basins collected at different elevations to identify the change from marine to lacustrine sediments using a multiproxy approach including XRF core scanning, magnetic susceptibility and diatom analysis. The marine-lacustrine isolations were dated using terrestrial macro fossils. Our new results will be compared to existing RSL curves from the area and with the latest RSL-based ice sheet model of Greenland.

POSTER

Putorana ice sheet advance over southern Taimyr, NW Siberia, during the Late Saalian (MIS 6)

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Previous studies in NW Arctic Siberia suggest that local ice caps around the Kara Sea shelf merged there repeatedly to form a Kara Sea Ice Sheet (KSIS). When assembled to a large ice sheet, initial northward flow from the Byrranga Mountains on the Taimyr Peninsula reversed as the ice sheet further expanded southwards. The most extensive glaciation over Taimyr occurred during the Taz/Late Saalian (MIS 6), during which the KSIS advanced from NW onto the Putorana Plateau south of Taimyr. However, stratigraphic sites along the Bol'shaya Balaknya River (situated on southern Taimyr) suggest that the Taz/Late Saalian expansion of the KSIS from NW was preceded by ice coming from the Putorana Plateau to the south, a conclusion based on our site BBR 16. This site reveals a fining upwards sequence from fluvial sands to shallow glaciomarine mud with shell fragments, dated with ESR to 171 ka BP. This sequence is glaciotectonically deformed and unconformably overlain by subglacial traction till. The glaciotectonic deformation as well as clast fabrics in the overlying till, indicate stress application from southerly directions. Our preliminary model suggests a marine transgression due to a growing Putorana ice sheet, before it overrode southern Taimyr during the Late Saalian (MIS 6). This occurred at the same time as a KSIS advanced

from the north beyond the Byrranga Mountains. The KSIS subsequently merged with the Putorana ice sheet and eventually pushed the maximum extent of Late Saalian ice well south of the Putorana Plateau.

POSTER

Facies model for a rebound cycle based on mid-late Quaternary sediments in the Kongsfjorden area, NW Svalbard

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Raised marine deposits found in coastal areas of the Arctic have been instrumental in reconstructing past sea-level change and glaciations during the Quaternary. This is because the high relative sea level indicated by the marine sediments is largely due to isostatic loading and thus implies a preceding regional (ice-sheet scale) glaciation. Kongsfjordhallet is one of several sites in the Kongsfjorden area in NW Svalbard with such deposits, and where successions of Quaternary sediments are exposed in up to 40 m high coastal cliffs (Houmark-Nielsen & Funder 1999). Here, we present results from a more detailed sedimentological and stratigraphical investigation of the uppermost 15 m of Kongsfjordhallet. While subglacial tills are scarce, marine and littoral sediments are volumetrically dominating, representing partial shallowing-upward sequences. Interestingly, we also find alluvial and periglacial deposits, which are not commonly recognized in this type of settings.

Based on this record we have further developed the facies model for rebound cycle by Alexanderson et al. (2011). An idealized record, representing glacial advance and overriding (facies A), deglaciation with isostatic rebound and successively shallower water (facies B-E) and eventually fluvial and periglacial processes (facies F) on ice-free land. Even if only a few of the facies are actually found per sequence, it still implies a regional glaciation. At Kongsfjordhallet, five cycles of glaciation and subsequent deglaciation during high but falling relative sea levels are recognized. These are dated by luminescence to range in age from ~190 ka to the last deglaciation (Alexanderson et al., this volume).

POSTER

The Weichselian chronostratigraphical framework of the Kongsfjorden Trough Mouth Fan, W-Spitsbergen

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The high-latitude Kongsfjorden Trough-Mouth Fan (TMF), situated on the continental margin west of Svalbard was fed by the Kongsfjorden paleo-ice stream system. A placement, which is ideally suited for recording glacial advances to the shelf break and thereby the development of the Svalbard Ice Sheet through time. During a survey in 2010, a regional seismic grid was established, consisting of 17 high-resolution seismic 2D lines (TOPAS). There were also retrieved a 12.65 meter long sediment core from the southern part of the Kongsfjorden TMF at 846 m water depth. Our preliminary conclusion fits well with the earlier proposed development models, which indicates that during the Weichselian glacial (117 – 11.6 ka), paleo-ice streams from the west coast of Spitsbergen advanced to the continental shelf-break three times. The new data acquired allow us to study the last two advances in greater detail than previously available. The upper half of the core displays a very varied character, with layers comprising ice rafted debris (IRD) inter-bedded with hemipelagic sediments, where the interval

between 2 – 5 m have been dated with AMS ^{14}C. An anomalous layer (at 270-335 cm) have been estimated to have an age between 23,3 – 25 ka, and is interpreted to comprise sediments from the last glacial maximum (LGM). The lower half of the core appears visually fairly homogenous, but have been interpreted to consist of alternating layers of GDFs and IRD related to the second advance during the mid-Weichselian, estimated to have occurred from about 70 ka.

POSTER

Evolution of Greenland's glaciers and ice caps in the 20th century

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About 20,000 glaciers and ice caps (GICs) surround the Greenland Ice Sheet. These GICs cover 7% of the glaciated area in Greenland but store less than 1% of the total ice volume. It is estimated that 14-20% of the total ice loss from Greenland between 2003-2008 could be attributed to the GICs, therefore they contribute far more to global mean sea level rise than their size relative to the Greenland Ice Sheet would suggest. They could make a significant contribution in the 21st century, as they are more sensitive climate indicators and adjust their size in response to climate change more rapidly than ice sheets. Estimates for the 20th century that predates the modern age of remote sensing, use records from half a score of GICs to obtain estimates of the mass loss for Greenland as a whole. This has implications for our understanding of past glacier evolution and its coupling to climate, and hence also limits our ability to predict the future. This project aims to produce an improved observational data set for physical and statistical modelling of ice loss with regional granularity. The record will extend back to the Little Ice age, when the GICs began to retreat from their maximum positions. Data and models will be developed to facilitate an analysis of factors driving GIC evolution in the 20th. Finally, the data will be used as input for inversion modelling of glacier evolution of a subset of ice caps enabling a forward simulation of future behavior.

POSTER

Paleoceanographic ocean surface conditions in Kongsfjorden, Svalbard over the last 400 years

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Marine subfossil diatom assemblages from Kongsfjorden are used to investigate sea surface temperatures (SST) and sea ice variability in high temporal resolution. The oceanographic conditions in Kongsfjorden are strongly related to the characteristics of the West Spitsbergen Current (WSC), transporting Atlantic Water (AW) and therefore heat and salt into the Arctic Ocean (Svendsen et al., 2002). Changes in the AW inflow can have a major impact on the environment of the Svalbard area (Ślubowska-Woldingen et al. 2007).

A 49 cm long marine sediment core was analyzed for diatoms and grainsize at 1.0 cm intervals. Diatoms were abundant in the top 16 cm. The AMS 14C dates suggest the basal age of ca. 400 cal yr. BP. The diatom-based SST reconstruction based on the North Atlantic surface sediment sample calibration data set (Miettinen et al. 2015) and WAPLS transfer function method (Ter Braak and Juggins 1993) indicates temperature variation between 4.1 to 6.0 ˚C with a mean temperature of 4.8 ˚C. The qualitative sea ice reconstruction is based on the Marginal Ice Zone (MIZ) diatom assemblage. Factor analysis with the North Atlantic diatom factors based on Andersen et al. 2004 was used to estimate the

variability of water masses. The preliminary results show a cooling trend in both SST and sea ice since the Little Ice Age, and a very recent warming during the past decades. Grain size is dominated by fine fraction, but in the upper 15 cm coarse fraction increases up to 40 %, indicating change in depositional conditions.

POSTER

Characteristics of wave-built sedimentary archives in Buor Khaya Bay (71°N/130°E), Siberian Arctic, Russia.

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Prograded sequences of beach deposits preserve valuable paleoenvironmental information on the long-term variability of the (wave-) climate forcing driving centennial to millennial coastal evolution. Buor Khaya Bay, NE Siberian Arctic, is located at the transition between the Verkhoyansk mountain range and the Arctic Ocean and is one of the few places along the Russian arctic coast, where wide beach-ridge systems exist. Two field sites in Buor Khaya Bay were visited during an expedition in August 2017 in order to obtain baseline information to assess the potential of the systems for the reconstruction of Holocene sea level and past sea-ice extent. The inner parts of the bay are ice-free for three to four months during the short boreal summer. The wave forcing of the system is hence a function of the duration of ice-free conditions and fetch across the open sea surface. Both systems are composed of several sets of beach ridges composed of sand- to cobble-sized shales of local origin. The morphological arrangement of landforms and the characteristics of the beach deposits evidence (1) extensive periods of continuous progradation, and (2) unconformities with changes in ridge orientation suggesting fluctuations in the directional components of energy supply and sediment delivery.

The project is at an early stage of investigation and we present first insights into a new and promising area of investigation. Work will be continued in summer 2018.

POSTER

Ice marginal fluctuations of local ice caps in McCormick Fjord, NW Greenland

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Knowledge about the glacial history of the Greenland Ice Sheet and its dynamic response to past climate variability is important to put the current changes into context. In southern and eastern Greenland, a number of recent studies have documented the ice marginal response to Holocene climate variability (Lowell et al. 2013, Larsen et al. 2016), but from northern Greenland there are very few observations.

In this study, we use a multiproxy approach to try and constrain the Holocene glacial history in McCormick Fjord in northwest Greenland. Due to the occurrence of moraines and the absence of marine content in several retrieved lake cores, we speculate that the area might has been subjected to an early Holocene ice advance that dammed the area from the inflow of marine waters from the fjord.

During the field season 2016 and 2017 we retrieved sediment cores from 5 lakes in different elevations, samples for cosmogenic exposure dating from two moraines, shell fragments and mosses from the margin of a nearby local ice cap. Here we present C^{14} ages and XRF data of 6 sediment cores and C^{14} dates of moss samples - the rest of the samples are scheduled to be processed in early spring 2018.

With the collected data, we expect to obtain an overview of the deglaciation history in McCormick Fjord. We will discuss the ages and data in relation to existing climate records from the area and put the new results into context.

8.2. Glacial processes, deposits and landforms

ORAL

Palaeo-ice streams in NE-Iceland: a new project and the first findings

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Current understanding of the configuration, geomorphological imprint, dynamics and recessional history of palaeo-ice streams in Iceland is limited. A new project aims to advance our knowledge of palaeo-ice streams in NE Iceland by investigating the glacial landform associations and sedimentary records in the Vopnafjörður, Bakkaflói, Þistilfjörður and Jökuldalsheiði areas, using multiple glacial geological, geomorphological, remote sensing, geophysical/geotechnical and chronological methods. The project is designed to elucidate the relative timing and spatial distribution of fast ice flow, the absolute timing of ice-stream/ice-sheet recession and thinning, and the mechanisms contributing to fast flow and the genesis of streamlined subglacial bedforms. The project can thereby provide insight into marine-ice sheet instability and the vulnerability of marine-terminating ice streams to sea-level rise, and further our understanding of ice sheet deglaciation dynamics. An important benefit of this project will be the value of its results for constraining numerical models aimed at illuminating subglacial landform development and the evolution of the Iceland ice sheet during the last deglaciation.

Preliminary mapping suggests that the flow sets of several apparently cross-cutting former ice streams are preserved in the glacial landform record. This includes onset zones with reticulated ridges and hummocky topography, and trunk-flow zones with elongate subglacial bedforms, rhombohedral ridge-networks and regularly-spaced transverse ridges. Reconnaissance fieldwork in 2017 indicates that elongate sedimentary bedforms consist of deformation till and sorted sediments, and that rhombohedral and transverse ridges are mainly composed of till. Future excavations and GPR surveys aim at revealing the internal structure of these landforms.

ORAL

Interpretation of glaciotectonic complexes from analysis of thin-skinned thrust-fault structures in seismic sections, an example from the Jammerbugt in eastern North Sea.

Lars Ole Boldreel[1] and Stig A.S. Pedersen[2]
[1]IGN, KU, [2]GEUS

During the last decade, a number of glaciotectonic complexes have been recognized in the North Sea (Andersen 2005, Bendixen 2016, Larsen & Andersen 2005, Novak & Leth 2015, Pedersen & Boldreel 2017). The mapping of these complexes are merely depending on interpretation of qualified seismic data, which enables structural interpretation. This presentation demonstrates the complexity of seismic interpretation of glaciotectonic structures by the investigation of the Jammerbugt Glaciotectonic Complex.

The Jammerbugt Glaciotectonic Complex, eastern part of the North Sea, occupies an area of more than 300 km^2 located about 10 km offshore the west coast of northern Denmark. The bedrock included in the complex comprise the main part of the Cretaceous Chalk Group in the North Sea. The detachment surface in the proximal part of the complex occurs in Lower Cretaceous greensand about 400 m b.s.l. In the central part of the complex the thrusting ramps the strong reflectors at the base of the Chalk Group and the

detachment surface continues in the lower part of the Upper Cretaceous chalk throughout the distal part.

The Eemian–Early Weichselian Skærumhede Group onlap the deformed beds at the boundary to the tectonic depression north of the complex indicating a Saalian age of the glaciotectonic deformation. The calculation of the displacement during balanced cross section construction demonstrates that the thrust sheets in the tailing end of the complex had their source in the Skagerrak Sea. Thus, we suggest that the hole caused by displacement of thrust sheets contributed to formation of the Skagerrak depression.

ORAL

Computer supported 3D modelling of the Hanklit glaciotectonic complex, Mors, Denmark

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The Hanklit coastal cliff is a glaciotectonic locality where an excellent cross-section through a thrust fault complex is exposed. The structural architecture and structural features of the glaciotectonic complex is modelled in the 3D modelling software, Leapfrog Geo.

The structural elements in the Hanklit Complex consist of thrust sheets interpreted to be the result of the Norwegian ice advance in a pro-glacial glaciotectonic deformation about 30-28,000 years ago. It consists of a 60m thick succession of Eocene diatomite overlain by 15m of glacial deposits. The Hanklit Thrust Sheet extends for more than 1km along the W-E strike and is displaced for more than 300m to the south (Klint & Pedersen, 1995). The Hanklit Thrust Sheet is thrusted across the foreland feature named Gullerup Thrust Sheet, whereas the Salgerhøj Thrust Sheet describes the northernmost thrust element ramping up and displaced upon the back of the Hanklit Thrust Sheet. In the frontal part of the Salgerhøj Thrust Sheet a hanging-wall anticline is developed with overturned limbs. This hanging-wall anticline can be followed for nearly 10km along the crest of the highest hills on Mors. A balanced cross section is provided. The depth to the décollement zone is determined and the displaced along the shallow dipping ramp and flat is calculated.

The Hanklit Thrust Fault Complex is a well-documented thrust fault structure, and the model is a good illustration of the thin skinned thrust fault, and can also be compared to structures that occurs in mountain ranges like the Jura mountains.

ORAL

Diagnosing ice sheet grounding line stability from landform morphology

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Marine-based ice sheet stability is largely dictated by processes at or near the grounding line, where marine and glacial processes and the topographic setting govern the duration of grounding line occupation and sensitivity to retreat. Landforms that are built at the grounding line, such as grounding zone wedges and recessional moraines, are inscribed extensively on formerly glaciated continental margins. These landforms directly mark former grounding line positions over a prolonged period of retreat (thousands of years), represent the history of sedimentation during the occupation of each position, and offer high potential for extracting information about grounding line dynamics.

We characterise the morphological traits and spatial distribution of thousands of grounding line landforms from the Ross Sea continental shelf, which mark Antarctic Ice Sheet retreat since the Last Glacial Maximum. Recessional moraines indicate a consistency of grounding line processes/setting and regularly forced retreat,

while grounding zone wedges are highly variable in size and shape, developing both asymmetry and sinuosity during landform growth. We attribute growth of sinuosity to lateral variability in sediment delivery along the grounding line, linked to basal meltwater drainage. This development of sinuosity over time is commonly associated with larger-magnitude retreat events. A 'stable' grounding line position of relatively long duration may thus be linked with an 'unstable' retreat event. Landform construction is surprisingly insensitive to the local topographic setting. We explore the processes controlling the production of contrasting grounding line landform morphologies and, consequently, what these morphologies reveal regarding the (in)stability of a retreating ice sheet.

ORAL

Details in glacial terrains detected from Digital Terrain Models brings new light upon the Danish glacial landscape

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Previously unnoticed landforms of former glaciated terrains in Denmark can now be revealed from studies using Digital Terrain Models (DTMs) provided by the Danish Geo-data Agency. The removal of buildings, vegetation etc. from DEMs with 25m, 10m and 1.6 m grids allow exposure of details in landforms not earlier subjected to investigation. GIS-based studies of hill shaded DTMs – on land as well as on the sea floor –combined with Quaternary geological mapping and data from open exposures as well as the use of the rich literature on the Danish glacial landscape and its origin, gives new insight into glacial landforms, that was formed along the lowland fringes of the Scandinavian Ice Sheet during the last two glaciations.

In this lecture focus will be on subglacial landforms and their distribution around the country. Here single or multiple generations of streamlined terrain with increasing size ranging from tens of meters to tens of kilometres are presented. Other subglacial features include eskers and tunnel-valleys. Examples are given on the combination of easily accessible on-land features and obscured terrains partly buried on the sea floor into a more whole appearance of glacial landforms. In order to establish a meaningful and modern model of the ice age landscapes in Denmark, subglacial terrains are but one of many pieces of the puzzle and they must be seen in relation to other glacial landforms such as terminal moraines, dead-ice land forms and features related to proglacial erosion and long time periglacial reshaping.

ORAL

Mapping of glaciotectonic structures and associated sedimentary deposition with ground penetrating radar

Peter Roll Jakobsen[1]*, Hans Lerche and Cecilie Skovsø Andersen*
[1]GEUS

The analysis of glaciotectonic structures and geological setting is best done in outcrops, but as they are limited both in occurrence and in lateral extent, geophysical methods are often used to interpret the geology. Ground penetrating radar has proven to be an excellent method to determine sedimentary structures as well as deformation structures.

Examples of structural analysis are given from small composite ridges in the northwestern part of Jylland created during the general retreat of the Main Glacial Advance in the late Weichselian. Other examples are given from Northwest Sjælland where two georadar investigations were carried out in the rim of the large end-moraines from a re-advance of the Young Baltic Advance, about 17.000 years ago.

The radar profiles are differentiated into radar facies with distinct reflection characteristics.

Glaciotectonic deformations such as thrusts and folds are interpreted from the GPR data. Furthermore syn-tectonic and post-tectonic sedimentation is interpreted from the radar profiles.

The examples show that the morphology of the ridges investigated is controlled by the deformation structures, and that penecontemporaneous sedimentary processes have smoothened the morphology created by the deformations.

ORAL

Geomorphology and distribution of subglacial triangular hummocks (murtoos) in Sweden and Finland

Mark D. Johnson[1], Joni Mäkinen[2], Gustaf Peterson[3], Antti Ojala[4], Jukka-Pekka Palmu[4], Kari Kajuutti[2], Christian Öhrling[3] and Elina Ahokangas[2]
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Triangular or V-shaped hummocks of subglacial origin have been identified in Sweden and Finland due to the increased resolution provided by LiDAR imagery. Their triangular shape is distinctive and recognizable as a clearly identifiable landform. These forms have been previously mapped in some cases as dead-ice hummocks, but geomorphic relationships with eskers, flutes and De Geer moraines show these to be subglacial. Good examples of these forms occur near Murtoojärvi, Finland, and we propose calling these new landforms 'murtoos.' Individual murtoos are diamond and triangular shaped with the axis of the triangle parallel to regional ice flow. Murtoos have a longitudinal spacing on 50 to 200 m, and their widths are on the order of 50 to 100 m. They are asymmetric with a gentle up-ice side and a steeper down-ice side. Often, they have a shingled appearance. In many cases, they occur in patches in an ice-flow parallel path with eskers defining corridors we believe to be of subglacial meltwater origin.

Murtoos are composed primarily of heterogeneous diamicton with minor amounts of bedded sand.

Murtoos are common in Finland and Sweden and we present a map of their distribution. They seem to be most common where ice-retreat rates were high during deglaciation, and they are absent where extensive frozen-bed conditions were present.

ORAL

The framework of glaciotectonic complexes and their position in the glaciodynamic sequence stratigraphy

Stig Schack Pedersen[1]
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The analysis of glaciotectonic complexes uses the classification of architectural surfaces. These comprise four orders of surfaces (Pedersen 2014). The first order includes the décollement zone and the topographic surface, which define the bottom and the top of complexes. The second-order surfaces are the thrust-faults, which bound the thrust sheets and duplexes that constitute the internal framework of tectonic complexes. The third order comprises folded beds appearing in the internal structure of thrust sheets. The fourth order includes all small-scale structures like joints and faults with minor displacement, which are important for the prediction of dynamic development (Pedersen 2000).

For the interpretation of the dynamic development, three macroscopic regimes are defined: the distal, the central and the proximal part of glaciotectonic complexes (Pedersen 2005). In the distal regime close to the foreland, flat-lying thrust-faults displace thin thrust sheets. In the central regime, steep dips of thrust faults occur together with hanging-wall anticlines. Towards the proximal part of complexes superimposed deformation of duplexes occur, which result in vertical orientation of surfaces. Glaciotectonic complexes may include superimposed deformation related to

development in one event or superimposing of several events. Glaciodynamic events are differentiated by application of glaciodynamic sequence stratigraphy, which combines depositional and structural features (Pedersen 2012).

ORAL

Subglacial till deformation: lessons from laboratory experiments

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In a detailed study of mega-scale glacial lineations (MSGLs) left by a Weichselian palaeo-ice stream in Poland, Spagnolo et al. (2016) analysed multiple parameters of the land-forming till and concluded that it originated by a combination of lodgement and thin-skinned deformation whose cumulative effect was the formation of the MSGL field.

To advance our understanding of till formation and deformation postulated by Spagnolo et al. (2016) we conducted a series of experiments on this till in a large ring-shear apparatus intended to mimic subglacial shearing (Bering Holdensen 2017). Undisturbed, oriented samples for micromorphological analyses were taken at displacement increments of 0, 9, 18, 36, 72, 144, 288, 576 and 1152 cm.

Till microstructures mapped on thin sections across the zone of shearing gave intriguing and hitherto unmatched insights into the development and evolution of till properties during the shearing under controlled boundary conditions. The deformation signatures often varied non-systematically between the sampled increments.

Three-dimensional microtomographic scanning showed intervals of relatively stable till fabrics intervening with phases of fabric re-orientation towards new equilibria. Shear stresses during the deformation showed a distinct cyclicity possibly indicating formation and collapse of grain bridges.

Collectively, we interpret the ring-shear data as a signature of permanent and sometimes unsystematic evolution of till structure with a general trend towards more ductile and less brittle deformation with increasing strain. These results bear on the reconstruction of past subglacial processes and we advocate extreme caution with interpreting the history of natural tills based on the micromorphological signatures alone.

ORAL

Glacial landform evolution in transitional cold – warm bed subglacial conditions in the central part of Scandinavian Ice Sheet, in northern Finland

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On-going glaciomorphological mapping in Finland based on airborne LiDAR (Light Detection And Ranging) interpretation has revealed new data that is useful for the glaciodynamic examination in the glaciated terrain. One of the key study areas in Finland has been the Kuusamo Ice Lobe area close to the Late Weichselian ice-divide zone in Finnish Lapland. The glacial morphology of the ice lobe is composed mainly of moraine morphologies such as the glacial streamlined lineations of the Kuusamo drumlin field in the eastern part and different hummocky and ribbed moraines in the western part, i.e. at the core of the ice lobe. The drumlin field was formed under surging type glacial movement during Younger Dryas while the core part of the glacier remained cold-based.

Glaciofluvial deposits (eskers and delta formations) occur in places representing last deglaciation phase. Particularly, ribbed moraines represent the depositional formations formed under subglacial conditions at the transitional zone between the warm and cold based glacier. However, an erosional, subglacial meltwater channel network cutting the ribbed moraine formations before the deposition of glaciofluvial deposits and smoothly lineated surface of morainic terrains by glacier reworking gives new knowledge of the formation phases of subglacial moraine formations in the core part of continental glacier. As the subglacial meltwater activity that formed the erosional channel system and later channel fills such as eskers was worked after ribbed moraine formation, the origin of the ribbed moraines must be earlier process, happened close to cold-based core part.

ORAL

Active retreat of a Late Weichselian marine-terminating glacier revealed by large-scale glaciotectonics in Melasveit, western Iceland

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Large and complete glaciotectonic sequences formed by marine-terminating glaciers are rarely observed on land, hampering our understanding of the behaviour of such glaciers and the processes operating at their margins. During the Late Weichselian in West Iceland, marine-terminating glaciers deformed glaciomarine sediments. These formations are now exposed in >5km long coastal cliffs in the Melasveit district, recording past glacier dynamics and the interrelationship between glaciotectonic and sedimentary processes under/in front of a marine terminating glacier. The sedimentology and glaciotectonic architecture of the coastal cliffs reveals a series of subaquatic moraines formed by a glacier emanating from Borgarfjörður to the north. The style of deformation demonstrates that these moraines were primarily built up by ice-marginal/proglacial thrusting and folding of marine sediments as well as deposition and subsequent deformation of ice-marginal subaquatic fans. The southernmost and largest of the moraines is over 1.5 km wide and more than 30 m high and is interpreted to indicate the maximum extent of the Borgarfjörður glacier. Generally, the other moraines become progressively younger towards the north, designating an advances or still-stands of the glacier as it oscillated during an overall retreat. Glaciomarine sediments rapidly accumulated in front of the glacier and filled in the depressions between the moraines when the glacier finally receded from the area. Previously obtained radiocarbon dates from the deformed sequence suggest that these moraines were formed in the Younger Dryas. This study highlights the dynamics of marine-terminating glaciers and may have implications for the interpretation of their sedimentological and geomorphological records.

ORAL

Glaciotectonic analysis of the geology in the NE part of Sjælland, Denmark, based on interpretation of vibro seismic data along the west bank of Esrum Sø

Line Winsløw[1], Stig A. S. Pedersen[2] and Lars O. Boldreel[1]
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In the northeastern part of Sjælland, two outstanding morphological elements are present: the composite hill ridges characterizing the terrain in Gribskov and the elongated depression lodging Esrum Sø. A simple glaciodynamic interpretation of their formation is that they represent a hill-and-hole pair with Esrum Sø representing the hole from where the material for

the composite hills in Gribskov derived. This interpretation satisfies the general N–S trend of the morphological elements.

However, the northern part of Esrum Sø trends SE–NW parallel to the buried Esrum-Alnarp valley suggesting a tectonic origin of the lake morphology. For the investigation of this hypothesis, a 6.3 km vibro seismic profile was collected along the western bank of the lake. During the analysis of the seismic profile, a large glaciotectonic complex was recognized. The complex comprises five sections, which characterize the distal to the proximal structural development. The translation of the complex was from a northerly to a southerly direction over a décollement surface, which stepwise rises from 95 m b.s.l. in the northern proximal region shallowing toward the southern distal region. The glaciotectonic complex comprises ramps and flats with related hanging wall and footwall structures.

The glaciotectonic complex developed during the advance of the Scandinavian Ice sheet in the Late Weichselian (30,000-20,000 B.P.). During the initial phase, glaciofluvial sediments accumulated proglacially. These were later thrusted into piggyback duplexes. Following the recession of the ice, a glaciolacustrine environment appeared. In a final phase, a superimposed glaciotectonic deformation occurred concluding the development the glaciotectonic complex.

POSTER

Subglacial or Pro-glacial Deformed Middle-Late Weichselian Ridges in Jyderup Skov, Odsherred, Denmark

Cecilie Skovsø Andersen[1]
[1]Former student at University of Copenhagen

The aim of this study is to investigate the glaciotectonic deformation of the ice-push ridges on the outer edge of the Vig-Hønsinge Arc in Jyderup Skov, Odsherred, Denmark. By measurements of Ground Penetrating Radar (GPR) reflections profiles across the structures, the project will aim to produce a geological model with emphasis on a structural analysis of deformed meltwater sediments. The ridges are parallel to the terminal moraine of the Vig-Hønsinge Arc formed by the Bælthav Readvance and are located on the proglacial meltwater plain ahead of the terminal moraine. The ridges were investigated by six 250 MHz GPR lines perpendicular to the ridges and one GPR line striking parallel to the ridges. The GPR lines were successfully recorded and needed only very little processing and patience with estimating the migration velocity, as diffractions were many. 8 Facies have been determined from the radar stratigraphic analysis. Two facies of glacio-fluvial sand and gravel, which are folded and thrusted respectively indicating both ductile and brittle style deformation, with complex imbricate fans. Additionally, deformed seasonal outwash, channels, till, kames, landslides and cover sands are interpreted as well. The GPR lines are deformational shortened by 7 % on average. Two different scenarios are suggested to explain this deformation; A: A surge and sustained advance and B: Recession on an annual scale. Based on the distribution of the radar stratigraphic facies is scenario B interpreted to be the most likely one to have happened.

POSTER

New subglacial landforms detected from LiDAR data

Kari Kajuutti[1], Joni Mäkinen[1], Elina Ahokangas[1], Antti Ojala[2] and Jukka-Pekka Palmu[2]
[1]University of Turku, [2]Geological Survey of Finland

High-resolution DEMs produced from LiDAR provide a revolutionary tool for the mapping and documentation of glacial landforms over wide areas (e.g. Johnson et al. 2015). The main resource for this study was the Maankamara map service (http://gtkdata.gtk.fi/maankamara/) of the Geological Survey of Finland (GTK) where LiDAR data is supplemented with base maps and maps of the Quaternary deposits as well as bedrock, striation and the highest shoreline data.

Indeed, while studying the deglaciation of the past Scandinavian ice sheet after the Salpausselkä III stage in SW Finland (Kajuutti et al. 2016), our attention was drawn to formations being surprisingly regular triangles in shape.

Even though the triangular landforms are clearly identifiable from LiDAR-based DEMs, they are almost impossible to detect from map contour-lines, other remote sensing images or even in the field within forest covered areas. The triangles consist of till and are typically 100 – 200 m long and 2 – 5 m high. Our hypothesis is that the triangular landforms and related other features belong to routed, large-scale subglacial drainage systems forming a continuum between channelized (eskers) and more widely spread small-scale distributed subglacial drainage (Mäkinen et al. 2017).

We have started co-operation with Swedish researchers (cf. Peterson et al.) aiming to a joint publication that will show the distribution of the triangles in both countries and moreover expand our knowledge of their sedimentology and origin. The name for the new landforms will be published both in our forthcoming paper as well as in the NGWM meeting.

POSTER

Using large-scale patterns and morphology of subglacial meltwater corridors to gain insight into the spatial organisation, formation and evolution of meltwater drainage beneath ice sheets

Emma Lewington[1], Stephen Livingstone[1], Andrew Sole[1], Chris Clark[1] and Sarah Greenwood[2]
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While spatio-temporal variations in the efficiency of the subglacial drainage system have been identified as a key control on ice sheet dynamics, the inaccessibility of the bed means its precise character and evolution remains poorly understood. Palaeo-bedforms provide one solution to this, enabling the reconstruction of relict networks over large areas. Such investigations have been facilitated by the release of freely available, high-resolution digital elevation models (e.g. ArcticDEM).

This study focuses on subglacial meltwater corridors (SMCs), characterised as elongated tracts of hummocky sediments often associated with eskers, glaciofluvial sediments and eroded bedrock. Similar features have been recognised before (e.g. Rampton et al., 2000; Utting et al., 2009; Peterson et al., 2017) but their distribution over ice-sheet scales has yet to be considered. This is an important consideration for determining the formation of these features and confirming their link to subglacial meltwater i.e. identifying the source, magnitude and duration of flow required.

We use a large-scale mapping approach to understand the spatial pattern of palaeo-subglacial flow beneath large parts of the former Laurentide and Fennoscandian ice sheets. An automated method for identifying and mapping these features is developed based on the high degree of roughness within these channels which distinguishes them from the surrounding bed. The outputs of this approach are compared to traditional manual techniques and detailed morphological investigations to provide insights into the nature of the drainage system and to contextualise limited observations of contemporary subglacial meltwater drainage.

POSTER

Sedimentology of the new subglacial landforms detected from LiDAR data in SW Finland

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New triangular-shaped glacial landforms have been identified and described from LiDAR-based DEMs in SW Finland (Kajuutti et al. 2016;

Mäkinen et al. 2017). Our hypothesis is that they and related other features belong to routed, large-scale subglacial drainage systems forming a continuum between channelized (eskers) and more widely spread small-scale distributed subglacial drainage.

We present the first sedimentological description of the new triangular landform from SW Finland and tentatively discuss the depositional environment and related processes. The general sediment characteristics include stratified gravel-sand core covered by loose sandy/gravelly, massive/matrix-supported diamictons interbedded with disturbed, laminated sand beds. The paleoflow pattern is lobe-shaped with boulder-rich margin. Maximum size of the boulders in the sediment is ca. 1 m and the clasts are angular to edge-rounded. The sediment characteristics do not fit into current conception of subglacial glaciofluvial deposits or tills, but rather support the continuum between these as also indicated by the morphological characteristics.

Ongoing co-operation with Swedish researchers (cf. Peterson et al. 2017) will expand our knowledge on the sedimentology and genesis of these new landforms. Their name will be published both in our forthcoming paper as well as in the NGWM meeting.

POSTER

Sedimentological and morphological implications for the understanding of murtoo formation in Sweden

Gustaf Peterson[1], Mark D. Johnson[2] and Christian Öhrling[3]
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During glacial landform mapping in southern Sweden, a new distinct landform was detected, which we refer to as murtoos. The landform appearance is a V-shaped hummock, generally pointing down ice with an asymmetric vertical profile along its axis. The LiDAR DEM of Sweden has been surveyed for murtoos, and they commonly throughout the country, most frequently north of the Younger Dryas ice margin and in areas deglaciated during Bølling-Allerød in the south. We have excavated murtoos at four localities and have studied the internal structure through detailed sediment description. The distribution, geomorphology and sedimentological properties of murtoos collected here provide an opportunity to understand their genesis.

Murtoo sizes are roughly 10-100 meters wide, 5 to 50 m long, and 2-10 meters high. The individual murtoos have an overlapping appearance and occur as fields. In places, elongated fields trend parallel to the overall ice flow direction. Commonly, Murtoos occur in close relation to ribbed moraine and, in places, they are draped by eskers and overprinted by flutes, indicating murtoos form subglacially. Murtoos predominantly consist of a heterogeneous sandy gravelly diamicton, with angular to sub-angular clasts. Lenses of sorted sediments are intermixed in the diamicton and boulders are common on the surface. Further, their distribution in Sweden suggests a formation during periods of rapid ice retreat. We list multiple hypotheses, their pros and cons, and discuss them to shed light on the formative process.

POSTER

A new glacial deposits and features database of Finland

Niko Putkinen[1], Pertti Sarala[1], Satu Putkinen[1], Jukka-Pekka Palmu[1] and Antti E. K. Ojala[1]
[1]Geological Survey of Finland

Renewing of the glacial deposits and features database is going-on in the Geological Survey of Finland (GTK). It includes both a new definition of the landform categories and mapping work based on the 2-metre resolution LiDAR (Light Detection And Ranging) data interpretation with ArcGIS software. Preliminary sources for map

polygons and lines are: 1. LiDAR-DEM data provided by National Land Survey of Finland, 2. GTK's Quaternary geological 1:20 000 and 1: 200000 data, 3. aggregate, engineering geological and groundwater aquifer investigations. The multi-year project aims to produce 'the best mapping data for each location in Finland' with a cost-effective, minimal fieldwork approach. The mapping process combines both the main geological unit (deposit) and a new, landsystems-based glacial geomorphological feature information. Recent studies have shown that previously detected large mega-scale glacial features, such as mega flutings, drumlins, end moraine complexes and glacial melt water systems show up in LiDAR-based digital elevation models (DEM) in greater detail than ever before (Putkinen et al., 2017). The new map database will significantly improve mineral exploration, groundwater studies, land use planning and management. In the future, the database will be linked to the nationwide stratigraphical units and be extended to the national subsurface 3D database. The glaciodynamic themes included in the database are: Glacifluvial deposits, glacially lineated terrains and various types of other moraine types referred to much slower ice flow velocities or different glacier margin landforms (ribbed moraines, hummocky moraines, De Geer moraines and end moraines).

8.3. Open session Quarternary geology

ORAL

Repeated fluvial sedimentation during the late Pleistocene in Kitinen valley, Sodankylä

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New studies confirm (Sarala et al. 2015, 2016, Lunkka et al. 2015) that Weichselian glaciation in Central Lapland has been more complex than previously assumed. Three to four interstadials have been suggested based on the existence of intertill sorted deposits and pollen assemblages of organic layers. In addition, subtill fluvial deposits have now been discovered in test sections of Kärväsniemi, in Sodankylä, indicating that the area was ice-free during Early and Middle Weichselian. The Kärväsniemi site consists of three till beds and four sorted sediment units. The OSL ages of the lower fluvial deposit vary between 67-79 ka, suggesting deposition during Odderade (MIS 5a). The upper sorted deposit, interpreted as fluvial bar and channel lag deposit, may have deposited during Middle Weichselian interstadials (MIS 3). These two subtill sorted deposits, separated by a thin till unit, could be also correlated to Tärendö I and Tärendo II (Hättestrand & Robertsson 2010) of the Riipiharju stratigraphy in northern Sweden. The sorted deposits in Kärväsniemi can be correlated with the lacustrine deposits of Sokli (Helmens et al. 2007).

A 3D model of surficial deposits was generated along with a GIS database and GPR interpretations to study sedimentation in the Kärväsniemi area (Åberg et al. 2017). The sedimentation history in Kärväsniemi has at least three phases of fluvial deposition, disturbed by deposition of three till units. The non-destructive

contacts of the overlaying tills suggests that they were deposited from a stagnant frozen-bed ice sheet indicating an overall weak glacial erosion in Kärväsniemi.

ORAL

An interglacial deposit from Copenhagen, Denmark: marine isotope stage 7

Ole Bennike[1], Jens Galsgaard[2], Joakim Stiel Korshøj[2], Geoffrey Lemdahl[3], Kirsty Penkman[4] and Richard Preece[5]
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During the construction of a new Metro station in Copenhagen, fossiliferous organic sediments were encountered. An investigation was undertaken on the organic sediments, which occurred beneath a succession of a lower till bed, glaciofluvial sand and gravel, an upper till bed and glaciofluvial sand. The organic sediments were rich in plant fossils and the flora show that the region was forested but included some light-demanding species. The flora includes Najas minor, which today has a northern geographical range limit in Germany. Shells of freshwater molluscs were frequent, but the diversity was rather low. Bithynia opercula were abundant, allowing the sediments to be put into an aminostratigraphical framework. The amino acid racemisation ratios indicate that the organic sediments formed during early MIS 5e or more likely during MIS 7. The older attribution is consistent with OSL ages of 206 and 248 ka. The assemblages from Trianglen are similar to those reported from deposits recovered during the construction of the free port (1.4 km away) in Copenhagen in 1892, except that Corbicula was not found at Trianglen. The presence of Corbicula indicates a pre-Eemian age. AAR data from Bithynia opercula from the free port were almost identical to those from Trianglen, indicating that the two sites are contemporary. We suggest the Trianglen interglacial be used as a local name for the MIS 7 interglacial deposits.

ORAL

A bag of sand from the ice-concealed, 31 km large Hiawatha crater in North-West Greenland: samples of the impact plume, ejecta blanket and crater floor from a recent meteorite impact through the Greenland ice sheet

Adam A. Garde[1], Tod E. Waight[2], Christian Weikusat[3], Carsten Guvad[1], Svend V. Funder[4], Kurt H. Kjær[4], Iain McDonald[5], Jette D. Møller[6] and Gernot Nehrke[3]
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Hand-picked, sand-sized grains from a recent glaciofluvial sediment from the Hiawatha Glacier draining the Hiawatha impact crater, Inglefield Land in North-West Greenland, provide rare new insight into melting and crystallisation processes and unusual incorporation of organic carbon in the uppermost parts of a large, young impact structure.

The bulk sand composition mimicks the regional Palaeoproterozoic, granulite-facies paragneiss bedrock. Predominating {10-13}, {10-12} orientations of shock lamellae in quartz indicate a threshold shock pressure of >16 GPa. Yellow, green, brown and black, variably carbon-bearing glass fragments have feldspar-, biotite- or garnet-like compositions and high volatile contents suggesting direct melting of these minerals and admixture of H_2O and organic carbon. Microporphyritic to microcrystlline particles have similar and occasionally crustal-melt-like compositions. Microliths of euhedral, zoned and/or skeletal feldspar, orthopyroxene, clinopyroxene, ilmenite and cordierite suggest rapid crystallisation and partial quenching. An

ellipsoidal grain with radial crystallites may represent a melt droplet from the impact plume. Ejecta blanket? microbreccias with glassy or microcrystalline matrix contain abundant bedrock mineral splinters.

Sand-sized carbonaceous grains and centimetre-sized charcoal fragments picked from glacier ice preserve conifer cell structures; their highly variable reflectance corresponds to 150-1200°C heating. Raman graphite-o-peak spectra of carbon in microbreccia matrix, glass and microlith coatings likewise show a wide range of ordering without evidence of metamorphic overprinting, unlike carbon in the Norwegian Gardnos crater (Parnell & Lindgren 2006). The Hiawatha carbon was probably derived from Pleistocene tree trunks buried under the ice; the ice sheet likely protected them from being blown away during the initial impact phase.

ORAL

The Last Glacial and Holocene Seismostratigraphy and sedimentation history of the Lake Bolshoye Schuchye, Polar Ural, Arctic Russia

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The seismostratigraphic studies of the 11 km^2 and the 136 m deep Lake Bolshoya Schuchye, Polar Ural, Arctic Russia, have unrevealed that the lake is apparently preserving up to a 130-150 m thick pile of seismostratigraphic laminated sediments. With aid of a Sparker array seismic and sub bottom profiling (SBP) surveys a dense grid of profiles have been collected allowing the sediment distribution and the geometry of the sediment units to be mapped out in some details. Three regional seismic horizons have been identified and correlated with the well dated 24 m long core retrieved from the lake. The detailed time constrain available on the upper stratigraphic units in the lake offer also excellent possibility to calculate the development in sediment fluxes in this Polar area from the Last Glacial Maximum (25 ka BP) to the present day. The detailed grid of seismic survey has also allowed the total sediment volume in the lake basin to be calculated and integrated with the well dated core the age of the initial sedimentation in the lake basin has been calculated to have started c. 55 ka BP, with a few thousand years uncertainty. Identification of submerged delta inside the lake basin suggest that the lake level must have dried in and be lowered with at least 26 m below the present level during the LGM period. This finding offer a new insight into the climate condition in the Polar Ural area, Arctic Russia, during the LGM and the early deglaciation period.

ORAL

Sandy deposits from a Preboreal glacier lake outburst flood (Nedre Glomsjø), southeastern Norway

Louise Hansen[1], Fredrik Høgås[1], Lars Olsen[1] and Georgios Tassis[1]

[1]Geological Survey of Norway

The major outburst flood from glacier lake Nedre Glomsjø in southeastern Norway, has been known for decades. Previously described deposits include pronounced boulder accumulations upstream and vast fine-grained flood deposits far downstream. In addition, new LiDAR data from the middle reaches of the Glomma valley has revealed spectacular mega bars and erosional features related to the dramatic flood event (Høgaas & Longva 2016). The LiDAR data provide a basis for further investigation of the event and its impact on the landscape and the valley fill. Sedimentological investigation of a sandy dune field provides new

insight into the variety of deposits from the outburst flood. The dunes were previously described as of aeolian origin. However, facies analysis shows that the deposits were deposited in association to the outburst flood. Beside the association with water-lain facies, such as e.g. diffuse, climbing ripple lamination, a diagnostic feature seems to be water-escape structures defined by numerous (sub)vertical tracks cutting through the bedding including the foresets of mega-scale bedforms. The tracks are interpreted as a result of a significant drop in hydrostatic pressure as the flood levels were lowered and triggered a release of excess pore pressure in the sediments. The study extends the understanding of the outburst flood as an extreme, landscape-defining event. In addition, the study has important impact on the understanding of the regions postglacial landscape as other, previously defined aeolian fields may show to originate from the flood, and comparable sedimentary features have been observed at Starmoen nature reserve.

ORAL

The Quaternary of the island of Falster, SW Denmark

Peter Roll Jakobsen[1] and Knud Erik Klint[2]
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The island of Falster is covered by the geological map sheets Geological map of Denmark 1:50.000 Stubbekøbing and Nykøbing Falster. During the geological mapping new data was collected regarding Quaternary stratigraphy, morphology and the evolution of the landscape.

The pre-Quaternary deposits on Falster are Maastrichtien chalk and Paleogene Clay. The pre-Quaternary surface is influenced by NW–SE-striking faults that act as weakness zones, and buried valleys are incised into the chalk surface. At Stubbekøbing, the course of the Fribrødreå valley is controlled by a fault.

The oldest till unit on Falster is seen in boreholes and is interpreted as the Ristinge Klint Till Formation (c. 50 000 years ago).

At Pomlenakke and on Farø sections show a till deposited by a glacier coming from NE, which is interpreted as the Midtdanske Till Formation (Late Weichselian 24 000–20 000 years ago). It is covered by two Baltic tills – Øst Jylland Till Formation and Bælthav Till Formation (19 000–16 000 years ago). A characteristic boulder pavement is seen at the base of the lower unit. The boulders are often more than 1 m in diameter.

The most pronounced geomorphological element is the push moraine Væggerløse Arc, formed by an advance from east. An esker stretches from the north-easternmost part of Falster and almost down to Nykøbing Falster. A small meltwater plain is associated with the esker. In the Northern part smooth ridges with a NW-SE trend are interpreted as older marginal moraines, subsequently overridden by glaciers.

ORAL

A large young impact crater beneath the Ice in Northwest Greenland

Kurt H. Kjær[1], Nicolaj K. Larsen[2], Svend Funder[1], Michael Houmark-Nielsen[1], Adam Garde[3], Mark Fahnestock[4], Ian McDonald[5], Olaf Eisen[6], Joseph MacGregor[7], Anders Bjørk[1], Veit Helm[6], Eske Willerslev[1], Matheu Morlighem[8], Jeremie Mouginot[8], Henning Haack[9], Kristian K. Kjeldsen[10], Horst Machguth[11], Tobias Binder[6], John Paden[12] and Shfaqat Abbas Khan[10]
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During Earth's history, cataclysmic impact events have been linked to major climate change and mass extinctions. Here, we report on the discovery of a large impact structure hidden beneath Hiawatha Glacier in northwest Greenland. Beneath nearly a kilometre of ice lies a 31-kilometre-wide, circular bedrock depression

with an elevated rim and a subdued central peak. Outwash sediments from the largest river draining from the glacier catchment contains shocked quartz and other unweathered impact grains. Geochemical analysis shows that the impactor was a Pt-rich iron asteroid that would have had a diameter of c. 1.5 km in order to produce a crater of the observed size. Radiostratigraphic, morphological and geochemical evidence suggest that the Hiawatha impact took place between 38 and 11.7 kyr ago, which would make it the largest known impact experienced by modern humans. Our discovery has potentially wide-ranging implications for our understanding of the recent history of Earth.

ORAL

Provenance and ^{10}Be surface exposure age of Late Weichselian glacial erratic boulders in southern Norway

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Boulders and cobbles of non-local lithologies (i.e. erratics) are found on all types of substrates in east-central southern Norway. The only exception is surfaces formed after the last deglaciation. Hence, erratics are found in superimposed on surfaces of bare bedrock, blockfield, till, glaciofluvial and glaciolacustrine material. The erratics must have been glacially transported at some point, either as isolated clasts or as till. Boulders resting on fragile substrates, such as sediments or weathered bedrock, are characteristic for areas with past cold-based, low-erosive ice sheets.

We present a preliminary synthesis of five studies that used provenance analysis of erratic boulders to reconstruct regional ice-flow direction east of the present day main water divide. The investigated mountains all have erratic material from source areas to the N and NNW. The westernmost mountains Kolla, Knutshøa and Blåhøe (Becker 2013), as well as Heidalsmuen (Tvedt 2013), also have material originating from source areas in the SW. The mountains Storsølnkletten (Eidsvåg 2013) and Tron (Hult 2011) located in the central part of the study area, and Søre Sølen (Kvamme 2012) in the eastern part, have additional boulders transported from source areas in the S-SE.

In addition, we report ^{10}Be surface exposure ages from 36 glacially transported boulders in the study area. ^{10}Be ages range from 7.7 ± 0.5 to 66.1 ± 1.9 ka, but cluster around 11 ka. The ages must be considered minimum ages as they are not corrected for snow cover, weathering or isostatic rebound.

POSTER

Mineralogical analysis of till by the Greenland Ice Sheet, Kangerlussuaq, West Greenland

Karin Grodzinsky[1], Eva-Lena Tullborg[2], Johan Hogmalm[1] and Ignasi Puigdomenech[3]
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Till sampled from terminal moraines close to Kangerlussuaq at west Greenland are analyzed through mineralogical observations along with chemical composition data including Sr-isotopes. This study focus on the weathering processes and interaction between glacial meltwater and till. Scanning Electron Microscope, XRD and leaching experiments are, among other methods, used to study chemical weathering and reactions. For example, minerals such as pyrite and biotite show weathered edges with loss of sulfur and potassium, respectively. Some feldspars may present caved surfaces which could indicate weathering processes. Leaching experiments indicate relatively fast interaction time between water and till, and the data are compared to chemical compositions of moraine ponds and pore water samples and even deep groundwater

from the same study area. These comparisons increase our understanding of the course of events and reactions for the glacial meltwater on its way from the glacier and further down the bedrock and in the watershed.

The study has been carried out as a complement to the Greenland Natural Analogue Project conducted by the Canadian Nuclear Management Organisation, the Finnish Posiva Oy and the Swedish Nuclear Fuel and Waste Management Co. (Claesson Liljedahl, L. et al. 2016). The aim of the project was to investigate how glacial conditions would affect a deep repository for spent nuclear fuel during future glacial periods.

POSTER

Sedimentary characteristics of a possible tsunami deposit in the Leirfjorden area, North Norway

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A material-extraction site near Leirfjorden in North Norway reveals a composite stratigraphy of interbedded glacial and marine deposits. A coarse-grained, crudely stratified event bed is interpreted as a possible tsunami deposit. It is underlain by marine deposits reflecting reworking of glacial deposits by waves and gravitational processes after glacier retreat. The event bed is divided into four main intervals reflecting different stages of the sedimentation process. From the base upwards, these are irregular, poorly sorted sand and gravel interbedded with massive fine sand overlain by thin-bedded silt and sand with clasts. The succession of facies reflects flow processes of varied concentration alternating with suspension sedimentation of sand. Silty intraclasts and poor sorting testifies to short and episodic transportation and fast sedimentation. The bed is overlain by subtidal sediments. The sedimentological characteristics of the bed show some similarities to previously described tsunami deposits from Norway but there are also differences such as absence of biogenic material except for a few reworked foraminifers. The high elevation of the inferred tsunami deposit at c. 75 m a.s.l. precludes a relation to the Storegga tsunami and it must be older. As there is no record of an older, regional tsunami, a local event is suggested. A marine sparker survey in Leirfjorden reveals a major mass-wasting deposit that accumulated in the fjord shortly after the last deglaciation. This mass-wasting could be a likely source for a local tsunami. Failure is explained by high sedimentation rates and emergence following glacier retreat, maybe combined with seismicity.

POSTER

Late Glacial and Holocene development within the source depression of the Vejrhøj end-moraine, NW Sjælland, Denmark

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[1]GEUS, [2]UNESCO Global Geopark Odsherred

The prominent arcuate end-moraines in NW Sjælland are the backbone of the geology of Geopark Odsherred. The largest and southernmost of the end-moraines, the Vejrhøj arc, is a glaciotectonic hill-hole pair landform. The source depression makes up the innermost part of one of Europes largest reclaimed areas, the Lammefjord. It constitutes a basin that has been filled with Late Glacial and Holocene deposits. As part of a large outreach programme the basin was investigated in a drilling campaign and ground penetrating radar investigations was used in the sandy areas.

In the deepest recognized part of this basin, 25 m of sediment has been deposited. Macro fossils show that the basin initially was a Late Glacial lake, where sand and clay is deposited. The freshwater lake environment continued into the Holocene, and peat was deposited at the shores of the lake.

During the Atlantic transgression the area was flooded, and the present surface is now 3.8 m below sea level. In the initial phase of the change of environment from freshwater to marine, brackish sediments are deposited in form of laminated gyttja deposits. In this phase some of the lake deposits where redeposited. Subsequently a full marine sequence deposited in the basin as marine gyttja with numerous shells.

At the edge of the basin marine sand is deposited, and oyster banks developed at relative shallow water depth.

POSTER

Lake sediment analysis of the Nedre Glomsjø outburst flood event, Southeastern Norway

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Sediment cores from lake and mires can provide geological archives of palaeofloods. By analysing the sediment we can better our understanding of the nature and impact of large flood events. This study aims to constrain the run-up height and timing of the outburst flood from glacial lake Nedre Glomsjø at the end of the last Ice Age. Cores from four lake basins will be examined for grain size distribution, total organic carbon (TOC) and macrofossil content. In addition to this, we aim to provide a geochemical profile (using XRF) of the floodlayer and properly constrain the event in time by radiocarbon dating macrofossils found above and below the flood sediment. Geochemical data will serve as a geomarker in order to identify the flood layer elsewhere. The probable flood layer stands out as a light, fine-grained layer in all of the retrieved cores. The upper boundary towards the organic gyttja as sharp, which signals that sedimentation stopped abruptly. Preliminary results indicate that the flood inundated basins more than 50 m above the valley floor in our study area.

POSTER

Lateglacial – early Holocene geomorphology between Lake Vänern and Lake Vättern, southern Sweden

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The arrival of Light Detection and Ranging derived elevation models enables efficient and accurate mapping of landforms. The region in central Sweden between Vänern and Vättern contains landforms created during two of the most important events during the late Quaternary of Sweden; the Younger Dryas cold interval and drainage of the Baltic Ice Lake.

Here, we present a 1:220 000 scale geomorphic map of this region covering approximately 18 000 km^2. Fifteen landform units have been mapped; end moraines, De Geer moraines, drumlinoids, crag-and-tails, hummock tracts, irregular ridges, eskers, deltas/sandurs, outwash complexes, meltwater channels, boulder bars/sheets, the Timmersdala ridge, raised shorelines, sand dunes and prominent landslide scars.

The mapped glacial geomorphology deepens the understanding of the deglacial history by the revelation of previously undetected geomorphic features and their relations, for example the abundant traces of meltwater erosion manifested as channels and hummock corridors, and previously unreported ice-marginal lines. Perhaps most striking is that all of these ice-margin positions are marked by distinct lobate moraines where they were formed above the highest shoreline.

This map provides a 'set table' for future research – e.g. glacier modeling, georesources, geologic history and geoheritage.

POSTER

Weichselian Stratigraphy and Deglacial Deposits from Kuusivaara, Sodankylä, Central Finnish Lapland

Markus T.O. Valkama[1], Seija Kultti[1], Annika K. Åberg[1], Emilia Koivisto[1] and Veli-Pekka Salonen[1]
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Central Finnish Lapland exhibits limited glacial erosion during the Weichselian. Therefore, the till units of Early and Middle Weichselian stadials are preserved in many places (eg. Helmens et al. 2007, Lunkka et al. 2015). This study describes lithostratigraphy from Kuusivaara, which is situated 140 kilometres north of Rovaniemi, east of river Kitinen. During deglaciation, the study area was first occupied by the Moskujärvi Ice Lake (207 m.a.s.l.) and later by the Ancylus Lake (186 m.a.s.l.) Stratigraphy and glacial deposits from the area were studied from six test pits and conducting fifteen kilometers of ground penetrating radar acquisition. Sediment logs were made from test sections and fourteen sediment samples were analysed for their granulometric properties. Preliminary observations suggest that weathered bedrock is covered by a probably Early Weichselian till with sandy sediments and a distinct soil horizon on their top, which may represent an interstadial deposit. The upper till is a stratified, loose sandy melt-out deposits overlain by aeolian sands, gravity flow or shoreline deposits. Stratigraphical evidence can be applied as a key to interpret landscape evolution based on LiDAR images.

9. Economic geology

9.1. Circular economy

ORAL

Turning anthropogenic stocks into economic viable 'ore' reserves – major challenges for the Circular Economy

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Classical mineral exploration and resource assessment techniques are inadequate tools for assessment of the financial viability of anthropogenic end-of-life stocks. In order to develop ample mining technologies and beneficiation flow-sheets that provides for a viable exploitation of secondary raw materials there is a fundamental need for characterizing the composition and properties of secondary raw materials.

Example; the Danish WtE plants produce c. 600.000 tpa of bottom ashes that potentially constitute important secondary multi-element resources, which is generally considered as waste by plant-owners, and left to be utilized by entrepreneurs. The entrepreneurs apply a scrap-metal approach to extract some of the metals, and the remains are used e.g. in road construction. In order to reduce leakages, some challenges need to be targeted and overcome:

Challenge 1: Physical and chemical characterization of the heterogenic resource. Metals mainly occur as primary alloys and sedondary alloys developed in the incineration.

Challenge 2: Representative sampling of the heterogenic flow of the 'ore' material, coping with a wide range of particle sizes and shapes of the 'ore minerals'.

Challenge 3: Estimation of the grades and in-situ 'ore'-value, are critical for developing a 'mining' set-up and beneficiation flow charts.

Challenge 4: Estimation of the dynamic reserve tonnage.

Challenge 5: Estimation of project viability: the in-situ 'ore'-value/'ore-concentrate'. Absence of parameters characterizing the 'ore' and the 'mineral concentrate', as well as non-transparent price schemes, prevents the development of feasibility studies.

In conclusion; inadequate resource assessments are major obstacles for addressing and closing leakages in the circular economy.

ORAL

Characterization of Raw Materials and Recycled Stone Wool Waste for Production of Stone Wool Melt

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Stone wool waste is generated either during production, where edges are cut off in the shaping process, or during renovation or demolition of buildings. Stone wool is produced by forming a melt that is spun into fibers. The raw materials include mineral raw materials as well as secondary raw materials i.e. waste from other industries. It is also possible to re-melt stone wool waste and thus recycle the waste material back into the production process.

This study investigates the differences in heat response of a conventional stone wool raw material mix and of stone wool waste. The study combined Differential Scanning Calorimetry

(DSC), X-ray Diffraction (XRD) and Hot Stage Microscopy (HSM). The materials are compared in terms of thermally induced processes occurring in the materials, melting temperature, crystallinity and energy consumption associated with heating and melting of the materials.

DSC reveals that the raw material mix and stone wool waste have fundamentally different heat responses: the raw material mix decarbonizes and the wool crystalizes before both melting. XRD is used to investigate the crystallinity of the mineral raw materials and the crystals formed in the stone wool waste upon heating. HSM reveals that stone wool waste initiates melting at lower temperatures than the conventional raw material mix.

Understanding the differences between the conventional raw material mix and the recycled stone wool waste will ultimately help to optimize the production process towards recycling larger amounts of stone wool waste.

POSTER

Utilization of biochar as a cover material in mine waste areas

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Good mineral waste coverages and landscaping solutions in northern mining industry will be developed and tested in the project 'Utilization of biochar in dry cover material and landscaping of mine waste areas' (Biopeitto) funded by the European Regional Development Fund. From the perspective of sustainable development and regional well-being, the solutions that will minimize the costs for environment and increase the local livelihoods should be developed in the northern region itself. Testing biochar, mine wastes and other rest materials as the component of mineral waste cover in tailings and waste rock pile solutions are environmentally important. The tests aim at finding the best ways to improve cover material's long-term durability and stability, prevent erosion, and improve the sustainability of water management, carbon balance and nutrient economy. Benefit of the use of biochar is its' local production which diminishes the transport and storage costs and opens new possibilities to develop local entrepreneurship. Tailings are produced in large quantities by the mining industry and it might be more economical and beneficial to use the waste as a resource than treat it as a waste. Available materials needed to improve tailings properties such as wood, fibre and bio sludge but also other rest materials from other industries should be tested to enhance their valorisation. The project is led by the Geological Survey of Finland and other research partners are the Natural Research Institute Finland and the Oulu Mining School of the University of Oulu.

9.2. Mineral resources and deep-sea mining in international and national seabed areas

ORAL

Deep-sea mineral resources within National Jurisdiction

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According to the UN Convention on the Law of the Sea, the continental shelf is the area of seabed that is under the jurisdiction of the coastal states, which in some cases may extend beyond 200 nautical miles. According to the Convention, the exploitation of any continental shelf resources beyond 200 nautical miles is subject to a royalty to be paid through the International Seabed Authority. In most parts of the world, the continental shelf consists of an inner, shallow part and an outer, deep-sea part. Oil and gas, placers and aggregates are associated with the shallow parts of the continental shelf, while polymetallic mineral resources are found in the deep-sea parts and likely to be relevant for royalty payments. In wide platform areas, like those of the Atlantic, oil and gas may also be subject to such payments. The polymetallic minerals are regarded as potential sources of nickel, copper, cobalt, manganese, zinc, lead, gold, cobalt, tellurium, and possibly REEs. Estimates of the mineral resources of the deep sea and their partition between the continental shelf and the international seabed are still very uncertain. Recently published studies indicate that, depending on the type of mineral, between 20% to 50% of the resource may be located within the continental shelf areas. Recent test mining by Japan and the development of the Solwara 1 Mine in Papua New Guinea indicate that sulphides will be the first deep sea mineral to be exploited, and that it will happen within the continental shelf.

ORAL

Exploration of seafloor massive sulfides: current status and perspectives.

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Seafloor massive sulfide (SMS) deposits present the third type of a short list of deep-sea minerals after ferromanganese nodules and cobalt rich ferromanganese crusts. The discovery of hydrothermal vents and associated massive sulfides in the end of 1970s had not only fundamental but also economic importance due to extraordinary concentrations of metals being discharged from hot vents to the sea bottom. The major components of SMS are Cu, Zn, Pb, Au and Ag. The high grades of such minor high/green-tech components as Se, Te, Ge, Bi, As, Cd, Ga, Tl and In are also detected in SMS deposits.

Most of SMS deposits are localised in the area beyond the national jurisdiction which administrating by International Seabed Authority (ISA). Currently 6 contracts for exploration of SMS deposits are signed between States Parties and ISA for the areas in the Atlantic and Indian oceans. Different geological and geophysical methods are used for the prospecting of active and inactive SMS deposits. The first exploration contract should be completed in 2026.

SMS deposits localized within EEZ are the subject for exploration study as well. Most of these deposits which distribute along the island arc systems in the Pacific are well explored and even ready to be mined (e.g. Okinawa Trough, Bismark Sea). The technologies for future mining are in process of being designed and methods of metals extraction from SMS already exist being similar to that of land-based volcanogenic massive sulfide deposits.

ORAL

Sulfide mineralogy of the Loki's Castle hydrothermal vent, Arctic Mid-Ocean Ridge

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Samples from the active Loki's Castle hydrothermal vent were collected from the seafloor by ROV during the MarMine cruise in 2016. The hydrothermal vent sites consist of black smoker systems, and as such have diverse mineralogy with highly heterogeneous macro and micro textures. The samples currently under investigation represent chimney collapse breccia rather than massive sulphide from the core of the deposit. Sulfide mineralization in the white smoker material is limited with minor sphalerite, galena and pyrite. The less common black smoker material is dominated by silica and sulfate gangue, with sulfides occurring as lenses and patches of fine-grained material and, locally, larger grains.

In the sulfide-rich areas, the sulfides occur in mineralogically and metallogenically distinct zones on the cm scale. The Fe-rich zones comprises intergrown pyrite and marcasite, the Zn-rich zones comprises sphalerite, and the Cu-rich zones comprises an isotropic Cu-Fe-S phase, likely isocubanite, with both sharp submicron lamellae and larger exsolutions of chalcopyrite. Minor pyrrhotite and galena was observed. There is significant overlap between the zones, especially the Zn-rich and Cu-rich zones, where the isocubanite replaces sphalerite. The sphalerite is infected with chalcopyrite disease, but under the optical microscope several grains and zones appear to be inclusion-free. However, SEM investigations show lamellae in sphalerite less than 100 nm wide, oriented in the same crystallographic planes as chalcopyrite lamellae in neighboring isocubanite, indicating that not all lamellae in sphalerite may be visible in the optical microscope.

ORAL

Uncertainties in grade, tonnage, and distribution estimates for seafloor massive sulfide deposits

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The economic potential of deep sea mining is ultimately dependent on the size, grade, and distribution of ore deposits on the seafloor. For seafloor massive sulfide (SMS) deposits, there have been several studies that have reported quantitative estimates of the resource potential at both global and regional scales (including the North Atlantic), and these resource estimates are being utilized to drive policy decisions related to the economic potential of SMS mining, and associated exploitation and environmental regulations. However, the geological uncertainty associated with these resource estimates is significant. Development and regulatory decisions must ultimately be tied to not only the grade and tonnage estimates of individual deposits, but also an understanding of the associated uncertainty of these estimates. In this presentation, we will discuss the current state of knowledge of the size, grade and distribution of SMS deposits. We will focus on how these estimates are determined, the evolving uncertainties related to these estimates, and strategies that should be implemented to reduce these uncertainties, including approaches to exploration, sampling and drilling.

ORAL

Deep sea mineral resources in the international seabed area

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According to the UN Convention on the Law of the Sea, the seabed and subsoil areas of the world oceans are divided into two parts: the international seabed under the jurisdiction of the International Seabed Authority (ISA), and the continental shelf under the jurisdiction of the coastal states. The resources of the international seabed area (termed "the Area"), are managed by the ISA on behalf of the mankind. Today, there is an increasing interest for the mineral resources of the deep ocean because of the demand for certain metals needed in green technology. The most promising mineral resources in the Area for supplying global needs are polymetallic nodules, polymetallic sulphides and ferromanganese crusts. They are regarded as potential sources of nickel, copper, cobalt and manganese (nodules), of copper, zinc, lead and gold (sulphides), and of cobalt, tellurium, manganese and possibly REEs (crusts). Currently, the ISA have 28 Contractors carrying out exploration activities in the Area, rising from eight before 2011. Estimates of the mineral resources of the deep sea are still very uncertain. However, exploration and scientific studies in recent years indicate that the Co and Ni resources of the deep sea exceeds those onshore by ten and four times, respectively. In the case of Mn and Mo, the resources of the deep ocean match those onshore. No one has so far started any commercial exploitation of these resources. The ISA is currently developing its regulations for exploitation, starting with the nodules. These regulations should be completed by 2020.

ORAL

The Seven Sisters Hydrothermal System on the Arctic Mid-Ocean Ridge

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We present new findings on the shallow, hybrid, seafloor hydrothermal system (known as the Seven Sisters site) with epithermal-style mineralization that is hosted by mafic volcaniclasts on the slow spreading Northern Kolbeinsey ridge on the Arctic mid-ocean ridge. The system lies on top of a flat-topped volcano at ~130 m depth from which relatively high temperature (up to 200°C) phase-separating fluids vent from smoking craters and unique pinnacle-like edifices on top of mounds. The hydrothermal mineralization at Seven Sisters manifests as replacement of mafic volcaniclasts, direct precipitation from the hydrothermal fluid, and as vapor elemental sulfur sublimates. Barite is ubiquitous and is replaced by pyrite, which is the first sulfide to form, followed by Zn-Cu-Pb-Ag bearing sulfides, sulfosalts and silica. The mineralized rocks at Seven Sisters contain appreciable amounts of 'epithermal suite' elements with secondary alteration minerals. Vent fluids have a pH of ~5 and are Ba and metal-depleted. Sulfide and secondary alteration mineralogy, fluid and gas chemistry, as well as d34S and 87Sr/86Sr isotope values indicate that mineralization at Seven Sisters is sustained by the input of magmatic derived fluids with seawater contribution. Radiometric dating of barite suggests that this hydrothermal system has been active for at least 4670 ± 60 years.

ORAL

Preliminary characterisation of potential seafloor massive sulphide ore from the Loki's Castle deposit, on the Arctic Mid-Ocean Ridge.

Ben Snook[1], Kristian Drivenes[1], Kurt Aasly[1] and Gavyn Rollinson[2]
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Ensuring efficient ore characterisation is necessary for all stages of mine planning, thereby streamlining deposit identification, resource extraction, mineral processing and waste management. It provides information for compositional, chemical, textural and mineral liberation considerations, and tracks the effectiveness of mineral processing. As such, defining the most effective assessment techniques for new ore types is of high importance.

In response to growing demand [1], potential new sources of copper and zinc have been identified in the deep sea, from seafloor massive sulphides (SMS) [2,3]. One site under Norwegian jurisdiction demonstrating good possibilities for SMS mineralisation is Loki's Castle, where active hydrothermal venting occurs at 2400 m depth on the slow spreading Arctic Mid-Ocean Ridge [4]. The site consists of two mounds, each approximately 150 m across and 30 m high, capped by 5 active chimneys releasing 320° C fluids [4]. During the 2016 MarMine cruise [5] boulders were collected from the mounds' flanks, which represent collapsed chimney fragments that have formed debris flows. The vent sites appear to consist of both white and black smoker systems, and as such have a diverse mineralogy with highly heterogeneous macro and micro textures.

We report initial approaches to determining analytical techniques to characterise SMS ore; petrography, geochemistry, and automated mineralogy. Preliminary results indicate that typical sulphide mineral assemblages in samples with elevated Cu and Zn grades comprise fine grained chalcopyrite, isocubanite, sphalerite and pyrite, often with complex textures: chalcopyrite overgrowths on isocubanite; sub-micron laminations of chalcopyrite within isocubanite; micron scale chalcopyrite blebs within sphalerite.

ORAL

CHARACTERISEING MINERAL REPLACEMENTS REACTIONS IN CU-FE-ZN-S MINERALS FROM THE ARCTIC MID-OCEAN RIDGE USING SEM, EBSD AND OPTICAL MICROSCOPY

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Ore minerals in samples collected from black smokers at Loki's Castle at the Arctic Mid-Ocean ridge show complex intergrowth and exsolution textures. Cu-Fe-S mineral(s) appear in sphalerite as several µm size rounded inclusions, or as fine lamellae parallel to {001}. Sphalerite (sph) (Zn,Fe)S is replaced by a Cu-Fe-S phase (isocubanite), which itself has exsolutions of mostly submicron lamellae (chalcopyrite?). The matrix phase is isotropic, appears pinkish yellow, and has a composition close to cubanite (CuFe2S3). The lamellae are less pinkish, and have compositions close to chalcopyrite (CuFeS2, tetragonal). In addition, a second set of exsolutions appears as wavy laths. Understanding the relations between the mineralizing phases are imperative to understand the genesis of the deposits and hence also to make realistic models of the economic potential.

Further work will reveal more details on the relationship between the phases. After polishing with Ar-ions the pattern of isocubanite and sphalerite were indexable, however because sphalerite and isocubanite have very similar structures they could only be differentiated using the combination of optical and backscattered electron imaging, EDS (energy-dispersive

spectroscopy) and EBSD. However, the EBSD reveals topotaxial relations between sphalerite and isocubanite that preserves the orientation of the host, reinforces the interpretation that isocubanite replaces sphalerite rather than growing together with sphalerite. Different methods of indexing the patterns and improved collection may enable us to distinguish also the chalcopyrite lamellae from the host isocubanite and sphalerite though the chalcopyrite structure is very similar to the host phases.

9.3. Open Session: Economic Geology

ORAL

Paragenetic evolution of hydrothermal REE mineralisation in the Olserum-Djupedal area, SE Sweden

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The REE mineralisation in the Olserum-Djupedal area is located at the border of the Palaeoproterozoic Västervik sedimentary formation and c. 1.8 Ga granitoids belonging to the Transscandinavian Igneous Belt (TIB) in SE Sweden. The mineralisation is dominated by the phosphates monazite-(Ce), xenotime-(Y) and variably REE-bearing fluorapatite. These mostly formed, along with subordinate (Y,REE,U,Fe)-(Nb,Ta) oxides, during an initial hydrothermal stage. During a subsequent stage, allanite-(Ce) formed locally, and secondary monazite-(Ce) and xenotime-(Y) also formed, mainly by leaching and remobilisation of REE from fluorapatite. Similar coupled dissolution-reprecipitation processes subsequently also affected primary monazite-(Ce), xenotime-(Y), and minor (Y,REE,U,Fe)-(Nb,Ta) oxide phase(s). This mobilised REE, Th, U and Nb-Ta, and caused the formation of additional xenotime-(Y), monazite-(Ce), fluorapatite and variable amounts of allanite-(Ce) – ferriallanite-(Ce), uraninite, thorite and columbite-(Fe) (Andersson et al., 2018). Bastnäsite-(Ce) and subordinate synchysite-(Ce) characterise the youngest REE mineralisation stage, and formed from the low-temperature alteration of allanite-(Ce) and ferriallanite-(Ce). We interpret the paragenetic sequence to essentially be the result of decreasing

temperatures, from an initial high-temperature hydrothermal stage (≥600°C) to a low-temperature stage (<<400°C). In addition, local differences in fluid chemistry, particularly the Ca content, as well as fluid oxidation state, facilitated the dissolution-reprecipitation processes, and ultimately governed the stability of the REE minerals in the ore assemblages of the Olserum-Djupedal area.

ORAL

Critical metal mineralisation in Sweden: overview and highlights

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Critical metals, as part of what is presently defined by the EU (https://ec.europa.eu/growth/sectors/ raw-materials/specific-interest/critical_en) as Critical Raw Materials (CRM), are increasingly sought for from both primary and secondary sources. The Swedish part of the Fennoscandian Shield, with its major ore provinces Bergslagen, Skellefte district and Norrbotten, contains a significant number of primary sources, mineralisations with variably well-known potential for critical metal production. Traditional by-product critical metals such as antimony , cobalt and indium are variably known, the latter confined to some skarn-associated sulphide-oxide mineralisations in westernmost Bergslagen, while the former mainly occurs hosted by accessory sulphosalts in polymetallic sulphide deposits in several regions, chiefly in Bergslagen and the Skellefte district. , Cobalt is represented by several different deposit types including e.g. skarns and volcanosedimentary-associated massive sulphides. While tungsten is known from a number of deposits, these are typified but not limited to skarn-hosted scheelite, which account for the most important and recently mined deposits, located in northwestern Bergslagen. Elevated gallium and germanium contents are associated with rare earth elements (REE)-rich iron oxide skarn deposits in Bergslagen, and the potential for REE is relatively good, in these and other types of mineralisations, as recently noted by Goodenough et al. (2016), in several areas from southern Sweden (Norra Kärr and Olserum), via Bergslagen, to, a.o., the Kiruna type apatite-iron oxide ores of Norrbotten. The REEs in Sweden will be outlined in more detail in an upcoming SGU report, based on work done within the EURARE project (www.eurare.eu).

ORAL

Towards Real-Time Ore Grade Evaluation using Laser-Induced Breakdown Spectroscopy

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On mining operations, Grade-control is based on laboratory measurements from blast-hole samples or appropriate type of well logging (e.g. gamma logging) to characterize each block. The problems with these techniques are that they slow, costly and the results are not immediately available. To overcome these issues, it is essential to develop new sensor technologies that can provide elemental and mineralogical information real-time and on-site.

Here, a case study using Laser-Induced Breakdown Spectroscopy (LIBS) and samples of Parainen limestone quarry is presented. The aim of the research was to resolve, if LIBS measurements can be used to characterize the ore body during the blast-hole drilling. The quality parameters that are used in Parainen for the ore grade evaluation are Ca/Si+Al and the magnesium content of the samples. The samples consisted of drill cuttings samples from three different blast-holes and four bulk samples of different ore grades collected from the stockpiles.

The bulk samples were crushed, sieved and resorted to get the same grain size distribution with the drill cuttings. The cuttings and the crushed bulk samples were measured by free falling them via funnel to mimic the moving particles in the drill tube.

The results from the LIBS measurements were validated using synchrotron X-ray diffraction and gamma logging from the blast-holes. Our preliminary results suggest that LIBS can be used as an on-line analyzing technique during the drilling process. The ore type and an approximation of the ore grade can be detected from the spectral data.

ORAL

Non-invasive and non-destructive quantification of wollastonite in limestones using Raman spectroscopy

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Wollastonite is an economically important mineral that is used to manufacture plastics, ceramics and other products. Finland is currently among the top producers of wollastonite in the world, and the largest in Europe. Finnish wollastonite is sourced from the Ihalainen deposit in Lappeenranta, southeastern Finland. Here, wollastonite is extracted from Paleoproterozoic (1.9 Ga) limestones that also host industrial-grade calcite. Processing of these rocks requires certain mineralogical compositions (e.g.: 21% of wollastonite) that determine the processing quality of the rock. Currently, labor-intensive laboratory analytical technology is commonly used for the mineralogical characterization of rocks. Laser-spectral methods have the potential to partially replace such technologies, and for this end, Raman offers a fast, non-invasive and non-destructive alternative.

To test the ability of the Raman technology to classify wollastonite-bearing limestone rocks into different quality categories, three samples were acquired from the Ihalainen deposit and these samples were scanned using a Raman setup. Different data analysis methods were then applied to map the spatial distribution and relative abundances of the minerals. The results were validated using the scanning electron microscopy (SEM) system of the Geological Survey of Finland.

The preliminary results suggest that the relative quantity and the spatial distribution of wollastonite can be mapped using high spatial resolution Raman data. The ongoing study will next focus on acquiring more samples from the study area, and using these samples, to further test the potential of Raman for the detection of the processing quality of rocks.

ORAL

Zn-Pb-Cu sulfide-bearing glacial sandstone erratics near Raahe on the western coast of Finland as indicators of Paleozoic base metal mineralization at the bottom of the Bothnian Bay

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Over the past tens of years, sandstone erratics variably enriched in Zn, Pb and Cu have been collected from the coast south of Raahe, but their source has remained unclear. In these non-metamorphosed and non-deformed erratics, detrital grains of quartz and minor feldspar are cemented by calcium carbonate, which is partly

or wholly replaced by ore minerals, including sphalerite, galena, pyrite, marcasite, and chalcopyrite. Analyzed boulders have yielded total base metals contents between 1 and 10 wt%. The FeS content in sphalerite is low and variable, ranging commonly between 0.5-15 mol-%, which is in harmony with its coexistence with pyrite.

Galena shows very radiogenic Pb isotope compositions, with $^{206}Pb/^{204}Pb$ falling in the range of 20.55–21.06 and $^{207}Pb/^{204}Pb$ between 15.90 and 15.94. These compositions are similar to those measured for the Laisvall Pb-Zn MVT deposit in the Swedish Caledonides, being consistent with a similar Ordovician age of ore formation. However, S isotope analyses of pyrite yielded mostly negative $\delta^{34}S$ values from −15.6 to −7.6, which are distinctly different from the generally heavy sulfur isotope compositions (ave. +24) reported from the Laisvall-type deposits. These results together with some mineralogical differences (presence of chalcopyrite, absence of fluorite and barite) suggest that the boulders were not derived from the eastern front of the Caledonian orogen but their source occurs much closer, likely being a so-far-undiscovered base metal deposit under the Bothnia Bay.

ORAL

Cu-Mo mineralization epochs in NW Iran and their temporal relationship with metallogenic zones of neighboring Lesser Caucasus and Central Iran

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The Tertiary Urumieh–Dokhtar magmatic arc (UDMA) in Iran represents the northeast-ward subduction of the Neo-Tethyan oceanic crust beneath the central Iranian domain during the late Mesozoic-early Cenozoic. It coincides with the porphyry copper metallogenic belt, including 3 metallogenic zones in NW (Ahar-Jolfa), central and SE parts, which host many porphyry copper deposits (PCDs) and prospects. The Ahar-Jolfa metallogenic zone includes the Qaradagh and Sheyvardagh batholiths and many smaller intrusions and includes porphyry, skarn and vein-type mineralizations. This zone shares many magmatic, geodynamic and mineralization features with the neighboring South Armenian Block (SAB), where the Meghri-Ordubad composite pluton of Eocene-Miocene age hosts many porphyry Cu-Mo deposits. By comparing the measured Re-Os and U-Pb ages of mineralizations in NW Iran [1,2,3,4,5], it can be concluded that porphyry mineralizations have occurred in three epochs of late Eocene (~35 Ma), middle Oligocene (31-25 Ma) and early Miocene (22-20 Ma). Mineralizations here coincide with the third epoch of such mineralizations in SAB, which are associated with Eocene to Miocene intrusions, while the older middle Jurassic-early Cretaceous and upper Cretaceous epochs of SAB [6] have no reported counterparts in Iran. The first epoch of NW Iran postdates all Eocene mineralizations in SAB. The second epoch is coeval with Paragachay and the first-stage of Kadjaran PCDs. The third epoch is younger than all mineralizations in SAB, except the second stage of Kadjaran PCD. These epochs are older than nearly all PCDs and prospects in Central and SE Iran, revealing an old to young trend along the UDMA.

ORAL

2D elemental mapping of pyrite by LA-ICP-MS: an application in visualizing Au enrichment process

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Pyrite is commonly associated with mineralization in deposits forming in different environments. The spatial distribution of trace metals in pyrite can be heterogeneous, and may

contain genetic information. With the development of 2D trace element mapping with Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) it is now possible to reveal, in much greater detail, the interior compositional textures of pyrite, and thus permit investigation of the mineralisation process that recorded in the crystallization history of pyrite.

Here we report two cases of 2D elemental mapping of pyrite in investigating Au mineralisation process. Pyrite samples were collected from a quartz pebble conglomerate of the fluvial Mississagi Formation, Canada (the basal part is Au abundant), and from the Qingchengzi Pb-Zn-Au-Ag ore field, NE China, respectively. The trace element maps reveal a common existence of core-rim structure for the pyrite from Mississagi Fm. The detrital origin of pyrite is readily demonstrated from rounding of individual grains and cores and the revealed truncated texture of originally rounded detrital fragments. Gold is finely dispersed in the detrital cores/grains, indicating a significant amount of Au was suspended in the river flows for the enrichment. Two distinct episodes of gold enrichment are distinguished from the element maps of pyrite from the Qingchengzi Pb-Zn-Au-Ag deposits: an early syn-sedimentary stage when invisible gold is concentrated in diagenetic pyrite, and maybe re-mobilized and re-concentrated later; and a later hydrothermal stage where gold forms as either free gold grains, or as invisible gold in the pyrite.

POSTER

REE-enrichment in Palaeoproterozoic banded iron formations, Bergslagen, Sweden: primary precipitation or hydrothermal overprint?

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In the Svecokarelian bedrock of south central Sweden, and specifically, the Bergslagen ore province, hematite-dominated banded iron formations (BIF) constitute one of three major types of iron oxide deposits. Recently, due to the increased criticality of rare earth elements (REE) through their applications in modern industrial and low-carbon/energy saving technologies, several projects have been undertaken to explore their potential distribution in previously unknown deposits and deposit types. Among the resulting discoveries were REE-mineralised BIFs (e.g. Jonsson & Högdahl 2013). In the Högfors mines, silicate-dominated [e.g. cerite-(Ce) and Fe-analogue of västmanlandite-(Ce)] REE mineralisation was interpreted to have formed from epigenetic processes resulting in localised REE-enriched skarn replacing carbonate interlayers, i.e. a post-depositional hydrothermal overprint. Subsequent sampling and analytical work revealed REE-enrichment in other BIF deposits in this part of Bergslagen, e.g. at the Nya Bastnäs field (8500 ppm REE_{tot}), Storgruvan (1300 ppm REE_{tot}), and Myrbacksfältet (8000 ppm REE_{tot}). The main REE hosts here are allanite-(Ce), REE-enriched epidote, and cerite-(Ce). These deposits are located in close vicinity to REE-rich skarn deposits in the REE-line (Jonsson & Högdahl 2013), but REE-anomalous BIFs have also been identified outside of this area. The BIF at Forsbo, located further to the north, has a REE_{tot} of 1800 ppm, mainly hosted by monazite-(Ce). A post-depositional, epigenetic, yet pre-tectonic origin for the the REE-enrichment in the BIFs along the REE-line is suggested by geological, mineralogical and textural evidence. The phosphate-hosted REE mineralisation in the Forsbo BIF, on the other hand, appears to potentially having formed through primary precipitation.

POSTER

Characterisation of the Kivilompolo Molybdenum Mineralisation, Peräpohja Belt, Northern Finland

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The Paleoproterozoic supracrustal Peräpohja Belt hosts several poorly studied metal occurrences. One of these includes the Kivilompolo molybdenite mineralisation, initially discovered in the 1950´s. Mineralisation occurs in boudinaged quartz veins within gneissic granites adjactent to the 1.99Ga pre-orogenic Kierovaara granite (Ranta et al. 2015). The ore minerals consist of abundant, coarse grained molybdenite flakes, in addition to pyrite, pyrrhotite and chalcopyrite. Mineralisation occurs in a roughly 3km long zone and, based on drillholes, extends to a depth of at least 150m (Yletyinen 1967).

Preliminary single molybdenite Re-Os dating of the mineralisation gives an age of 1.99Ga (Holly Stein pers.comm), which is consistent with the adjacent Kierovaara granite. The precise age of the host granite is not known, but the close proximity of the Kierovaara granite would suggest a similar age. Discovery of high-grade Palokas Au and Rompas Au-U mineralization in the Peräpohja Belt has given impetus to study this occurrence.

Combined outcrop and boulder mapping was carried out in June of 2017 in order to determine the extent of the mineralised zone. Detailed petrographical analysis of the host rock and mineralised zone will be carried out to better understand the nature of the occurrence and the relationship between deformation and the mineralisation. Whole rock analysis of a number of channel samples will be carried out to determine the presence or absence of a mineralised halo around the deposit. U-Pb dating of zircon from the host rock will provide a precise control on the age of the mineralisation.

POSTER

Au-Ag-(Bi-Te-Se)-enriched polymetallic vein mineralisations in SW Sweden: ore mineralogy and thermal evolution

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Polymetallic Au-Ag-(Te-Se)-bearing quartz (-carbonate) veins formed in association with large-scale crustal deformation processes during the c. 1 Ga Sveconorwegian orogeny and its aftermath are widespread in SW Sweden, chiefly in Dalsland and Värmland. Previously, ore mineralogical data have been reported for some Värmland veins (cf. Alm & Sundblad 1994, Alm 2000, and references therein), whereas information on the Dalsland veins has been overall lacking. The present study forms part of an attempt to increase the knowledge of the noble and critical metals-rich deposits in this region; within this framework, new observations from the Värmskog veins were also supplied by Nysten (2013).

In most of the studied deposits, the occurrence of Ag-Bi-Te-Se-rich minerals is interpreted to mainly represent unmixing during cooling of a higher-T sulphide phase carrying abundant trace metals; mostly represented by bornite, but also galena, chalcocite and chalcopyrite. Observations, including the presence of exsolved Bi-rich minerals such as wittichenite (Cu_3BiS_3) and miharaite ($Cu_4FePbBiS_6$) suggest such high initial temperatures; Bi-rich bornites able to exsolve such phases have been termed "bismuth-saturated" and form >400°C (cf. Cook et al. 2011). The identification of accessory ore minerals (and textures) such as altaite (Ag_2Te), argentopyrite-sternbergite ($AgFe_2S_3$), clausthalite (PbSe)-galena solid solutions, empressite (AgTe), hessite (Ag_2Te; both twinned and untwinned), Hg-amalgams, jalpaite (Ag_3CuS_2)-galena intergrowths, matildite ($AgBiS_2$) in galena,

mckinstryite [$(Ag,Cu)_2S$], native tellurium, naumannite (Ag_2Se)-sulphide intergrowths, stibnite (Sb_2S_3), stromeyerite (AgCuS), petzite ($AuAg_3Te_2$) reaction rims, and uytenbogaardtite (Ag_3AuS_2) combine to reveal an extensive evolution at decreasing temperatures, from above and around 300°C, to below 100°C.

POSTER

Crustal structure and hosting lithology account for the spatial distribution of gold mineralisation in SW Finland

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New gold occurrences have been recently discovered in the Häme Belt, southwestern Finland (Grönholm and Kärkkäinen 2012, Tiainen et al. 2017). The Geological Survey of Finland and the University of Turku launched a two-year collaborative project to investigate the link between the spatial distribution of the gold mineralisations, the regional-scale bedrock structure and the hosting lithologies. The project also aims at training young geoscientists within the field of economic geology.

Two months of field work carried out in the western part of the study area in 2017 concentrated on structural mapping to characterize the kinematics of the major N-S and E-W trending shear zones, and structural and lithological mapping of the Uunimäki gold mineralization (Kärkkäinen et al. 2016), located close to the intersection of the shear zones. Moreover, conducted mapping and sampling of mafic intrusive rocks provides material to study the geochemical signatures and fertilities of mafic rocks which seem to host several known gold mineralizations in the target area.

The next stage of the project involves U-Pb age determinations to date the gold-hosting intrusive rocks and the shear zone activities, and shifting of the spatial focus on the central and eastern part of the Häme Belt. Thematically, we will apply the methods of prospectivity analysis to understand the exploration potential for gold mineralisations within the area.

POSTER

Accessory minerals within the SAM – a preliminary case study

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Suwalki Anorthosite Massif (SAM) is a part of Mesoproterozoic, beltiform magmatic AMCG [anorthosite - mangerite - charnokite - granite rapakivi] suite known as a Mazury Complex (Wiszniewska J., 2002). Fe-Ti-V large ore deposits were established within SAM. Nanoconcentrations of REE (La, Ce, Nd), PGE, Au and zircon minerals are often present in sulphide Fe-Cu-Co-Ni dispersed mineralisation. Their size ranges from 10-150 μm or in some cases up to 250 μm.

Hydrothermal concentrations of unusual zirconium elongated forms have been observed within the polymetallic SAM mineralization, suggesting their hydrothermal origin (Bin F., 2009). Zircons form also dispersed grains, which are of igneous origin and thin fillings, filaments and rims around ore minerals. Thin zircon rims are of 80-250 μm in length and 4-30 μm in width and they accurate imitate the shape of ore minerals. The biggest form was observed in untypical zircon form of "blown candle flame" structure. Enrichment of large quantities of Hf (0,5-0,8 mass %) were measured by SEM-EDS method. Wider parts of thin zircon rims around ore minerals were prepared for age determinations and isotopic analyses by SHRIMP IIe machine at PGI in Warsaw.

Numerous small inclusions of Te (0,4-0,7 mass %) were measured in hydrothermal sulphides, especially in millerite. They are grouped in small forms, which are directed along flow of hot solutions. 2-4 μm in size of single inclusions were observed.

New results of accessory minerals in polymetallic mineralisation may increase our knowledge of the evolution of documented SAM.

POSTER

Platinum Group Element Mineralization of the RF-4 drill core, Reinfjord Ultramafic Complex, Troms, Norway

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The Reinfjord Ultramafic Complex (RUC) is a part of the Seiland Igneous Province (SIP). The SIP is given an age of 560-570 Ma (Roberts et al. 2006), and is a part of the Kalak Nappe Complex. Thus, the SIP is a part of the Middle Allochton of the Caledonian thrust nappe. The RUC comprises rocks that of dunitic, wehrlitic and olivine-clinopyroxenitic composition and is surrounded by metasediments and gabbro. Chemical data of four drill cores from the RUC (RF-1, RF-2, RF-3 and RF-4) display platinum group element (PGE) anomalies in the upper third part of the drill cores.

Detailed work on the PGE mineralization in the RF-1 drill core of the was performed Even Nikolaisen (2016). Nikolaisen discovered that majority of the platinum group minerals (PGM) were present as tellurides hosted by base metal sulfides (BMS).

The writer desires to continue the work by Nikolaisen by investigating the PGM in the RF-4 drill core. The RF-4 drill core is located on the footwall of what is likely to be a normal fault, while the RF-1 drill ore is taken from the hanging wall of the same fault. The writer will investigate the distribution and chemistry of the PGM to gain a better understanding into the ore forming processes. Scanning electron microscopy (SEM) and electron probe micro analyzer (EPMA) will be utilized, as well as transmitted-and reflected light microscopy for studying base metal sulfides. Thermodynamic software such as Perpl_x and MELTS may be used to model stability of silicates and sulfides.

10. Engineering and enviromental geology

10.1. Geohazards in the Nordic and Arctic regions

ORAL

Artificially supply of water for release of the Veslemannen instability at Mannen in Romsdalen, western Norway

Lars Harald Blikra[1], Lene Kristensen[1] and Gustav Pless[1]
[1]The Norwegian Water Resources and Energy Directorate

Permanent monitoring and early warning systems were established at the unstable rock slope Mannen in 2009. The instrumentation includes a comprehensive surface network in addition to 120 m deep instrumentation in two boreholes. A periodic ground-based InSAR campaign in 2014 identified large displacements in a small portion of Mannen (Veslemannen instability). The volume is between 120.000 and 180.000 m^3. The possible runout area includes some few houses, a farm and the railway. Stages of increased velocities in 2014, 2015 and 2016 led to evacuation of people, animals and closing of the railway. These events have attracted a massive media interest. This has shown to be a challenging situation for the evacuated people, the municipality and for NVE having the responsibility for the monitoring.

NVE decided to artificially add water in order to reduce the stability and possibly release a part or the entire Veslemannen instability, and was performed two times in October 2017 during periods were people were evacuated (red hazard level). The displacements before the experiment was already significant and the additional water supply had an effect in terms of increased displacements. However, the area stabilized again when temperatures lowered below zero and the precipitation came as snow.

There are a series of challenges related to "helping nature" in terms of artificial triggering of landslides. This includes the media attention and communication issues related to evacuated people, municipality and other

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ORAL

An automatic watch of a slope, Lac à l'Eau-Claire, Nunavik

Armelle Decaulne[1] and Najat Bhiry[2]
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The slope topography and talus morphometry in Lac à l'Eau-Claire (56°20'N; 76°17'W) indicate inherited and active gravity processes. Evidence of recent activity has been observed during field investigations. However, the identification of gravity processes on slopes remains difficult, as no event has ever been reported and no witness is able to relate any event in this remote area. Nevertheless, Lac à l'Eau-Claire is traversed by Cree and Inuit hunters and fishermen all year-round, and a well-known place for trap. Lac à l'Eau-Claire is also part of the Tursujuq National Park, and welcomes tens of tourists each year. Gravity processes thus become not only physical processes, but raise hazard and risk issues.

In an attempt to better know the year-round gravity processes acting on Caribou slope, we installed in August 2016 an automatic camera. This slope has been selected because it presents fresh scattered boulders indicative of recent slope activity; furthermore, the apical rockwall is heavily affected by frost weathering and deep cracks are opening on the uppermost of the rockwall. From the collection of 2855 pictures, we are able to survey gravity movements and snow cover evolution on the slope.

The camera at Caribou slope, and three other on different slopes, is now operating. Additional cameras surveying slopes and slope processes have also been installed in other places

encountering gravity processes in Nunavik: in Tasiapik valley, south-east of Umiujaq; and over the road leading to the airport in Kangiqsualujjuaq.

ORAL

Artificially triggering of Rock Fall in Norway. Methods, consequences and lessons learned.

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[1]Norwegian Geotechnical Institute

Securing roads, housing areas, construction sites and protective work from rock fall may involve artificially blasting, scaling and other means in addition to ordinary protective work with rock bolts, wire rope nets, wire rope fences and dams. Foreseeing the consequences of artificially release of rock fall for human activities below are difficult to evaluate due to the complexity of such activity. Making evacuation plans without knowing the exact outcome of rock fall release is necessary to do before executing the rock fall release. Improved planning, hazard zoning, involvement of local authorities, police and rescue team can give a successful outcome. Close cooperation with entrepreneurs and decision makers during the work is vital. Information in peoples meeting and in local newspapers is necessary. Triggering of loose rock with moderate volumes may cause larger rock fall volume than expected, producing dust cloud and rock fragment splashing far beyond known runout. Rock fall material may also trigger debris flow days after the event itself. Removing loose rocks with water or free hanging iron ball under helicopter is efficient to clear an unstable area. Use of air pillow or rubber mats may be efficient to release single blocs but can be difficult in steep mountainsides. Systematic assembled knowledge of methods, cases, and unforeseen consequences from artificially triggered rock falls is needed and will be beneficial to all sides of the industry.

ORAL

Continuously monitoring of Gámanjunni 3, 26 Mm³ unstable rockslide, Kåfjord, northern Norway.

Gudrun Dreiås Majala[1], Lars Harald Blikra[1], Lene Kristensen[1] and Ingrid Skrede[1]
[1]NVE

Gàmanjunni 3 is classified as a high-risk object based on the movement, structures and the consequences of the rockslide. As a high-risk object, the unstable rockslide need continuously monitoring.

The section for rockslide management in NVE are in charge of all unstable rock slopes (7 in present) that are classified as high-risk objects and some objects that needs periodic monitoring. NGU is responsible for the mapping and classification of large rock-slope failures.

Gámanjunni 3 is a 26 Mm³ large unstable rockslide located in Kåfjord, northern Norway, and is the third monitored site in the municipality. Gàmanjunni 3 has a movement of 2-6 cm/year towards W-SW and has a fully developed wedge with a 150 m vertical displacement. A large rockslide from Gámanjunni 3 will cross the valley and dam the river.

Since October 2016 NVE have established 10 GPS-antennas, 3 different web cameras, 4 platforms for helicopter and a weather station that forms the monitoring network. A ground-based radar in the valley further monitor the rockslide. In order to improve the signal from the satellite radar (InSAR), corner reflectors are placed in the unstable area. Investigations in terms of resistivity and seismic surveys have been performed in order to build a better geological model. Run-out modelling, dam-breach analysis and flood modelling are completed.

ORAL

Permafrost rock walls in norway - Thermal regime and geomorphological processes in time and space

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The role of the ground thermal regime on geomorphological processes in settings associated to steep slopes has received considerable attention in the past. It is evident from recent studies that e.g. rock walls have a profound effect on the thermal regime in mountain sides, a.o. influencing rock wall stability, weathering regimes and glacier-permafrost interaction in space and time. This presentation discusses the importance of the thermal regime in space and time on geomorphological processes in steep slopes. We combine direct observations of air, ground and rock wall temperatures with numerical simulations. We present results from both thermal (2D transient thermal model - CryoGRID 2D) and thermo-mechanical modelling along with Electrical Resistivity Tomography (ERT) validation of different sites dominated by unstable rock slopes in Norway. We analyse how thermal gradients in rock walls may influence important geomorphological processes related to weathering, talus developments, material accumulation and ice aggregation in coarse material. On longer time scales we hypothesise that permafrost dynamics associated with glaciation and deglaciation phases may have influenced the development and stability of large-scale valley systems.

ORAL

Artificial trigger of the large-scale Chapf rock instability by two blastings in 2001/2002, Bernese Oberland, Switzerland.

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A large unstable rock mass of about 250'000 m^3 called Chapf near Innertkirchen (Bernese Oberland, Siwtzerland) was continuously monitored during 50 years. The Grimsel Pass road is situated about 1'000 m below and was thus endangered. The movement was accelerating from about 1 cm/year up to 0.6 cm/day during the years 1999 to 2001. Therefore the Canton of Bern decided to take emergency measures. First, the collapse was intended to be triggered by infiltrating water into the open joints, as the movements reacted strongly to precipitation. The watering had to be stopped due to the seasonal decrease of the available water. Finally, the unstable rock mass was removed by two big blastings.

The removal was carried out in two steps from the top to the bottom. In a first step, 156 boreholes up to 95 m deep were drilled in the upper half of the about 150 m high rock wall. With a digital elevation model based on aerial photographs and laser scanning a 3D-model of the joints was elaborated in order to determine the explosive charge. The blasting in October 2001 with a total of 19'000 kg of explosiv denudated about 150'000 m^3 of rock.

The second blasting in August 2002 was planned with a similar approach as 2001 (21'000 kg of blasting charge). About 110'000 m^3 of rock were blasted. Both blastings were very successful: The stable rock wall of the Chapf was not affected and consequently this area does not endanger the Grimsel Pass road anymore.

ORAL

Geological observations of the landslide of June 17, 2017 in Karrat Fjord (central West Greenland)

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[1]GEUS-Geological Survey of Denmark and Greenland

On June 17, 2017 a landslide occurred along the southern slope of the 2180 m-high Umiamakku Auffaa in the Karrat Fjord, central West Greenland (Lat. 71º 38'). The rock mass slid into the Kangilleq Fjord generating a tsunami that severely damaged the village of Nuugaatsiaq located 35 km to the south-west. The Karrat Fjord region is part of a geological mapping project in the Uummaanak region between the Geological Survey of Denmark and Greenland (GEUS) and the Government of Greenland. During field operations conducted in 2015-2017 a large number of oblique, high-resolution stereo-images were acquired for photogrammetric studies coupled with geological observation covering the entire region. This allows us to study the geology and structure of the region in three dimensions and in great detail. Detailed oblique photos along the southern flank of Umiamakku Auffaa were collected in 2015, two years before the rockslide event, and again in July 2017, one month after the disastrous event. This gives us unique control of the geological and structural setting before and after the landslide event and furthermore allows us to estimate the size of the landslide precisely. The geology of that particular area is represented by quartzites, amphibolites and meta-pelites belonging to the Palaeoproterozoic Qeqertarssuaq Formation. 3D-photogeology in the GEUS Photogrammetry-Lab and field data shows strongly foliated meta-volcanic and meta-sandstone rocks dipping 20° to the SW. The downslope setting toward the fjord and the tectonic layering suggest a lithological and structural control for the landslide mechanism.

ORAL

Cosmogenic nuclide dating of rock-slope failure deposits and rock slope deformation in Troms county, northern Norway

Reginald L. Hermanns[1], Martina Bøhme[1], John Gossse[2] and Samuel Niedermann[3]
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Systematic mapping for unstable rock slopes has been carried out in Troms county since 2007 and 129 unstable rock slopes were recognized (more than one third of all known in Norway). Despite this large number, the 1810 Pollfjellet rock avalanche is the only historic event in the county. We dated deposits of rock-slope failures and rock slope deformation by cosmogenic nuclide (CN) dating. Most of the deposits of rock-slope failures date to shortly after deglaciation in this region. However, ages also span the entire Holocene.

Four sliding surfaces that dissect high altitude flat surfaces have been sampled for CN dating. Two of these top surfaces have been dated to be older than LGM, while for the remaining two results are expected soon. Two of those surfaces are dissected by deep-seated gravitational slope deformations (DSGSDs). Both topmost sliding surfaces have ages in the upper part that predate LGM. Both DSGSDs have collapse deposits along their foot that date shortly after deglaciation. The other two top surfaces are dissected by rockslides. Both became active within or at the end of the thermal maximum within the Holocene. None of those are related to any rock-slope failure deposit. Our data thus suggest that rock-slope deformation in Troms county is a process that has been active from before the LGM and DSGSDs can survive glacial cycles in cold-based ice environments, while rock slides rather seem to be phenomena that started and peaked after deglaciation and maintain on a low constant rate within the Holocene.

ORAL

Destabilisation and temporal deformation patterns of rock-slope instabilities in Northern and Western Norway

Paula Hilger[1], Reginald L. Hermanns[2], Kristin S. Myhra[3], Bernd Etzelmüller[4] and John C. Gosse[5]
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More than 300 active rock slopes demonstrating post glacial deformation are mapped in Norway, whereof seven are classified as high-risk objects because of their sliding rates and potential impact on infrastructure. In addition to post-glacial stress increase, we expect water pressure and altitudinal permafrost dynamics to significantly impact these gravity driven slope processes along complex pre-existing bedrock structures.

To improve understanding of the potential influence of post-glacial permafrost dynamics on rock-slope failures, we use terrestrial cosmogenic nuclide (TCN) dating along three sliding surfaces to derive the timing of initial failure and potential sliding patterns since the onset of deformation. Preliminary TCN ages of the Mannen and Revdalsfjellet 2 instabilities in western and northern Norway respectively, suggest that sliding started close to the Holocene Thermal Maximum, when mountain permafrost presence was at a minimum. This indicates that permafrost thawing may have contributed to the timing of these rock-slope instabilities. The preliminary results of Revdalsfjellet 1, which is an adjacent but independently moving rock body to Revdalsfjellet 2, suggest a movement onset during strong temperature fluctuations in the mid Holocene.

Recent acceleration of deformation at the Mannen site could be connected to late stage permafrost thawing at the lower boundary of altitudinal permafrost, whereas relatively slow displacement rates at the Revdalsfjellet instabilities connected to their low elevation of 600 m a.s.l. seem to be dissociated from continuous permafrost. The different timing of the initial failure at the two adjacent instabilities demonstrates the structural complexity of the sites and importance of local settings.

ORAL

Monitoring active rock fall and avalanche events

Lene Kristensen[1], Ingrid Skrede[1] and Lars Harald Blikra[1]
[1]NVE

Movements in release areas have been measured prior to both rock fall events and snow avalanches in Western and Northern Norway. Our results indicates that both prior movement and acceleration phases can be identified rock falls and avalanches and may potentially be used as early warning. However – in several instances we have measured large movements and accelerations that stopped due to changed conditions (meteorology etc.).

The movements have been measured primarily using ground based InSAR systems (LiSALab), while change detection and analysis has been aided using point clouds from terrestrial laser scans. In combination the datasets allows for detailed detection of how movement relates to rock structures.

The examples presented are a part of a research project, aiming to obtaining acceleration curves of different types of slide events. NVE is responsible for all types of geohazard relating to slides (rock, clay, avalanches etc.) as well as flooding in Norway. The Section for Rockslide Managements primary responsibility is monitoring of seven high risk rock slides in Norway, and periodic monitoring of less risky objects. We base the monitoring on the assumption that large rock slopes develop over time and accelerates prior to failure. In the project we extend the methodology and equipment to study other types of slides.

Measurements of movement in source areas can greatly aid a visual inspection of stability and provide a basis for handling crisis situations after slides to buildings or infrastructure. Furthermore is increases NVEs preparedness to handle various types of geohazards.

ORAL

Sensitivity to coastal erosion in southern Sweden shown in a map viewer

Kärstin Malmberg Persson[1]
[1]Geological Survey of Sweden

A rising sea level is expected to cause increased coastal erosion in southernmost Sweden where the postglacial isostatic uplift is negligible. To predict where coastal erosion will be most intense and which areas are most sensible to erosion, detailed geological data are necessary. The coast of Skåne displays great variation in geology and topography and while some parts are highly sensible to erosion, other parts are very resistant.

The Geological Survey of Sweden has carried out combined land- and sea-based geological mapping along the coastline of Skåne. The collected data on land include beach sediment composition, beach morphology, sediment stratigraphy, signs of active erosion and constructions for coastal protection. Information collected on the sea floor includes surface sediment composition, detailed bathymetry and patterns of erosion and deposition caused by waves and currents.

The information has been used to classify the shoreline into different coastal types with different sensitivity to erosion (Malmberg Persson et al. 2016). An attempt to estimate the erosion conditions after a one-metre rise of the sea level has also been made. The most common coastal type today is sandy beaches with alternating erosion/accumulation but in balance over an extended time (31 % of the coast). 12 % of the coast is subject to net erosion.

These features, and more information, are shown in a map viewer: https://apps.sgu.se/kartvisare/kartvisare-skanestrand.html

The information can be used for e.g. coastal physical and marine spatial planning and for study of sediments and sedimentary processes in coastal environments.

ORAL

Integrated analysis of past, and potential future rock slope failures of various size from Rombakstøtta, Norway

Odd André Morken[1], Reginald Hermanns[2] and Paula Hilger[1]
[1]NGU, [2]NGU, NTNU

Catastrophic failure of large rock slopes has led to fatalities in Norway several times per century. The Geological Survey of Norway (NGU) carry out systematic mapping of potentially unstable rock slopes in Norway. In this context, a hazard analysis and preliminary consequence assessment of the unstable rock slope at Rombakstøtta, has been carried out. Additionally, a fragmentation cycle analysis, used to assess the fragmentation of the rock mass during a failure, and to separate rock fall deposits from rock avalanche deposits, has been developed and tested.

The study area is in a north facing slope along a fjord, within the arctic circle and close to the city of Narvik. Based on delimiting lineaments observed in the field, aerial photos, photo

panoramas and digital elevation models, eight failure scenarios are defined. Application of NGU´s hazard analysis as well as volume estimation and run-out analysis were done for all scenarios. Four of the scenarios have modelled run-out reaching vital infrastructure and the fjord.

The fragmentation cycle analysis has been developed and applied inspired by Charrière et al. (2016). Results suggest that the rock avalanche deposits at Rombakstøtta underwent 0-3 fragmentation cycles during failure and transport. And that rock fall deposits generally experienced more than 4 fragmentation cycles during failure and transport.

ORAL

The triggering factors of the Móafellshyrna debris slide in northern Iceland: intense precipitation, earthquake activity and thawing of mountain permafrost

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On the 20th of September 2012, a large debris slide occurred in the Móafellshyrna Mountain in the Tröllaskagi peninsula, central north Iceland. The slide initiated after an unusual warm and dry summer followed by a month of heavy precipitation. Furthermore, the slide originated after a seismic sequence. The main source of material was ice-rich talus deposits perched on a topographic bench. Blocks of ice-cemented deposits broke off the frontal part of the talus cone and fell onto the talus slope below. Further downslope, the landslide material became over-saturated, causing it to evolve into a debris slide. We estimate that the total volume of the debris slide is around 500,000 m^3 and that its primary cause was intense precipitation. We cannot exclude the influence of the seismic sequence as a contributing factor. The presence of ice-cemented blocks in the slide deposits shows that thawing of ground ice could have played an important role as a triggering factor. Ice-cemented blocks of debris have been observed in the deposits of two other recent landslides in northern Iceland, in the Torfufell Mountain and the Árnesfjall Mountain. This suggests that discontinuous permafrost is degrading in Iceland, due to climate change. This study highlights that ground ice thaw could represent a new source of hazard in Iceland. The knowledge of the detailed distribution of mountain permafrost on the island is poorly constrained and should be a priority for future research.

ORAL

Geomorphologic Evidence and Timeline Reconstruction of Holocene Jökulhlaups along the Hvítá River and Gullfoss, Iceland

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Gullfoss is one of Iceland's most visited tourist sites, a two-tiered waterfall where the Hvítá River plunges 32 meters into the Hvítárgljúfur canyon. This system is one line of evidence for paleofloods that surged across the region ~9500 years BP. Over a span of 100-200 years, a series of floods drained the ice-dammed glacial lake Kjölur in the southwestern highlands. The largest events reached an estimated maximum peak discharge of 3×10^5 m^3 s^{-1}, ranking them among the largest known floods in Iceland and on earth. Most research on Icelandic jökulhlaups has focused on floods generated by volcanic and geothermal activity beneath the southernmost ice caps; but the little-studied Kjölur floods, not triggered by volcanogenic processes, may provide a better analog for most global glacial lake outburst floods. A pioneering study by Tómasson (1993) reconstructed the Kjölur paleofloods based on geomorphologic evidence and paleolake strandlines. This project builds on previous research by employing new methods to better constrain flood timing, magnitude, and routing. This presentation has three main goals: 1)

present new and synthesized geomorphologic field evidence; 2) outline a sampling strategy for geochronological analyses; and 3) situate the Kjölur jökulhlaups in the broader context of catastrophic flood geomorphology in Iceland. This research will yield insight into drainage dynamics of ice-dammed proglacial lakes, which pose an increasing hazard worldwide due to rapid climate-driven glacial lake expansion. It has excellent potential to bridge the gap between academic research and public outreach through communication to a high number of international visitors.

POSTER

A structural and InSAR study of the unstable rock slope in Oksfjellet, Troms

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Oksfjellet is one of many unstable rock slopes in Troms, Norway. Due to the hazard and risk posed by potential slope failures, it is important to obtain precise deformation measurements. In this study, a combination of field observations and InSAR data was analyzed to better understand the geological structures susceptible for sliding in Oksfjellet.

Field mapping in Oksfjellet revealed a ductile shear zone/thrust that is interpreted to have formed during the Caledonian nappe emplacement. Mapped fractures, trending NE-SW and NW-SE, coincides with regional Mesozoic brittle structures.

Satellite InSAR data (TerraSAR-X and Radarsat-2) revealed subsidence of the unstable slope at a rate of 4 – 5 mm/year. Additionally, satellite InSAR data detected subsidence of a larger area, at a rate of less than 1 mm/year, that is thought to relate to active down-faulting. Results from Ground-Based InSAR revealed displacement estimates at rates of mm/day, indicating that seasonal changes related to water and ice influences the stability of the unstable rock slope.

Based on structural measurements and displacement patterns detected by InSAR, the deformation in Oksfjellet is interpreted to be controlled by a complex interaction between ductile and brittle structures, following a common deep seated sliding surface between foliation/thrust and fractures. The combination of InSAR data and field mapping proved valuable in order to assess displacement patterns at different temporal and spatial scales. This contributed to an improved understanding of the evolution of the unstable rock slope in Oksfjellet.

POSTER

The Kassen and Håkåneset rock slope instabilities along fjord lakes in Telemark show large postglacial gravitational strain but no present day deformation, Southern NorwayThe Kassen and Håkåneset rock slope instabilities along fjord lakes in Telemark show large postglacial gravitational strain but no present day deformation, Southern Norway

Kaja Krogh[1], Reginald L. Hermanns[2], Trond Eiken[3], John Gosse[4], Martina Bøhme[2] and Ivana Penna[2]
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The Kassen and Håkåneset rock slope instabilities lie along fjord lakes. The Kassen instability lies at the tip of a plateau dipping steeply towards Bandak lake. The instability stretches 2,5 km E-W. Its up to 100-m-high steep back scarp separates undeformed crystalline bedrock from strongly desintegrated rock mass

breaking the slope in various compartments. In the central part a depression exists, that has descended an additional 25-50 m. Below that, bathymetric data reveal a 13.4-million-m^3 large rock-avalanche deposit on the bottom of lake Bandak. Preliminary cosmogenic nuclide ages indicate that the top of the mountain melted out of the ice at 14.1 ka and was mainly active in the early part of the Holocene. Differently the top of the Håkåneset rock slope instability lies mid slope but similarly the up to 75-m-high back scarp separates strongly deformed and cracked rock mass from stable rock mass. Bathymetric data of Tinnsjø lake reveal that the instability extends down to ~330 m below lake level. At the foot both a 40-m-high pressure ridge within a terrace and several generations of slide scars within this terrace suggest that the instability reaches down to the lake bottom.

Kinematic feasibility tests at both locations show that simple failure modes are possible in the steepest slope parts but bi-planar sliding is feasible at both locations for larger compartments. Displacement rates determined by dGNSS show velocities below significance level (< 2mm/yr) for the past years suggesting that both rock slopes stabilized in comparison to the pronounced postglacial deformation.

POSTER

Stability Analysis of Preikestolen (Rogaland county, Norway)

Katrine Mo[1], Reginald Hermanns[2], Martina Böhme[3] and Pierrick Nicolet[3]
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The hike to Preikestolen is one of the most popular trails in Norway, with more than a hundred thousand visits each year. Despite the popularity, the stability of the rock formation is not yet determined. The Geological Survey of Norway (NGU) is now mapping potential unstable rock slopes in Rogaland County. Hence, Preikestolen is included as one of the main investigation objects. The master thesis “Stability analysis of Preikestolen" is a part of this project, and will be based on data collected by NGU in addition to student work.

In September 2017, the rock formation was scanned from four different angles with a ground based LiDAR scanner. These scans will be put together to create a detailed 3D model of Preikestolen. In addition, two 3D models will be created using photogrammetry. One model will be based on photos taken from helicopter and the other one from drone photos. These models will be compared to field data in order to test which remote sensing data give the closest results and can be used best as a standard method. Further, the 3D-models will be investigated in Coltop-3D to gather structural data measurements. These measurements will be used in combination with structural data from fieldwork to do a kinematic feasibility test. Further, the stress distribution in the rock formation will be modelled with RS2. To gather input data, several test are planned in the rock mechanics laboratory at NTNU. Eventually, all data will be discussed to give a final evaluation of the stability.

POSTER

Assessment of risk posed by slope failures at a coastal cliff in Hyllestad municipality (Sogn og Fjordane, Norway)

Vegard Nes[1], Reginald Hermanns[2], Ivanna Penna[2] and Jon Runar Drotninghaug[1]
[1]NTNU, [2]NGU

In the last years, the Norwegian Geological Survey has been mapping unstable rock slopes in Sogn og Fjordane county. Several of them developed on fjord slopes, which implies that in addition to the direct impacts, the consequences related to displacement waves need to be addressed. In this context, slope instabilities along a 6 km coastal cliff in Aafjorden has been

identified, and two of them are currently being monitored (NGU, 2017). The aim of this work is to give a complete overview of the unstable slopes present along the coastal cliff of Aafjorden, as well as their main controlling factors by including the results of a recent survey.

The mapping was completed through field work, and interpretation of photogrammetric models and a 1m resolution DEM. The mechanism of failures is based on site measurements as well as structure detection with COLTOP3D. Volume estimates of the unstable blocks were calculated using CloudCompare.

Our analysis shows that there are 8 unstable blocks with volumes up to 170 000 m^3 along the coastal cliff of Aafjorden that can lead to considerable displacement waves, as already occurred in 1992 (Harbitz, 2001). The detachments are controlled by steep N-S and E-W striking joint sets in the western domain, and joint set dipping 70 degrees towards east in the eastern domain. The kinematics of the unstable blocks have exposed both potential toppling-failures and planar failures. Future work includes the risk assessment of all the potential scenarios, using the methodology developed by NGU (Hermanns, et al., 2013).

POSTER

Monitoring of surface processes in Gråfonnfjellet, Rauma municipality, Norway

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Loose rock masses remain on the headscarps and after historic and prehistoric rock avalanches on Gråfonnfjellet mountain, Innfjorddalen, Norway. This material is remaining after at least three post-glacial rock avalanches that have been deposited in Innfjordalen (Scheiler et al. 2016). At this site, in addition to the rock avalanche deposits, a large colluvial fan can be observed (Skei 2016). The objectives of this work are to describe the source of sediments and the surface processes contributing to the development of the fan. This study takes advantage of permanent monitoring equipment (3 cameras and 1 meteorological station) and periodic measurements (LiDAR, photogrammetry, gigapixel pictures) to study the slope processes that are active nowadays. An area of intensively fractures rocks, that remains in the headscarp, is shown to be the main source of sediments. Indeed, 93 negative differences (e.g. missing blocs) have been observed between 2014 and 2016 on the gigapixel pictures in this area. In addition, 63 positive or composite differences (e.g. deposited bloc or sediments transported on a short distance) have been identified in the same area, which suggest that the sediments are often transported only on a short distance. Furthermore, the permanent camera placed in the valley permits to identify several snow avalanches that remobilize sediments down to the lower parts of the fan. During snow melt season or precipitation events, materials are transported in form of debris flows along two main channels. Further work is needed to better relate the observed events with the meteorological conditions.

10.2. Open session Engineering and enviromental geology

ORAL

The modelling of ice-marginal complexes and salt structures using 3D layer models

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Among the most challenging geological structures to interpret and model in the Danish area are the ice marginal complexes with complex stacked internal structures and areas with salt domes intruding Neogene and Quaternary strata. The geology will reflect complex tectonics that must be interpreted and turned into a sequence of tectonic events in order to represent this in a 3D model.

The development of a reliable conceptual model is essential in this work and this conceptualization must encompass a thorough analysis of all data sources available including drillings, geophysics, geomorphology, previous investigations ect. representing a cross-discipline investigation.

The development of a geological 3D model that reflects the conceptual geology and tectonic structures requires special techniques when using layer models including sophisticated positioning of digitalization-points, interpolation and adjustment procedures in order to develop steeply dipping or vertical strata, faultlines or saltdomes that may be developed as true dome structures or horst structures.

Examples will be shown from well-known geological Danish geological sites as the Røsnæs Icemarginal complex, Thyborøn (Rønland Saltdiapir) and Suldrup Saltdiapir where these methods have been used in connection with ground water modelling projects and for geotechnical purposes. The modelling technique takes the layer-model method to its limits but this type of model can be integrated with the overall geology of an area fairly easy in contrast to a site specific voxel model.

ORAL

Geochemistry of deposited mine tailings in Repparfjorden, northern Norway, and their effect on bottom fauna.

Malin Andersson[1], Tor Erik Finne[1], Hilde Trannum[2], Kristine Pedersen[3], Anita Evenset[3] and Paul Renaud[3]
[1]Geological Survey of Norway, [2]The Norwegian Institute for Water Research, [3]Akvaplan-niva

Submarine tailing disposal (STD) involves the discharge of mine tailings below the sea surface as an alternative to on-land deposits. Norway, a country with deep, sheltered fjords, is one of the few countries in the world where these disposal operations are in use. This study investigated a four decade old mine tailing deposit in Repparfjorden, originating from copper ore processing in the 1970's. Bathymetry from this project revealed that the deposit is still presently almost intact. The issue is of interest as the mine is likely to reopen in 2019.

The mine tailings are, in relation to the natural materials lying under the tailings and on top, clearly enriched in the elements Au, Ba, Bi, Cr, Cu, Hf, Ni, Re and Zr, but also depleted in the elements: Be, Cd, Cs, In, Li, Nb, P, Pb, Rb, S, Sc, V and Zn, therefore establishing the chemical signature of the tailing material. To be able to compare geochemical results and execute fauna experiments, newly fabricated flotation tailings were produced. The old tailing deposit differs considerably from these, which could be due to differences in ore material or flotation process, or chemical changes during deposition. These differences make chemical predictions for a future deposit difficult.

The bottom fauna study revealed differences in the number of species and individuals present in the surface sediments depending on the influence

of the tailings. Depending on the depth of tailings on top of surface sediments, a decrease in biomass amount was evident during a re-colonisation experiment.

ORAL

Development of a direct tensile test method for microtextural fracture studies

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Traditional macroscale rock strength tests generally aim at characterizing and comparing different rock types in a standardized way. However, these methods rarely shed light on the crack development in relation to the material structure. Often the loading situation and specimen geometries are complex, resulting in difficulties identifying the contribution of different synchronous deformation processes. Examples are compressive loading tests, in which a combination of compression and shearing occur, and Los Angeles tests, in which crushing, abrasion, tension and shearing occur simultaneous. Due to this shortcoming, a new methodology which combine detailed cracking monitoring techniques with mechanical rock tests – allowing the examination of different isolated deformation mechanisms – is presented.

The methodology combines tensile stage testing of a rock specimen with continuous monitoring of the cracking processes by Digital Image Correlation and Acoustic Emission. After completion of tensile test, examination of microcracks and fractures by fluorescent transmission microscopy is conducted. This methodology enables the spatial and temporal visualization of the cracking processes within a rock sample, on micro- and mesoscale, linking the cracking processes (e.g. initiation, reactivation, propagation and bridging of microcracks, and the final development of the open fracture) to rock texture and microstructure. The methodology has been demonstrated on 28 samples from three granitic rocks of different textures and structures. The strength of the methodology is the increase in knowledge of critical parameters affecting cracking processes in rock materials and how these are related to the rock micro- and mesostructure.

ORAL

Construction geological map of Stockholm- and example of geo-data recycling.

Phil Curtis[1] and Claes Mellqvist[1]
[1]SGU

The original construction geological map of Stockholm was produced during the 1970s and is still widely used today in the early planning stages of new infrastructure projects. Although it was digitized in 1997 it has not been updated since its original publication. The Geological Survey of Sweden (SGU) has been working on such an update that includes the incorporation of geological data from existing infrastructure projects from external sources such as (Swedish Transport Administration) Trafikverket and the construction industry. The new map is to be issued on the web in a 2D format for ease of use, however, much of the visualization and interpretation process has been performed in 3D and the results will be available for viewing on a separate website.

ORAL

Weakness Zones in the Bedrock - Geophysical Studies in City Area

Taija Huotari[1] and Marit Wennerström[1]
[1]Geological Survey of Finland

As the amount of underground building in city areas grows the need for information of bedrock under the ground surface is increasing.

Problematic features for underground construction might be weakness zones in the bedrock. Information on the location, orientation and properties of weakness zones before starting construction will improve the schedule and cost estimates of the project, as well as usually reduces the construction costs. The potential of different geophysical methods were tested to detect weakness zones in the bedrock in the project called 'Intrageo' (Huotari & Wennerström, 2017). Further, the geophysical results were integrated with structural geological interpretation of weaknesses in the bedrock.

The investigations were carried out at Hannusjärvi and Finnoo in Espoo on the planned route for the 2nd phase of the West Metro, as well as in the area of the new underground wastewater treatment plant of HSY (Helsinki Region Environmental Services Authority) water services at Blominmäki, Espoo. Both investigation areas are located in the Helsinki metropolitan area in Finland. In 2nd phase West Metro targets the measurements were concentrated on tests of ground geophysical methods. The aim was to test different methods along the same survey profiles to perform integrated interpretation and to evaluate the usability of different methods. In Blominmäki tests concentrated on geophysical drill hole measurements and magnetic measurements with dense line spacing in the most fractured rock area. Petrophysical properties, as well as the rock type and structural features, were studied from drill core samples for the sake of comparison and verification.

ORAL

Digital archive for strong ground motions recorded in earthquake sequences

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Numerous structures and infrastructures systems have been recorded to encounter extensive damages or total collapse due to successive earthquake ground motions occurred in short time spans. A list of recent earthquake sequences, found to be detrimental for both humans and the building stock, comprises of seismic events from Amatrice-Italy (2016) and Kumamoto-Japan (2016), Gorhka-Nepal (2015) and Tōhoku-Japan (2011). Nevertheless, the current seismic codes prescribe the structural design on the basis of a single "design" earthquake waiving the sequential seismic events that may increase the seismic vulnerability of structures. It is, thus, important to focus on this hazardous phenomenon in order, eventually, to mitigate its consequences. Over the last 15 years, the effects of earthquake sequences on the structural performance have been elucidated [1-3]. However, the use of real strong motions from successive ground shakings is commonly restricted to a single earthquake sequence event that may dominate (or bias) the structural response results [4]. Additionally, the artificially-developed earthquake sequences may derive questionable seismic demand [5]. Hence, this study is dedicated to compile a dataset including almost 7000 suitably selected strong ground motions, which were recorded worldwide during earthquake sequences and found of interest for studies addressing the structural response imposed by multiple earthquakes. The dataset compiled provides metadata related to seismological characteristics and strong ground motion parameters while, when necessary, the records were processed (i.e., base-line correction and frequency-based filtering). Finally, systematic analysis of the selected motions revealed trends on the basis of the several

parameters associated with the successive earthquakes.

ORAL

The quaternary history at the Horns Rev 3 site.

Joakim Stiel Korshøj[1]
[1]Geo

In 2013 Geo was contracted to carry out pre investigations for Energinet, for the offshore windfarm Horns Rev 3. The pre investigations revealed a buried landscape, with dislocated floes of Miocene clays.

The Horns Rev 3 bank is composed of a rather complex sequence of Postglacial and glacial sediments, including glacial floes of Tertiary sediments. The area was not covered by ice during the Weichsel glaciation. The sea-level was approximately 120 m below current sea-level. The only deposits from Weichsel that is observed in the area is from meltwater rivers flowing in the lower lying areas. Two Postglacial units have been deposited during the Flandrian transgression. Deposits consist of non graded sand and organic clayey silt and clay. The deposits are generally loose/soft, locally the organic content is high, here they are described as organic clay (gyttja). Some smaller deposits of peat have been observed, one of which was dated by C14 determination. The peat layer was found in the bottom of the Postglacial sequence and was dated to between 8211 and 7791 years BC. In-between the meltwater deposits smaller till layers are seen, as well as floes of Tertiary sediments.

Tertiary deposits have been found as floes interbedded in the meltwater deposits and two borings stopped in Tertiary deposits. Since drilling stopped in these layers, it is not possible to say if they are parts of folded Tertiary sediment by Saalian or earlier glaciations, floes or if the Tertiary sediments are in situ.

ORAL

Risks of arsenic exposure through agriculture

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Arsenic is a toxic and carcinogenic semi-metal which can enter into agricultural soil and water due to human activities or from natural deposits. AgriAs Water JPI project started 1st April 2017 and evaluates arsenic contamination in Europe focusing in two study areas with intense anthropogenic pollution. Research institutes, universities and companies from five EU countries participate in the project. AgriAs summarizes national and European databases (e.g., Tarvainen et al. 2013) and develops recommendations and guidelines for sustainable management of arsenic risks in agricultural areas. The French study site is a historical area of destruction of WWI chemical weapons located in a sensitive zone for agriculture and groundwater. The German site is characterized by 800 years of mining. Arsenic removal technologies will be developed and demonstrated in both areas. Biological tools will be applied to manage ecological, environmental and human risks. Dissemination activities will follow the procedures of the successful LIFE + project ASROCKS which developed guidelines for rock aggregate production in arsenic-rich areas (e.g., Parviainen et al. 2015). In the first stakeholder workshop organized in Freiberg in September 2017, interaction and discussions between farmers, authorities and researchers were active.

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ORAL

2,5D Open Source Modeling of Rock Aggregate Resources in the Helsinki Metropolitan Area

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The objective of this study is to develop a method of appraising rock aggregate resources, using open data and open source tools. The availability of aggregates in Finland is mostly determined by competing land use and restrictions on extraction. Therefore, it is important to determine the extent of available resources, especially near areas of high demand.

The study area consists of the 14 municipalities in the Helsinki metropolitan area, a total of 3841 km^2. The data used are open access, provided by GSF and NLS. These are combined in a GIS to identify locations where extraction of aggregates is possible. Geology, limitations and the highest and lowest point of possible extraction are detrmined. These are used to estimate the available resources and locate the economically feasible sites. Data used include a digital elevation model and layers on geology and land use.

The results show that competing land use has sterilized most aggregate locations in the area. Remaining locations are concentrated on the edges. However, some potential sites remain. Field evaluations and comparison to previous studies show that the method is sound and able to locate possible localities.

The model is fast in coarsely determining aggregate volume. It is highly suitable for focusing expert fieldwork. Land use in the area continues to sterilize new locations. To avoid economic and ecological damage, a plan should be implemented for securing this resource. This may include the reserving of locations, reducing use, checking legislation on production and recycling used aggregates.

ORAL

Developing of Geothermal District Heating solutions for 4 towns in Poland

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Poland possesses proper geothermal energy to supply low-emission thermal energy. Polish, Icelandic and Norwegian experts collaborate to develop geothermal district heating solutions for four towns in Poland. Three of the towns, Konstantynów Łódzki, Sochaczew, and Poddębice, are located in sedimentary rocks central Poland in the Permian-Mesozoic Szczein – Lodz Miechow. The last town, Lądek Zdrój is situated in crystalline rocks in Sudet Mountains close to the boundary to Czech Republic. The town is one of the oldest Polish health resorts using thermal water.

A 10 MW_{th} geothermal district heating plant was established in Poddebice in 2013, substituting fossil energy. The geothermal well of 2101 m depth is extracting water of 70 °C from Lower Cretaceous sandstones. Maximum flow rate is 252m^3/h. The water is discharged into the Ner river and it is a challenge to satisfy the requirement of a maximum temperature of 35°C on the water discharged. There is also a need for

better understanding of the effect of long-term geothermal exploitation

A new geothermal well of 2800m depth extracting water of 70 C from Lower Jurassic is planned as an additional energy source for Konstantynów Łódzki incooperated in the existing Łódź district heating system.

The authorities in Sochaczew plans a geothermal district heat pump solutions utilizing water of 40°C from Lower Cretaceous sandstone.

A new geothermal well of 2500 m depth is planned in Lądek Zdrój producing water of 70°C from fracture zones.

The joint Polish/Icelandic/Norwegian project was funded by EEA Grant.

ORAL

Geological studies of the possible Helsinki–Tallinn undersea tunnel route

Keijo Nenonen[1] and Ossi Ikävalko[1]
[1]Geological Survey of Finland

Geological Survey of Finland (GTK) and Estonian geological Survey (EGS) conducted geological studies and acoustic-seismic surveys of the possible linings for an undersea railway tunnel between Helsinki and Tallinn.

The surveys provided a detailed overview of the geological structure of the sea floor basement and deposits between Finland and Estonia. A new finding was that the crystalline Proterozoic basement sea floor continues all the way to Naissaar and to the shallows near the Estonian coast. A thick layer (100-150 m) of soft sedimentary rocks from Cambrian - Ordovician age (sandstones, claystone and limestones) covers the hard granitic bedrock on the city of Tallinn area. Presently ongoing FinEst Link project between Finland and Estonia examines the possibilities of building a 100 km long railway tunnel. The geological findings provides new and useful information for further detailed engineering geological surveys.

The FinEst link project examines the technical and economic feasibility of the undersea tunnel and the logistic solutions in addition to its cost-effectiveness and economic, environmental and social impacts. Results are to be expected during the present year 2018. The viability of planning the tunnel can be assessed only after receiving these results.

The research work on the feasibility of the tunnel project was enabled by EU funding under the Interreg Central Baltic programm. The project is led by the Helsinki-Uusimaa Regional Council in cooperation with the City of Helsinki, the Finnish Transport Agency, the City of Tallinn, the Estonian Ministry of Economic Affairs and Communications and the Harju County Government

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ORAL

Nyt borearkiv ser dagens lys - Øget adgang til private borearkiver

Mikkel Wendelboe Toft[1]
[1]Cand.scient

Geo har skabt en ny online adgang til viden om undergrunden. Formålet er at sikre at fagfolk på tværs af organisationer kan arbejde med bedst muligt udgangspunkt så projekterne bliver løst mest effektivt og med mindst risiko. I dette oplæg vil vi fortælle om strategien bag frigivelsen af virksomhedens data, samt om de tekniske problemstillinger som vi bliver mødt af under udviklingen af et sæt helt nye services. Desuden perspektiveres der mod potentialet ved af tilgængeliggøre andre virksomheders data. Initiativet er blandt andet motiveret af Statens beslutning om at stille sit kortgrundlag gratis til rådighed, hvilket har skabt helt nye forudsætninger i markedet. Vi har udviklet en række værktøjer som, via bagvedliggende 3D modeller af undergrunden, kan lave virtuelle boringer, udstille 3D jordartskort i fladesnit, samt gøre det muligt at lave hurtige og brugervenlige

profilsnit af høj kvalitet. Ved at udstille værktøjerne online, søger vi at skabe maksimal tilgængelighed, og mulighed for høj brugervenlighed. Et interessant potentiale i tendensen med åbning af adgangen til data i de private virksomheder, er værdien ved sammenstilling af data fra andre kilder. En sammenstilling gør det muligt eksempelvis at se relationen mellem registreret jordforurening, arealanvendelse eller befæstelsesgrad, og den overfladenære geologi. Mulighederne for anvendelse er utallige, og når først brugeren i særlige fagdomæner får adgang, så vurderer vi at anvendelsesmulighederne vil spire frem.

POSTER

Development of a database for stratigraphic information on Quaternary deposits at the Geological Survey of Norway (NGU)

Louise Hansen[1], Bo Nordahl[1], Alexandra Jarna[1] and Inger-Lise Solberg[1]
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A National database for superficial deposits have existed in Norway for decades and is developed and hosted by the Geological Survey of Norway. The database is the basis for web services presenting Quaternary map information at different scales and associated products and services (www.ngu.no). The maps are used in society for various purposes from research to public planning. Stratigraphic information has previously only been presented as a somewhat complicated text strings locally on analogue Quaternary maps, or in associated reports/articles. There has, till now, not been any database to receive stratigraphic information in a structured way. As there is a growing need in the Norwegian society for subsurface geological information there is also a need for the development of a stratigraphic database. A prototype of a stratigraphic database is presented. An important aspect of the database is that it can host varied types of stratigraphic information from different sources. The newly developed National Database for Ground investigations (NADAG) is a potential source for valuable stratigraphic information from e.g. linked drill reports. Well organized and standardized stratigraphic information in a digital format is needed for extending the present day geological map products into the subsurface, and for further analyses and modeling. Possible web solutions are presented.

POSTER

Provenance and Contamination History of the Paraná Delta, Argentina

Jane Ihrfors[1], Matilda Schütz[1], Rodney Stevens[1], Juan Pablo Milana[2] and Claudio Parcia[3]
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This is a sedimentological and geochemical study documenting sediment provenance and contamination of the Paraná Delta front during the last 150 years. The Paraná river system is a pristine landscape home to several endangered species and South Americas second largest drainage basin containing some of the world's largest wetlands. The basin has been cultivated for a long time but with an expanded human activity during the last century with increased deforestation and industrialisation. Therefore, studies in the Paraná could give an indication on how the Amazons will be affected by increased human impact. Previous studies of the delta front have mapped and dated beach ridges (Medina et al, 2013). A transect sampled perpendicular to these provides a historical record of the delta progression and development. The aim is to see how the change of climate and human activity in the catchment area have affected the sediment provenance at the delta front. The samples are analysed using methods to identify the mineral composition in the clay and sand fractions to reveal their provenance and roughly estimating each sub-basin's sediment supply to the delta front. Sediment geochemical trends over the sampled timeline, with a particular emphasis on

heavy metal contents, are interpreted in terms of provenance and contamination, which in turn are linked to human impact through deforestation, afforestation, population growth, urbanisation and industrial activity. In general, the delta-forming processes themselves need to be re-evaluated on the Paraná Delta since these are also affected by changing climate and increasing human impact.

POSTER

Investigations of clay deposits as barrier for a final repository for Denmark's low- and intermediate level radioactive waste in subsurface to 500 m depth.

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The Danish radioactive waste from the research station Risø must be stored on Danish land territory (exclusive Greenland). The radioactive waste is consisting of the waste from the decommissioning of the nuclear facilities at Risø, and the radioactive waste produced in Denmark from hospitals, universities and industry.

The Geological Survey of Denmark and Greenland has until 2011 been responsible for the geological studies of near-surface areas (100-200 meter depth) for the repository. The task has been to locate and recognize non-fractured clays or Precambrian bedrocks with low permeability which can isolate the radioactive waste from the surroundings. Six potential areas have been located based on the most favorable conditions in relation to geology, hydrogeology, nature protection and climate change conditions.

Five of the six localities Paleogene and Neogene clays are considered as suitable as the last barrier in the repository based at these criteria: 1.The clay layer shall be at least 50-100 m thick, 2. The clay layers shall have a continuous horizontal distribution in the selected area. 3. The clay layers shall be low permeable without fractures and with very low groundwater content. 4. The selected area shall be without groundwater and drinking water interests. The last locality was located in Precambrian basement rocks.

In 2018 new technical studies will be carried out to determine possible future locations for a deep geological final repository at ~500 meter depth. As the existing data and previous studies do not make it possible to conclude where a deep repository can be placed.

11. Hydrogeology

11.1. Groundwater transport in cold, changing climates: theory, experiments, models

ORAL

Modelling snowmelt infiltration in a seasonally-frozen soil monitored by electrical resistivity measurements

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Infiltration during snowmelt can be highly heterogeneous due to the formation of ice on the ground surface below the snow cover. In situations where snow is contaminated, such as along highways and airports due to de-icing agents, the area that takes part in the early infiltration will determine the retention time and potential for degradation in the unsaturated zone. In 2001, French and Binley (2004) observed a highly variable snowmelt infiltration over a small area at Gardermoen, Norway, monitored with time-lapse electrical resistivity measurements. In this study, we want to test the suitability of a newly developed numerical model for water and heat transport including phase change (modified version of SUTRA_ICE, described in McKenzie et al.,2007) in a variably saturated soil against field observations. Monitored weather and snow melt data defined the boundary conditions of a simulated unsaturated profile with seasonal freezing. The dependency of capillary pressure and permeability on water saturation is taken from the van Genuchten equation. Soil physical data and heterogeneity was based on local soil measurements. Different infiltration scenarios were tested. Soil temperatures, TDR measurements of soil moisture, a tracer experiment conducted at an adjacent site and changes in electrical resistivity were used to validate the model of infiltration and thawing. The model was successful in reproducing the thawing and soil moisture patterns observed in the soil, and hence looks like a promising tool for predicting snowmelt infiltration and melting of ground frost in a sandy unsaturated soil.

ORAL

Numerical simulations of temperature-dependent transport in waste rock piles in permafrost-dominated environments

Daniele Pedretti[1] and Leslie Smith[2]
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Waste rock piles (WRPs) contain unsaturated materials that can yield water with elevated solute concentrations as a consequence of sulphide mineral oxidation. Tracer tests can be used to provide insight to transport properties that affect the evolution of the effluent water quality over time. In cold environments, flow and transport are also affected by variably freezing conditions within the pile, a process that complicates the interpretation of tracer tests.

This contribution describes a numerical model simulating conservative solute transport in a homogeneous WRP with temperature-dependent boundary conditions and variably freezing cycles within the pile. The conceptual model is based on the experimental waste rock piles at the Diavik Diamond Mine in northern Canada, located in an area of continuous permafrost.

The results illustrate the key role of an explicit solution of temperature-dependent flow conditions to evaluate the seasonal and annual release of solute loads. The model illustrates the annual drainage cycles in the core of the pile, which were hypothesized to be characterized by distinct spring flushes and steady decline in flow prior to freeze-up. Solutes move within the

unfrozen core of the pile even when the external portion of the pile starts to freeze. The temperature boundary conditions affect the (transient) flow geometry within the piles, and can complicate the interpretation of tracer tests. In particular, an apparent dual-porosity-like effect is produced on solute breakthrough curves even when the pile is physically simulated as a hydraulically and geochemically homogeneous single porosity domain.

ORAL

Groundwater levels real time monitoring and visualization software demonstrated for Precambrian valley sediment aquifers in Ostrobothnia, W Finland

Niko Putkinen[1], Holger Kessler[2], Ben Wood[2], Elina Lindsberg[1], Harri Issakainen[1], Tero Rönkkö[1], Esa Kauniskangas[1] and Miikka Paalijärvi[1]
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Old buried Precambrian valleys in Ostrobothnia, Kurikka, W Finland play a major role in the groundwater system and will ensure the future municipal drinking water supply for over 150000 people. Several year's of intensive hydrogeological studies include 70 boreholes to the bedrock, ~200 km gravity measurements, numerous seismic profiles in the 100km2 study area. According to the reported results, it is possible to conclude the bedrock structures promote the most conductive hydrogeological units interlinks between faults, fractures and other structures, the topography of the glacially eroded bedrock surface and the overlying weathered bedrock surface and 50-100m thick highly variable glacial deposits include several confined - semi confined sand and gravel sediment aquifers and clayey till and marine silt aquitards.

In this project GTK and BGS are working together for water companies on developing free–to-use geological software for use in hydrogeological investigations and environmental monitoring. Data (e.g. gw-levels) will be collected in the field in real-time using an innovative sensor technique. The project will develop visualization capability for this data and interpolation routines will be added, allowing analysis of trends across monitoring sites. Connections to GTK corporate databases will be established, making data exploration simple and intuitive for GTK geoscientists and the supervising authority. Sharing real time groundwater data in Groundhog Desktop, and visualizing interactively in maps, logs and cross-sections, will significantly help environmental agencies to monitor and control the sustainable use of water.

POSTER

Subpermafrost Groundwater and Pingos in Adventdalen - Evaluating the Implication of Holocene Permafrost Formation in Near Coastal Areas

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In previously glaciated areas of the Arctic, substantial isostatic rebound and associated relative sea-level fall have lead to Holocene permafrost formation in former shallow marine areas. The study area for this work is Adventdalen in Svalbard, a glacial valley for which an extensive amount of research on geological and permafrost-related subjects exists. The implications of this landscape's history for subpermafrost groundwater is investigated in three ways: 1) Electrical Resistivity Tomography (ERT) surveys around a pingo enable location of intrapermafrost groundwater flow paths. 2) A decoupled 1D/2D heat and groundwater flow model provides quantitative estimates of the potential discharge from the subpermafrost groundwater system as permafrost aggrades. 3) Artesian springs at three pingos facilitate hydrogeochemical interpretation of controlling processes along groundwater flow paths. Results

from the flow and heat transport models suggest that the permafrost thickness has not yet reached equilibrium, and so frozen ground might still be developing in the lowest part of the permafrost. This implies that groundwater discharge from the subpermafrost aquifer could be driven by permafrost aggradation, leading to the artesian springs seen at the pingos. However, the spring water analyses show complex hydrogeochemistry probably due to freeze and thaw processes, although a common source is probable and a subpermafrost origin seems most likely. On the basis of the model results and the ERT, a new conceptual model of open-system pingo formation will therefore be presented.

11.2. Groundwater – surface water interaction; chemical and quantitative impacts on rivers, lakes, wetlands, fjords and coastal areas.

ORAL

Groundwater discharge and recharge patterns in complex aquifer system in a mine exploration area in Northern Finland

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A prominent Cu-Ni showing named to as Sakatti has been discovered in Sodankylä (Brownscombe et al. 2015), close to Kitinen river and below the Natura 2000 protected Viiankiaapa mire. Understanding of the interaction of surface and groundwater is essential for sustainable ore exploration and development. However, the complexity of the sedimentation history of the surficial deposits makes the groundwater occurrences scattered and elusive. The mire hydrology and its relationship with groundwater recharge–discharge patterns is also crucial for mire vegetation, but has seldom been studied in Finland (Laitinen et al. 2005). Understanding groundwater-surface water interaction areas is also important when protecting habitats of groundwater dependent ecosystems (GDE).

MODFLOW-NWT model was utilized for defining the groundwater recharge and discharge patterns and to relate them with GDEs in the area. Hydrostratigraphic units of the model based on the previously created conceptual sedimentary model (Åberg et al. 2017). At the same time annual groundwater table fluctuation was studied from monitoring wells for definition to initial recharge rates. The recharge parameters were calibrated with parameter estimation. Hydraulic conductivities were manually

calibrated with interpolation from previous k-value calculations. The model results indicated that major flow direction is towards the Kitinen river. The model underestimated the distribution of the discharge zone within mire area. It also slightly overestimated the recharge rates. The fluxes from the bedrock are needed in order to get more reliable results. Flow modelling was found to be effective tool for evaluating the conceptual sedimentary model.

ORAL

Coastal groundwater in Western Sweden: Hydrogeological and societal challenges

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Groundwater at the Swedish coast occurs in fractured bedrock or in isolated, shallow quaternary sedimentary formations. Those resources are of limited interest for public water supply. However, a large and growing number of poorly regulated private wells create an increasing pressure on groundwater in attractive coastal areas and on islands.

The "Koster" archipelago forms a microcosm of coastal groundwater problems in Sweden. Koster's geology is dominated by fractured, crystalline bedrock, occasionally overlain by quaternary deposits. With around 300 permanent residents, and up to 6,000 summer guests in peak holiday season, the existing water supply based on 800 private wells reaches a limit. Water availability forms an obstacle to future development and the current situation is regarded as being unsustainable.

Groundwater on Koster was monitored over a period of 1.5 years. All observations were made in about 220 private, pumped wells. 350 samples were analysed for major ions and metals. Groundwater levels and in situ physicochemical parameters were measured at six occasions, and data loggers were installed in 10 wells.

Studies dealing with saltwater intrusion in fractured (bedrock) aquifers are rare. The hydrogeological assessment on Koster thus reveals interesting new insights into coastal groundwater in crystalline rock formations. However, the dominating management problem on Koster appears to be rather a combination of a lack of national regulations and an overly complex framework of responsibilities. This contribution attempts to combine hydrogeological and societal aspects and draws some wider-ranging conclusions on the relation between hydrogeological research and its application in decision making processes.

ORAL

Spatial variability of water and nutrient fluxes in groundwater discharging to Ringkøbing Fjord

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River and groundwater discharge to coastal waters bring nutrients that may cause eutrophication, algal blooms or hypoxic events. The quantification of nutrient discharge to coastal waters is essential for the management these areas and it is especially relevant in estuaries with a limited flushing by seawater. The quantification of the groundwater component is challenging since it takes places in the subsurface and under the water. Often it is estimated indirectly based on water budgets or regional numerical models on the scale of the estuary or study area. Likewise, the quantification of nutrient loading is usually carried out by assuming an average concentration. Nevertheless, it is well known that groundwater discharge, as well as nutrient concentrations are highly variable over short distances. This introduces uncertainties in the quantification of

coastal nutrient exports. In this work, the spatial variability of the groundwater discharge and the groundwater nitrate and phosphorus concentration to Ringkøbing Fjord is measured directly at the horizontal and vertical meter scale to assess the range of variability that can be considered at these environments. The data are compared with the hydraulic conductivity measurements to investigate the potential correlations between fluxes, nutrient concentration level, and hydraulic conductivity at variable distances from shore and depths below the seafloor.

ORAL

Use of Water Stable Isotopes and End Member Mixing Analysis to Map and Quantify Groundwater Exchange with Lakes

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Groundwater-lake exchanges are important in order to establish water budgets for lakes.

We used water stable isotopes (^{18}O) to map discharge and recharge zones. In groundwater downstream of lake recharge zones (lake water seeping to groundwater) one expects to find a signal similar to that of the lake (typically enriched in ^{18}O compared to groundwater) and in groundwater discharge zones, one expects to find a groundwater signal.

However, concentrations are 'noisy' due to rainfall-evaporation processes, groundwater flow, changes in residence time etc. An End Member Mixing Analysis accounting for end member uncertainty (rainwater, groundwater and lake water) was used to map seepage zones at Lake Tvorup Hul in National Park Thy, Denmark. A two-component analysis (Electrical Conductivity (EC) and 18O) was also used to better constrain the analysis under the assumption that EC behaved as a conservative tracer.

The 4 ha lake is located in sandy deposits. ^{18}O and EC were measured in 30 wells (depth of 1.25 m) around and close to the lake. End member concentrations and uncertainty were determined by sampling groundwater in wells on the discharge side, as well as lake water and rainfall.

^{18}O and EC were robust tracers able to identify discharge (South) and recharge (West, North) zones. On the Eastern shore the analysis showed a mixture of discharge/recharge explained by the proximity to a water divide and/or a more complex geology with near-surface clay and chalk. The identified seepage zones agree with an iso-potential map and spot measurements of seepage.

ORAL

An integrated and coupled surface/subsurface water model to estimate lake hydrologic and biogeochemical budgets over Northern lake-rich regions

Zachary Hanson[1], Jacob Zwart[1], Alan Hamlet[1], Stuart Jones[1] and Diogo Bolster[1]
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Lakes are intense biogeochemical processors and play key roles in the global carbon cycle. However, to date large-scale models rely on multiplying a mean observed areal rates by regional or global lake surface area, treating all lakes as the same. This ignores the heterogeneous nature of these systems and their static nature renders them incapable of predicting how lake carbon cycling will change under future global change scenarios. To rectify this, we developed a process-based model incorporating surface and groundwater hydrology, physics, and ecology. The model can be applied over large geographic regions to hindcast and forecast lake hydrologic

and carbon fluxes. We applied our model to simulate lake levels and daily carbon fluxes and pools for 3675 lakes in the Northern Highlands Lake District (NHLD), Wisconsin, USA from 1980-2010. The model produces patterns consistent with observations. We show that variability in lake carbon fluxes are related to some simple hydrologic metrics, such as the fraction of hydrologic export as evaporation. This can then predict important carbon processes and fluxes for the region. Hydrologic characteristics were evenly distributed across lake sizes; therefore, median areal lake carbon emissions and burial across the lake size gradient were similar, which meant that large lakes constitute an overwhelmingly large proportion of the total lake carbon flux for the region. Preliminary results forecasting behaviors over the next 50 years under climate change suggest dramatic changes in hydrologic and biogeochemical characteristics in the region.

ORAL

Investigating groundwater contribution to lakes in clay dominated catchments

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Groundwater discharge to lakes is normally investigated in geological environments dominated by permeable, high hydraulically conductive sediments, which can facilitate the groundwater-surface water interaction. This includes, for example, lakes set in glacial meltwater outwash planes comprising coarse-grained sandy aquifers. In other investigations, a sand, chalk, or other water baring hydrogeological units, are in contract with some parts of the lake, either in a bathymetrical deeper part, or in a horizontal zone of the lake. Few studies has been carried out in hydrogeological settings where the upper 10-20 meters near surface geology are dominated by low permeable materials as clays. Groundwater inputs, or exchanges with lakes in such hydro-geological settings are generally believed to be small and therefore often ignored in water balance calculations.

The presented study investigates the groundwater component in the water balance for a lake located on the island of Funen, Denmark. The lake rests upon 20 meter of low permeable till moraine clay which overlays an artesian aquifer, as indicated by piezometric heads and the occurrence of a spring located on a small island on the lake. Evaluation of the water balance combines results from continuous water quantitative and qualitative measurements at 11 surface inlets, 1 outlet and at the spring. Furthermore, in order to understand the physiography of the lake–aquifer system, geophysical surveys are conducted. The measured water fluxes shows an important discharge of groundwater to the lake, supported by isotopic analysis. Groundwater modelling is used to validate the measured water balance of the lake.

ORAL

Geo-hydro-ecological factors affecting the distribution of endangered species of Viiankiaapa mire, in ore prospecting site

Kirsti Korkka-Niemi[1], Anne Rautio[1], Paula Bigler[1] and Susanne Åberg[1]
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Potential impacts of ore prospecting, as well as mining development activities, are often related to surface and groundwater resources and their interactions. A prominent Cu-Ni-PGE sulphide discovery named Sakatti has been discovered below the Natura 2000 protected Viiankiaapa mire, in Northern Finland. It is important to understand the possible association of the mire vegetation with groundwater–surface water

interactions, as well as the geochemical features of the local bedrock.

This study aims to answer the question of how much the hydrological and hydrogeochemical factors control the patterns of endangered vegetation in Viiankiaapa mire. Especially in the areas rich in Hamatocaulis vernicosus, groundwater recharge-discharge patterns have been compiled on the basis of data collected by field studies, thermal infrared (TIR) remote sensing and laboratory analyses. Groundwater flow patterns have been determined by measuring water tables in observation wells and peat layers. Water samples (N=137) have been taken from groundwater and from peat layer, in order to determine the variations in water chemistry including stable isotopes, dissolved silica, main ions, pH, EC, DOC and trace elements. TIR survey using unmanned aerial vehicle has been used in order to observe groundwater discharge locations in the mire and to assess if endangered species prefer groundwater influenced habitats.

Temperature anomalies were detected, indicating cold groundwater discharging into the soil surface at some locations in the studied mire. Groundwater and surface water chemistry revealed significant vertical and horizontal variation. Geochemical stratification in peat layers could be observed in pH, EC, stable isotopes and some dissolved elements.

ORAL

Lacustrine groundwater discharge and its relevance for eutrophication

Jörg Lewandowski[1], Karin Meinikmann[1], Gunnar Nützmann[1] and Donald O. Rosenberry[2]
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Eutrophication is still a major threat to lakes. Typical anthropogenic nutrient sources include fertilizers, manure and sewage. As a first step towards an effective lake management all nutrient import pathways need to be precisely quantified. Nutrient loading via some pathways, for example streams, can be easily quantified quite accurately. The estimation of nutrient import to lakes by lacustrine groundwater discharge (LGD) is usually much more difficult. We discuss some reasons why LGD has often been underestimated and disregarded in lake nutrient budgets. We give a brief overview of measurement techniques, and present volumes, concentrations and loads reported in literature for LGD. Most measurement techniques are based on separate determinations of seepage volume and nutrient concentration of exfiltrating groundwater, and then multiplying both values. Concentrations of groundwater compounds vary along the flow path from the catchment to the lake. Especially the aquifer-lake interface is often considered a reactive zone. We describe the fate of nitrogen and phosphorus on their subsurface pathway from the catchment through the reactive interface into the surface water body. As a case study we present results from Lake Arendsee (Germany) where LGD is the major driver of intense eutrophication in the lake. More than 50 % of the total P load is of groundwater-borne origin in this case.

ORAL

"Translating" a density-independent groundwater model into a SEAWAT model

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In coastal regions, the higher density of the saline groundwater influences the flow pattern of the lighter fresh/brackish groundwater as it makes its way to the sea. In order to get the best possible understanding of the flow patterns when modelling such coastal aquifers it is necessary to take the density difference into account, e.g. by setting up a SEAWAT model. However, SEAWAT can easily become unstable if the cell volumes across the model are not uniform, and it does best if several model layers represent each geological

unit [Guo & Langevin, 2002]. These requirements make it difficult to assign values of hydraulic parameters to the model, as the geological units rarely are uniformly distributed across the modelled area. Besides this, when considering density differences and solute transport, the complexity of the calculations means that the runtime of such a model is much longer than for a density-independent model of the same system. In my Master's thesis I set up a 5-layer density-independent MODFLOW model with non-uniform cell volumes, and calibrated it from measurements of hydraulic head. Subsequently, this model was "translated" into a 10-layer density-independent model with uniform cell volumes, and then further developed into a SEAWAT model, and it was shown that these three models produced very similar results, as far as hydraulic heads go. In this talk I will present the technique that was used for translating the model, and show that the models do indeed produce similar results.

ORAL

Developing methods to assess quantitative and chemical contact between groundwater and the various surface water bodies in relation to update of river basin management plans in Denmark

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The European Water Frame Directive (WFD) sets out objectives for the water environment. These include the protection of, enhancement and restoration of surface water, groundwater and groundwater dependent terrestrial ecosystems (GWDTE).

The Geological Survey of Denmark and Greenland has in collaboration with Aarhus University recently started developing methods to assess the chemical and quantitative interaction between groundwater bodies, rivers, lakes, coastal water and GWDTE. The task is to review national monitoring programs in terms of how well the data collection on hydrological and chemical data capture the potential interaction between the around 400 Danish groundwater bodies and surface water bodies. The hydraulic contact between the groundwater, rivers, lakes and coastal water will be quantified using a national hydrological model for Denmark. Results and experiences obtained on the various parts of the hydrological cycle will be presented. The work is funded by the Danish EPA.

ORAL

Using the stable oxygen isotope of phosphate as a tracer for various phosphorus sources to Lake Nørresø, Denmark.

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Eutrophication of freshwater ecosystems is in particular sensitive to phosphorus input. Thus, identifying the different phosphorus sources and their relative fraction of the total phosphorus load is essential for restoration and improvement of eutrophic aquatic ecosystems. Analyzing the oxygen isotopes of phosphate ($\delta^{18}Op$) of phosphate in the various PO_4 fractions could provide the necessary knowledge for tracing the origin of the different phosphorus sources. Furthermore, $\delta^{18}Op$ could also be used to identify which sources are most significant in the degradation of the associated freshwater ecosystems at a local scale. The method utilizes that the P-O bond in the orthophosphate, is resistant to inorganic hydrolysis at temperatures

and pH levels found in natural abiotic aquatic ecosystems. Subsequently, the δ^{18}Op will reflect the isotopic signature of the sources [1]. However, biological activity alters the source δ^{18}Op signatures, which leads to an isotopic equilibrium between the ambient water and the phosphate [2].

This method is contingent upon an extended knowledge of the δ^{18}Op signatures from different phosphate sources. Nonetheless, the various source signatures have not yet been entirely evolved and more research has to be conducted in order to constrain these signatures further.

This study focuses on identification of the δ^{18}Op signatures for the main phosphate sources to the eutrophic lake, Nørresø, in Denmark. The aim was to i) identify which of the phosphate sources constituted the largest fraction of the total phosphate input to the lake, and ii) investigate if some of the sources in fact came from the same place of origin.

ORAL

Trophic state control of groundwater-fed ecosystems by groundwater-borne phosphorus

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Understanding P cycling in the terrestrial hydrosphere is important to manage ecosystems. We conduct a cross-disciplinary study of groundwater P cycling by comparing the current water and P balance of a 70 ha lake (Nørresø, Fyn, Denmark) in a clayey till dominated landscape to the lake's Holocene trophic history, as retrieved from sediment cores. The diatom and pigment records of core samples with ^{14}C ages predating human influence (>6000 yr BP) indicate that the lake was never P-poor but rather meso- to eutrophic. The current lake water balance indicates a ~35% groundwater contribution, while ~65% comes from about ten ditch streams and direct precipitation. A groundwater-fed spring at 1 m elevation above lake level exists on a small island and shows that there is an artesian aquifer beneath the confining till. Furthermore, metre-scale circular ice holes during the winter supports groundwater discharge to the lake from an artesian aquifer via discrete discharge zones in the lake bed. The spring water is anoxic, ferrous, and contains 130 µg P/L. Similar water quality and total-P contents of 150-390 µg/L are observed in artesian glaciofluvial sand probed by water supply wells distanced 0.5 to 2.7 km from the lake. If the P concentration of the spring is representative for the artesian aquifer, the aquifer's groundwater discharge constitutes ~90% of the external source of P to the lake. The combined data suggest that geogenic P may be mobilized within and transported through aquifers and may ultimately control the trophic state of groundwater dependent ecosystems.

ORAL

Transport and transformation of nitrate in a riparian wetland

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Even though riparian wetlands have been intensively studied during the past 30 years these

areas still function as a "black box" with regards to removal of nitrogen input from surrounding areas. To comply with regulations of the European Water Framework Directive, Danish agriculture is to reduce the load of nitrogen from agricultural fields to fresh water bodies. One initiative is moving from a uniform regulation of nitrogen application to a spatially differentiated regulation where less fertilizer should be applied to vulnerable areas. This leads to the identification of vulnerable and robust areas, in which riparian wetlands plays an important role.

The present case study investigates the transport and transformation of nitrate entering a riparian wetland via drain water from surrounding agricultural areas. The drain pipes are cut off at the hillslope and drain water irrigates the wetland. Depending on the saturation state of the wetland soils and the amount of water entering during precipitation events, a part of the water infiltrates into the wetland sediments and travels towards the stream. Some of the infiltrated water may be caught by drains within the wetland soils and transported directly to the stream. The remaining water can be either evapotranspired or transported directly to the stream via overland flow. Preliminary results show an efficient denitrification of nitrate infiltrating into the studied wetland soils. The nitrogen removal efficiency at different drain outlets seems then to be largely controlled by the amount of drain water input relative to the infiltration capacity of the wetland soil.

ORAL

Mapping surface flow in low-gradient areas with thermal remote sensing

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Thermal infrared (TIR) imagery has long been used for mapping groundwater-surface water interactions and mainly for locating areas of groundwater seepage in lakes and shorelines (Rundquist et al. 1985, Banks et al. 1996). In this study, we used the method for locating discharge from tile drains into lowlands and water bodies (lakes, streams, ditches etc.). Tile drains are one of the main end points for nutrients applied to the agricultural fields and a fast conduit. When studying the function of riparian lowlands and wetlands as nutrient buffer zones, it is essential to know 1) the location of drainage input into the buffer system and 2) the flow path of the water. The TIR imagery was collected by a UAV (eBee from SenseFly) with a thermal camera (ThermoMap from SenseFly) at early spring in 2016 and 2017. The surveys are conducted in cold periods where discharging drainage water (and groundwater) are warm anomalies compared to the cold soil. We hereby obtain maps of the area's thermal signature at the time of flight. The drainage outlets are easily observed as sharp point sources of warm water and surface flows are also remarkably clear making TIR a usable approach for mapping of flow direction in low-gradient areas such as riparian lowlands and wetlands. The flow systems can be compared to topographically modelled surface flow using high-resolution DEMs and flow direction algorithms.

ORAL

Using land-based and waterborne hydrogeophysical methods to infer geological controls on groundwater discharge to a lake

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The geological heterogeneity of stream and lake sediments can lead to spatially heterogeneous groundwater discharge to surface waters, which can be detected by Distributed Temperature Sensing (DTS). The heterogeneity of underwater sediments can also be mapped by waterborne geophysical surveys such as floating electrode

Electrical Resistivity Tomography (ERT). However, ERT and DTS measurements are rarely combined to detect the spatial variability in groundwater discharge to surface waters. The aim of this study was therefore to: (1) test the use of DTS in a deeper lake environment up to 4 m of water depth and (2) assess if sediment heterogeneity indicated by waterborne geophysical surveys can result in potential discharge patterns detected by DTS.

Lake Tissø is the fourth largest lake in Denmark with a surface area of 12.3 km^2, maximal depth of 13 m and a present surface water extraction of 5 million m^3/year. At the Eastern lakeshore potential locations of groundwater discharge in the near-shore region were mapped by DTS. Sediment properties were surveyed with both on-land and waterborne ERT and the resulting resistivity data were used as input to a 2D flow model aimed to test the potential discharge locations interpreted from the DTS survey. Our results show that potential patterns of groundwater discharge agree well with the location of a higher resistivity/coarser material zone detected 60-140 m offshore. The numerical flow model also confirmed that the surveyed sediment distribution can result in discharge patterns detected by DTS measurements.

POSTER

Potential for Lake Bank Filtration at Lake Tissoe, Denmark

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In collaboration with Kalundborg Forsyning (KALFOR), COWI is currently investigating the potential of Lake Bank Filtration (LBF) at Lake Tissø, Denmark. Challenges associated with pumping up groundwater in close vicinity to the lake are the temporal variability in the groundwater-lake seepage, where clogging of the lakebed, as well as the drastic changes of the lake stage throughout the year (160 cm), may influence LBF efficiency. Several field methods were applied to understand the temporal behavior of the transient seepage patterns and to investigate the (in)filtration potential of the near-lake area. Based on data (hydraulic conductivity values, borehole information, resistivity profiles, sediment samples) about the geological setting of the area, a conceptual 2D/3D geological model was developed in GeoScene3D. In addition to hydraulic field and tracer data the geological model was used to develop a 2D/3D hydrogeological conceptual model to examine the groundwater-lake interaction. Finally, a 3D flow- and multiple tracer transport model was developed in MODFLOW and MT3D to explore the impacts of a pumping test carried out at the field site for assessing the potential for LBF.

POSTER

An evaluation of tools to standardise groundwater resource assessment for coastal areas in Sweden

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Groundwater problems in coastal regions are usually not associated with the sparsely populated shores of water-rich Scandinavia. However, the combination of local geology and the specific conditions of water usage create challenges even there. Along the Swedish coast, much of the groundwater occurs in fractured bedrock or in relatively small, shallow, and isolated Quaternary sedimentary formations. Those aquifers are usually not considered relevant as water resources and have thus previously not received much attention from water authorities or researchers. Nevertheless, a possible long-term solution to the increasing pressure on water resources could be found within the utilisation of these groundwater systems.

No attempt has been made to review and evaluate the results of individual investigations carried out by different municipalities in coastal areas. Thus the status of coastal groundwater systems in Sweden remains unclear and a standard methodology that could be applied for groundwater resource assessment in Swedish coastal areas does not exist. Hydrogeological investigations involve high costs, meaning that performed investigations should yield reliable results that fill multiple uses. With the project presented here, an attempt is made to develop a standard methodology for the specific hydrogeological conditions on the Swedish coastline.

We present firstly the results of an online survey carried out among Swedish coastal municipalities, illustrating the various types of problems, methods of investigation used and measures taken. We secondly review various methods commonly applied, in conjunction with a proposal for a standard methodology that may be applicable on a national level.

POSTER

Formation of saltwater intrusions in the low-lying coastal areas during the Holocene in Southern Jutland

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Aquifers in low-lying coastal areas are threatened by saltwater intrusions, as a result of low head gradients, high abstraction rates and land management, and climate change. Understanding the evolution and driving mechanisms of saltwater intrusions can help to adapt water management strategies to mitigate the impact. The 1700 km^2-large study area in the border region between Denmark and Germany, adjacent to the Wadden Sea, has undergone a complex (hydro-)geological evolution; lying in the glacial foreland likely under permafrost conditions during LGM and experiencing a relative rise in sea level during the Holocene. Airborne electromagnetic surveys indicate saltwater up to 20 km inland. Reclaimed from the Wadden Sea, these low-lying areas have been protected from flooding by dikes for the last 200 years and have been heavily drained. In order to identify the origin and dynamics of the saltwater and the role of heterogeneous geology, a 3D regional-scale density-driven flow-and-transport model was used. The formation of saltwater intrusions was simulated during the Holocene taking into account changing conditions caused by flooding and dike construction. The results reveal that the saltwater originate from a combination of remnant (pre-Holocene) seawater, Holocene transgression and recent drainage. Main features controlling the progression of the modern seawater into the coastal aquifers are buried valleys providing preferential flow path for saltwater in combination with an extensive Miocene clay layer hindering saltwater intrusion and land management with dike construction transforming the shallow aquifer from being salt saturated during flooding to being refreshed after the dike was built.

POSTER

Temperature profiles to measure groundwater discharge to Ringkøbing Fjord.

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Groundwater discharge or upwelling plays an important role in the ecological and hydrological dynamics in coastal areas, bringing fresh water inputs to saline water systems. However, locating it both in space and time as well as quantifying how much groundwater flows upward to coastal areas requires a big effort since these are very

heterogeneous systems. Seasonal changes in rainfall, temperature and water level lead to temporal variability, while variations in the hydraulic properties and hydrological processes can generate spatial heterogeneity, making the process of measuring those fluxes complicated and requiring multiple measurements to obtain accurate results. Furthermore, the non-steady position of the fresh water-salt water interface increases the uncertainty surrounding these processes. Using temperature as a tracer, the groundwater inputs to a surface water body can be calculated by means of solving analytically the conduction-convection equation, shortening considerably the amount of field work needed to obtain groundwater upwelling fluxes. In this work groundwater upwelling in the Ringkøbing Fjord coastal area was obtained using two methods: direct upward flow measurements and indirect flow calculations with shallow fjord bed temperature profiles. These two different sets of data are compared in order to assess their feasibility to map and quantify upwelling. Addressing the strengths and weaknesses of each method, we aim to better constrain the reliability of them in order to improve the quality of the data collection process.

11.3. Integrated Hydrological Modeling

ORAL

Assessing the impact of model structure on uncertainty in integrated hydrological modelling

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Understanding and quantifying model uncertainty is essential for decision-making in water resources management. Model uncertainty comes from the forcing data (rainfall, evapotranspiration), the boundary conditions and the parameters. It also arises from the model structure, including the process descriptions, numerical approximations, and geological models. In practice, we trade-off the complexity of the model required to capture the relevant catchment processes against the accuracy needed to make reliable decisions.

In this paper, we examine the impact of model structure on model calibration and prediction uncertainty in three case studies. The first study assesses the impact of land use change in the Napa Valley, USA. We present a model framework that allows for a range of model structures, which we used to calibrate in separate steps the surface water and then the groundwater. In the second case, we systematically explored different models and model structures for rainfall-runoff processes in the Blue River, USA. In this case, the uncertainties in the predicted flows due to model structure were larger than uncertainties from both the rainfall and the model parameters. Finally, we are currently using the same modelling framework to investigate the impact on model structure and calibration on an integrated hydrological model of the Hinds catchment, New Zealand where changes in water allocation and land use may result in unacceptable flow reductions in an extensive

coastal spring system. The aim is to explore different facets of risk calculation based on Bayes equation to determine whether the proposed changes lead to unacceptable flow reductions

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ORAL

Can new drain concepts improve local drain flow performance in catchment scale modelling (MIKE SHE)?

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Nitrate leaching to groundwater, surface water and oceans are an increasing issue for areas with intensive agriculture. The drainage flow system is important for the transportation of water but also works as a potential fast track with limited reduction for nitrate pollutants. As the need for catchment models that can simulate and predict nitrate transport and degradation grows, so does the necessity for models able to adequately represent drainage flow on local scale.

In this study (TReNDS, Højberg et al. 2016-2018) the aim is to test whether or not knowledge about the mechanisms controlling drain flow creation can be used to develop new drain concepts; that can improve local scale performance. The concepts must be founded in data obtainable on catchment scale; as they potentially should be incorporated into national modelling schemes.

A fully distributed hydrological MIKE SHE model for the 101 km^2 Norsminde catchment, Denmark is used (Hansen et al., 2014; He et al., 2015). The catchment is dominated by agriculture and an extensive drainage network. The concepts are built on theses of differentiated occurrence and parameterization for different drain types (tile, natural and urban drain); and important variables (such as TWI and clay content in the soil, (Iversen, 2016)) controlling the generation of drain flow that can be accounted for within the limitations in the MIKE SHE model concept. Measured drainage from eight drain flow stations (Kjærgaard et al., 2011-2015) are used for evaluating any gain of the implementation of the drain concepts on dynamics and quantity.

ORAL

Integrated hydrology in the COHERENT project

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The COHERENT project, funded by Innovation Fund Denmark, was instigated on Nov. 1 and addresses risks in the coastal zone of both natural and anthropogenic origin and the interplay between them. The presentation will present work led by the presenting author which specifically addresses the impact of inland/watershed hydrology on natural hazards in the coastal zone, most often flooding events on coastal cities, and the interactions with adaptation practices, urban development and management. The topic is highly relevant due to projected increases in frequencies and magnitudes of natural hazards in the coastal zone under current climate change potentially resulting in high social and economic costs.

The physical impact of coastal flooding is made up of mainly the impact of the storm surge itself as well as waves, tides and a general increase in sea level and the assessment of potential adaptation measures can be complex. The vulnerability can however increase for the fluvial part with higher stream flow and groundwater level, with temporal scales in the order of days to seasons. Another influence comes from the pluvial side when rainfall events occur simultaneously, with temporal scales in the order of minutes to days. A key objective of the work is therefore to assess the influence of inland-watershed hydrology on the risk hazards for current and future conditions within the three cases of the project; Skive, Ringkøbing and Aabenraa municipalities. A key objective is close interaction with municipalities and stakeholders

to reflect applied conditions and assess true projected urban development goals.

ORAL

A watershed scale approach to model iron concentration in river

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Numerous studies have reported increases in iron concentrations in freshwaters especially in boreal regions. The significant role of iron in biochemical processes and element cycles makes this matter of concern among research community. With infrequent sampling (weekly interval) in main rivers we have limited process understanding to evaluate main drivers behind the iron transport in watershed scale. To enhance this, we used watershed scale SWAT model for typical clayey soiled and agriculture dominated river basin in Southern Finland. In this type of watershed, the mobility of iron is dominated by the erosion and transportation of suspended solids, especially clay particles. The strong linear correlation between TSS, turbidity and iron concentration was utilized to model iron transportation in watershed scale. Successful model calibration and validation allowed us to study main sources for iron transport and seasonal dynamics. Based on the modelling results the most crucial times for iron transport are late autumn rainfalls which cause significant erosion on agricultural lands. We further used the model to predict future land use and climate change scenarios and possibilities to mitigate their joint effects to iron transport.

POSTER

Estimated variation in pesticide leaching through greens and fairways based on detailed fate-descriptions in 12-cm soil profiles

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Leaching resulting from treating golf courses with pesticides is presently not well known. Although studies have shown that 90-100% of applied pesticides can be microbially removed in turfs with a surface near thatch layer, this is not ubiquitous. The retardation of pesticides in soils is compound specific, but also controlled by the hydrogeological setting that for fairways can include the presence of wormholes. Thus, potential rapid preferential flow and transport may make fairways more vulnerable in regards to leaching.

Based on both detailed fate (degradation and sorption) and hydrogeological descriptions of the upper 12-cm soil profile of golf courses, the leaching potential of tebuconazole (TBZ) through six greens (three USGA and three push-up greens) and of MCPA through three fairways (low, medium and highly fertilized) were estimated numerically using COMSOL Multiphysics. All the golf courses were located in areas characterized as macro porous clay till settings. The impact of fate processes on the leaching potential of:

· TBZ as:

- an analytical grade compound,

- a commercial formulation,

- a commercial formulation in combination with a surfactant product

· MCPA as:

- an analytical grade compound

- a commercial formulation

was evaluated numerically for greens and preferential transport for fairways given the presence of a wormhole. The preliminary simulation results indicate that

- TBZ has a high potential for leaching through the greens in high concentration

- MCPA has a low potential for leaching through the fairways given a high degree of degradation in the upper 12 cm.

11.4. Open session Hydrogeology

ORAL

Skåningshave - a new major well-field on the island of Lolland (S.Denmark). Development and hydrogeology.

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The Island of Lolland lies in the southern part of Denmark and comprises 1242 km^2. The Island is very flat having an average of 7 m in altitude and a maximum of 30 m above sea level. The surface of the Island is dominated by glacigene sediments of late Weichselian age, clayey tills and glaciofluviatile outwash sediments forming discontinuous basins. The prequaternary are Maasthrictian-Campanian chalks in the north and Paleocene clays to the south. Non-saline groundwater forms a shallow lens with a maximum depth of 50 m in the northern 2/3 of the island. The water supply structure is based on 4 municipal and 25 community waterworks, delivering a total of 2 + 1 million m^3 per year. A new infrastructure project demands up to 450 000 m^3/year. 100 000 m^3/year can be delivered by the existing waterworks. In the central part of the island a widespread layer of outwash sands was recognized. The area had just been subjected to an intensive geological and geophysical mapping using all existing well data, seismic profiling and extensive SkyTem mapping, which had been used to make a new regional geological and hydrological model of the area. This model was used as the basis for producing a detailed well field model later improved with additional data from MRS soundings and 6 new wells including a major testpumping. This led to a new model and an abstraction strategy minimizing the impact on the surrounding wetlands including the large NATURA 2000 area, the Maribo Lakes.

ORAL

Investigating controls on groundwater drought hazard in Scandinavia

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Drought has historically been a minor issue in Sweden and Finland, countries of high water abundancy. However, since late 2015 into 2017 large parts of Sweden and Finland have been classified with medium to high risk for drought impact according to the drought monitor of the JRC of the European Commission. In Sweden, the Swedish Geological Survey (SGU) has reported falling groundwater levels through their monitoring program, particularly during the summer in Southeastern Sweden. By spring of 2017, this problem had intensified and groundwater drought had been registered in large parts of the country. Impacts on society have been rules on water use, irrigation ban and private drinking water wells running dry in certain regions. In Finland, groundwater levels have been periodically reported to be low during the 2000s based on the monitoring network by Finnish Environmental Institute, which has caused worries in water usage. Although some of the Swedish aquifers are recovering as of autumn 2017, the drought is still persisting in many systems. The current understanding of severity and persistence as well as propagation of drought into groundwater for Swedish and Finnish groundwater systems is very limited. Here, we investigate patterns of groundwater droughts historically and geographically. Furthermore, we explain the sensitivity and persistence based on geologic and environmental controls for different types of groundwater systems with decision tree learning.

POSTER

Sustainable Water Resources in Iranian Qanats

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Qanats are water-transport tunnels with a lower slope than the groundwater surface they intersect, typically in arid regions with alluvial-fan geomorphology. Since the traditional qanat technique (Persian origin in 1st millennium) relies solely on gravitational drainage to assess deep groundwater resources, they are suitable in rural areas, and the over 50,000 active qanats in the Middle East are a crucial supply for drinking and agricultural water for numerous population centers. Qanat sustainability is related to changes in climate, population and land-use. Importantly, groundwater lowering by excessive pumping decreases or stops qanat discharge. We have considered the qanat sensitivity to these influences by characterizing the geomorphologic, geologic, climatic and resource-management associations in selected case studies. Debris-flow alluvial fans can be expected to have steeper groundwater gradients than do stream-flood fans. This is due to the greater surface slope and the lower hydraulic conductivity associated with fine-grained, debris-flow deposits. The internal stratigraphy can further reflect the fan evolution over time and further influence reservoir character. This poster presents a problem analysis of qanat resources, their future potential and vulnerability. The study is a part of the KERMIT project (Knowledge Exchange for Resource Management and International Trust, see separate abstract by Stevens et al., this volume), which uses the endemic knowledge of refugees in Sweden to develop case studies and cooperation networks both within Sweden and abroad.

POSTER

Fracture minerals investigations at Kyläniemi, Southern Finland: Paleohydrogeological implications

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In crystalline bedrock environments, a bulk of groundwater flow occurs in channels provided by fracture networks. Isotopic compositions of precipitated fracture minerals can be utilized to gain information about the origin, age and compositional evolution of the deep groundwaters in crystalline bedrock.

The aim of this study is to investigate the hydrogeochemical evolution of groundwaters in the crystalline bedrock at Kyläniemi, located in Southern Finland near Salpausselkä end-moraines. Fracture mineral samples containing calcite and/or pyrite were collected from water-conducting fractures at the upper ~500 m of the bedrock. These fracture filling calcites occur as thin ~200–350 µm crusts on open fracture surfaces, and the pyrites as small euhedral crystals.

In addition to optical microscopy and chemical composition analyses, the calcite fillings are analyzed for the isotopic composition on carbon and oxygen, and the pyrites for the isotopic composition on sulfur. The $\delta^{18}O$ values of the latest calcite generations are expected to show values indicating the influence of glacial melt waters. The $\delta^{13}C$ values of calcite and $\delta^{34}S$ values of pyrite should demonstrate the evolution of redox environment fronts.

The results of this study are compared to those of previous studies conducted at Olkiluoto (Sahlstedt et al. 2010, 2013, 2016) which is the chosen geological repository site for spent nuclear fuel. Unlike Olkiluoto, the Kyläniemi site rose above the sea-level in early Holocene. Thus, late-stage groundwater evolution is unaffected by brackish water intrusions related to Yoldia Sea and Littorina Sea stages.

POSTER

Stable water isotopes in snow: Changes throughout the season in Finse, Norway

Evelien van Dijk[1]
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Here we present changes of stable water isotopes within the snow pack throughout one season from the Finse area in southern Norway.

Stable water isotopes have become a key element in hydrological and atmospheric research topics. They can be used to get an understanding about the changes in the snow pack throughout the snow season. For this study, 215 samples from several snow pits were analyzed for stable water isotopes throughout the snow season 2016-2017. Sites were selected by looking at the snow drift patterns and snow accumulation to get an undisturbed stratigraphy. The Lagrangian particle model Flexpart will be used to model the moisture sources for this snow pack to get a fuller understanding of the snow processes and the atmospheric part of the hydrological cycle. As snow is a water storage it is important to understand which processes play a role within the snow pack during accumulation and melt and how these processes influence the deformation and melting. By understanding how the snow melt phases change, better predictions about the spring floods can be estimated. Modeling the moisture sources is important to give a better understanding of the atmospheric part of the hydrological cycle. The atmospheric part of the cycle is not yet fully understood, and by using the isotopic composition of snow to track air parcels back in time a better understanding can be accomplished.

12. Geophysics

12.1. Open session in Geophysics

ORAL

Data acquisition in the North and e-infrastructure by the EPOS-Norway team

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Integrating multidisciplinary transnational infrastructures is a key challenge for solid Earth Science. EPOS (European Plate Observatory System) is a European project to integrate existing research infrastructures within the fields of seismology, geodesy, geophysics, geology, rock physics and volcanology in Europe. Within this framework, the EPOS-Norway project is working in several directions, from developing new e-infrastructure to integrate Norwegian Solid Earth data to improving the monitoring capacity in the Arctic, including Northern Norway and the Arctic islands of Jan Mayen, Bear Island and Svalbard. Two main recent developments will be presented.

A prototype of the e-infrastructure to visualize and analyze geophysical and geological data will be demonstrated, and we will also present how we are working to implicate the scientific community in the development of the software.

We will also report on the results from the survey conducted in August-September 2017 to determine the exact locations of the six planned co-located seismological and geodetic stations on Svalbard. The survey was conducted with the vessel Ulla Rinman who set out from Longyearbyen with a crew of scientists and technicians from UiB, Kartverket and UNIS. Svalbard is currently experiencing increased seismic activity in Storfjorden and continued seismic activity in Nordaustlandet, and the new stations could greatly increase our understanding of this activity.

ORAL

Very deep structural contrasts across the Northern Tornquist Zone

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The Tornquist Zone defines a major tectonic lineament across Europe. It extends from the Black Sea to the North Sea and separates old Precambrian cratonic units to the east and northeast from younger Phanerozoic tectonic units in Central and Western Europe. In its northern part, this tectonic zone splits into two main elements, the Sorgenfrei-Tornquist Zone (STZ), trending northwest from around the island of Bornholm to the Skagerrak Sea, and, further south, the Thor Suture between palaeo-continents, Baltica and Avalonia.

This presentation is focused on the STZ. Here, a wide range of geophysical studies reveal marked differences in crustal and upper-mantle structure. From shield units in southern Sweden to deep basins in Danish areas, we observe pronounced crustal thinning, increased surface and upper-mantle heat flow and different gravity and magnetic field anomalies. From traveltime (Medhus et al. 2012; Hejrani et al. 2015) and surface wave (Köhler et al. 2015) tomography, very deep structural contrasts, down to 250-300 km, are recently revealed along the STZ as well as further north. A marked, narrow lithosphere transition zone is outlined with high upper-mantle P- and S-wave velocity below Swedish shield areas and low velocities below Danish Basin and most of southern Norway. Despite markedly different crustal structure between Denmark (deep basins) and southern Norway (Scandinavian Mountains), similar low upper-mantle velocities are observed. These results emphasize the significance of the STZ and the

importance of including deep structural information in understanding different tectonic evolution and associated contrasting geological environments.

ORAL

Magnetic characteristica of Paleogene sediments in Jutland, Denmark.

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During the last decades we have carried out palaeomagnetic work on the Cenozoic sediments in Denmark. Eocene sediments investigated are: The Ølst Formation, including the basal Eocene Stolle Klint Clay, Røsnæs Clay and Lillebælt Clay Formations, and two upper Eocene members of the Søvind Marl Formation: the Moesgård and Kysing members. The magnetic properties vary according to the geochemic environment, biogenic factors and mineralogy, particularly concentration of magnetite.

The Stolle Klint Clay has a weak remanent magnetisation due to the anoxic depositional environment, with its organic content causing degradation iron oxides. The overlying Ølst Formation has a stronger, well defined remanent magnetisation due to its favourable environment for preservation of iron oxides. In both units the remanent magnetisation is sitting in multidomaine grains. A change to high-intensity magnetisation occurs in the Røsnæs Formation due to that the magnetic grain fractions are dominated by single domaine grains (>90%) throughout the rest of the Eocene up till the base of the Moesgaard Member. Separation of the magnetic phase and subsequent analysis by translucent scanning electron microscoping (TEM) identified magnetite grains smaller than 50 nanometers, similar to the ones produced by magnetotactic bacteria. Their occurrence in this stratigraphic interval may be due to the warm clima and/or the marine sedimentary facies. The result is an excellent palaeomagnetic recording which makes it possible to define secondary magnetic components and use them for dating Quaternary tectonic episodes e.g. at Albæk Hoved where Eocene sediments were tilted by the ice.

ORAL

Crustal structure across coastal Nordland (Norway) from teleseismic receiver functions

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The uplift and erosional history of the coastal Nordland region, in northwestern Norway, is of great scientific interest as it may have caused hydrocarbons to accumulate differently than expected across the area (Nyland et al. 1992). Elucidating this history requires a solid understanding of crustal structure in the region. To help address this need, 26 broadband seismic stations were deployed across coastal Nordland from 2013 to 2016, as part of the broader NEONOR2 project. Here, we present preliminary results of an inversion of teleseismic receiver functions computed at these stations, with the aim to map the crustal velocity structure and Moho depth beneath the region. We employ an automated workflow based on the methods of Schiffer (2015) and Svenningsen and Jacobsen (2007), which inverts simultaneously receiver function waveforms and Ps polarizations at discrete frequencies to obtain S velocity structure in the crust and uppermost mantle. The data quality is highly variable from one station to the other. Some stations yield a very clear Moho pulse at relatively shallow depths (~20-30 km). Conversely, other stations return ringy receiver functions that are either associated with complex crustal layering or, more likely, with strong near-station noise and scattering. The robustness of the method and the results is tested with synthetic datasets. The most robust results from high signal to noise ratio stations are integrated into regional maps of seismic velocities and Moho depth.

ORAL

The 3D stress field of Nordland, northern Norway - insights from numerical modelling

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The Nordland area in NW Norway is one of the tectonically most active areas in Fennoscandia. It exhibits patterns of extension, which are in contradiction to the first-order regional stress pattern that reflects compression from ridge-push. The regional stress field stems from the interaction of ridge push and GIA (glacial isostatic adjustment); the local stress field mainly results from gravitational stresses, as well as the flexural effects of sediment erosion and re-deposition.

We develop 3D finite element numerical models of crustal scale, using existing geometric constraints from previous geophysical studies. Internal body forces, induced by variations in density, topography or Moho depth, already yield significant deviatoric stresses, which are often omitted in stress models. We show that these can strongly influence the near-surface stress regime. Similarly, existing weakness zones (such as faults) control the local stress field.

We apply the far-field stress fields (GIA, ridge-push, sediment redistribution) as effective force boundary conditions to the sides or base of the model. This way, we can account for all stress sources at once, but can also vary them separately in order to examine their relative contributions to the observed stress and strain rate fields.

We compare our models to the stress and strain observations derived from different recent seismological and geodetic data sets.

ORAL

Relative relocation of earthquakes along the northern North Atlantic ridge using Rayleigh waves

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Earthquake activity along mid-oceanic ridges is particularly difficult to monitor due to the lack of nearby stations. Precise location of earthquakes is however required in order to reach a better understanding of the relation between the seismic activity and the tectonic mechanisms at play during the geological history of the mid-oceanic ridges.

We present the results from the relative relocation of 153 shallow moderate-size earthquakes along the North Atlantic Mid-Oceanic ridge from Iceland to Svalbard. Rayleigh waves are usually a major and well-recorded seismic phase for mid-oceanic earthquakes. Nearby earthquakes produce very similar Rayleigh waveforms even when recorded at rather distant seismological stations, and cross-correlation provides a good measurement of their time delays. Injected in a double-difference algorithm, this can be used to relocate the earthquakes relative to each other. The mean distance shift is found to be about 8km. Visual inspection shows a better alignment of the seismicity after relocation and plotting on a high-resolution sea-bed map shows that the earthquakes locations are better consistent with tectonic features after relocation. The relocation is also compared with an independent study made in the same area that uses a Bayesian approach to relocate the seismic activity based on a large set of recordings of regional Pn and Sn arrivals.

ORAL

High-resolution seismic investigations of the Caledonian Lower Allochthon and basement transition in Jämtland, Sweden

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During August-September 2017 we acquired high-resolution reflection seismic data in the Jämtland region of west-central Sweden to increase our understanding and knowledge regarding mountain building processes. Of particular importance is the nature and extent of deformation within and across the lowermost allochthonous units of the Caledonides, the main orogenic décollement and underlying Precambrian basement of the Fennoscandian Shield. The Lower Allochthon host structures that strike parallel with the orogenic compression in this region. Therefore, deformation zones, faults and fracture systems in the near surface are also of interest since they may be important in controlling the current hydrogeological environment and influence ground water circulation and the transportation of pollutants. The study area is in close connection with a planned 2.5 km deep borehole of the Collisional Orogeny in the Scandinavian Caledonides (COSC) project (Gee et al., 2010) and previous regional seismic (Juhlin et al., 2016) and magnetotelluric (Yan et al., 2017) studies, which will allow interpretation in a regional context.

In addition to these more scientific objectives, the current project presents an opportunity to evaluate and develop equipment and methodology for efficient and versatile acquisition of high-quality multi-purpose reflection seismic data. We used a 500 kg Bobcat-mounted drop-hammer as the seismic source. Recording was done along two perpendicular profiles simultaneously, using 1C and 3C wireless units (20 m separation) and a high-resolution seismic landstreamer comprising 100 fully digital 3C MEMS sensors (2-4 m separation).

The data are currently being processed and the first results will be presented at the conference.

ORAL

Seismological observations of Landslide and Tsunami in Karrat Fjord, Greenland, June 17 2017

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On June 17, 2017, a large landslide occurred in NW Greenland, around 20 km from the small village of Nuugaatsiaq, population 100 in Karrat Fjord. The slide slipped into the fjord, inducing a large tsunami, which inundated much of the village, producing widespread destruction – 11 houses were swept out to sea, and four people lost their lives.

The slide generated seismic energy equivalent to a magnitude 4.1 earthquake, visible across the globe. Careful examination of the seismic waveforms indicates no triggering tectonic event. The landslide lit up all 30 GLISN stations (http://glisn.info). One station, NUUG, is located in the village of Nuugaatsiaq and recorded the seismic energy generated by the slide and responded to the ground tilt induced by the fluctuating water levels from the resultant tsunami.

The time series from NUUG clearly records both the slide and the resulting inundation events. Seismic waves from the landslide reaching the town had a duration of about 5 minutes. This long duration and the relatively monochromatic, long-period part of the signal that slowly increases in amplitude are indicative of complex landslide signals. The long-period, large-amplitude tsunami waves are seen in the seismograms as signals with a period of 3 min, lasting for over 3 hours.

The long-period signals observed across the GLISN network, and around the globe, are

consistent with a landslide source. The long-period signal suggests failure occurred in two or more stages.

ORAL

Towards a new global crustal model derived from rapid receiver function inversion of GLImER data

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Teleseismic receiver functions provide a relatively easy way to image structure in the Earth's subsurface. Despite its general ease of use, the method often requires substantial user input to yield stable and robust results. This is also the case for the inverse modelling of receiver functions, which can yield highly variable results depending on the choice of independent constraints and model parameterisation used in the inversion workflow. As a consequence, large-scale applications to global datasets have been limited. We developed a generalised receiver function inversion approach to obtain robust estimates of the crustal and uppermost mantle shear-wave velocity structure. The automated and rapid inversion technique uses the polarisation of incident P-waves in conjunction with the original receiver function waveforms to constrain the S-wave structure beneath seismic stations. We apply it to a global receiver function database, GLImER (Global Lithospheric Imagining using Earthquake Recordings), with the aim to construct a new global crustal model consisting of thousands of individual 1D crustal models. We use previous global estimates of Moho depth and intra-crustal structure as starting models and refine these during the inversion. The greatest improvement of our approach over existing ones will be the additional information it provides about layering and absolute S-wave velocity in the upper mantle. Future work includes the integration of absolute P-wave velocity from teleseismic S-wave polarisations into the inversion workflow, something that should yield important new constraint on the composition of the crust and uppermost mantle.

ORAL

Late Mesoproterozoic, Sveconorwegian orogenic mantle preserved beneath SW Fennoscandia, reflected in seismic tomography and assessed by thermal modelling

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The Late Mesoproterozoic Sveconorwegian orogeny in SW Fennoscandia comprised a series of geographically and tectonically discrete events between 1140 and 920 Ma, involving accretion and partial subduction of continental fragments behind an active continental margin (Slagstad et al., 2017). Today, this region is characterised by low seismic velocities compared to other parts of Fennoscandia (Medhus et al., 2012; Gradmann et al., 2013). A channel-like zone with particularly low velocities in the lithospheric mantle beneath SW Norway coincides spatially with the inferred Sveconorwegian continental-margin arc. Based on results from thermal modelling, we argue that the channel-like, low-velocity zone, at least in part, reflects the thermal (radioactive) effects of the refertilised mantle wedge of this continental magmatic arc. Similarly, the generally low seismic velocities in the interior of the orogen are interpreted to reflect refertilisation due to subduction of continental material (cf. Hieronymus & Goes, 2010). Thermal effects from younger tectonic events, such as Permo-Triassic rifting or late Palaeozoic Caledonian orogenesis can be all but ruled out. In contrast, hot mantle material derived from the Iceland plume may have an effect on temperatures beneath SW Norway, but is unlikely to produce the observed tomographic variations. The geological record in

SW Fennoscandia suggests that active-margin magmatism terminated as a result of rapid slab roll-back and trench retreat starting at ca. 1 Ga. The rapid shift from active- to passive-margin processes was probably critical to preserve the mantle wedge, and their identification can therefore shed light on how active-margin processes terminated in ancient orogens.

POSTER

Geological characterization of clayey till using cross-borehole ground penetrating radar.

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Approximately 40% of Denmark is covered by clayey till. Knowledge of the water flow and transport pathways through these glacial deposits is necessary in order to sustainably exploit and protect our water resources. In clayey till, the presence of macropores dominates the transport pathways as they create a three-dimensional network of pathways that enable a much faster water and contaminant transport than through the surrounding fine-grained diffusion-limited clay matrix. These macropores exist as fractures, biopores from burrows and roots, as well as sand lenses. The macropores are non-trivial to map and at present, a low-cost non-invasive technique for mapping such networks does not exist. We aim to use existing ground penetrating radar (GPR) tools to develop such a technique for geological characterization of clayey till. This study will present preliminary results from Havdrup, Eastern Zealand, first of four field sites, and will focus on correlation between cross-hole GPR data and XRF core-scanner acquired major and minor element variation.

POSTER

3D geomodelling workflow using high performance computing – the vuonos and keretti deposits in Outokumpu Mining area, eastern Finland

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The Outokumpu district hosting a number of ore bodies is located within the Palaeoproterozoic North Karelia Schist Belt. Mining activity started 1913 and several mines have already been closed (e.g. Keretti/Outokumpu and Vuonos) but serve as valuable data sources for ore exploration. Project GECCO combines expertise in high performance computing and geomodelling, and aims to develop tools for faster geological common earth model (CEM) modelling in a powerful computing environment.

This paper demonstrates the GECCO workflow for the area containing historical Keretti and Vuonos massive Cu-Zn-Co and disseminated Ni sulphide ore deposits hosted by a distinct lithological assemblage, the Outokumpu assemblage, consisting of peridotite and serpentinite enveloped by Cr-bearing carbonate-quartz rocks. Geological structures and lithological heterogeneity of the Outokumpu assemblage were modeled by using geostatistical simulations constrained by drill core data, geological cross sections and fault zones. Hundreds of simulated realizations were summarized as stochastic geological 3D models, i.e., 3D voxets populated by probabilities for each rock type. The calculated gravity and magnetic responses were used to validate the alternative geological 3D voxel models and compared with the Vuonos-Keretti 3D model built by traditional 3D modelling. High performance computing using GPU for simulation and visualization made it possible to make gravity and magnetic forward modelling in real time. The suggested approach gives a possibility to analyze uncertainties associated with geological 3D models spaced on sparse data sets.

POSTER

Geophysical modelling of the Leka Ophiolite Complex

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The ~497 Ma Leka Ophiolite Complex (LOC) on the island of Leka in central Norway is one of northern Europe's most complete ophiolites complexes. The LOC is comprised of oceanic lithosphere that formed near the margin of Laurentia in a subduction-initiated setting, was obducted on to Laurentia in the early Ordovician, and later transferred to Baltica as part of the upper allochthon in the Scandian Orogen. The LOC has excellent exposures of partially serpentinized mantle rocks, crustal cumulate dunites and wehrlites, the petrologic and geophysical paleo-Moho, gabbro, sheeted dykes and pillow basalts. Here we present a model for the structure of the LOC based on its geophysical and petrophysical properties. This is the first geophysical study of the LOC that utilizes both gravity and magnetic data. New ground-magnetic surveys combined with a recent aeromagnetic survey by NGU are use to model the LOC, and investigate the enhanced magnetization associated with the major faults. The Bouguer gravity high near the center of the island is 50.5 mGal with a magnetic high 2800 nT. Using gravity surveys, new aeromagnetic data and the petrophysical properties of 564 rock samples, three model sections that transect the island northwest to southeast were created. Depth of the base of the model was constrained by the gravity data while magnetic data was used to constrain contacts and structures within the LOC. The new models suggest the depth of the complex is near 2 km and the ultramafic part of the LOC has a synclinal structure.

POSTER

Why the mantle transition zone does not appear to be thinned at plume sites

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Deep mantle plumes and associated high thermal gradients are expected to cause an upward deflection of phase transitions defining the lower-upper mantle boundary and an overall thinning of the mantle transition zone in receiver function data. We use forward calculation of mineral assemblages, seismic velocities, and receiver functions to explain the common absence of these observations by means of large temperature-dependent variations of seismic velocities in the lower mantle transition zone. At high thermal gradients, primitive mantle compositions display assemblages dominated by majoritic garnet and periclase. Associated seismic velocities would be 5-10 percent lower than for wadsleyite- or ringwoodite-rich assemblages characteristic for undisturbed thermal conditions. The identified low-velocity zone at upwelling sites could cause a miscalculation of the lower-upper-mantle boundary in the order of 20 kilometers. Our results also confirm and explain existing propositions of low velocities in the lower mantle transition zone at plume sites, which are based on the observation of negative conversions in receiver function data in 500-600 kilometers depth.

POSTER

The seismic signature of the Mantle Transition Zone in different geodynamic scenarios

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The Mantle Transition Zone (MTZ) is defined by a series of phase transitions that form the transition between upper and lower mantle. At about 410 km, olivine transforms into wadsleyite, at 510 km into ringwoodite and at about 660 km, ringwoodite and garnet decompose into bridgemanite and periclase. These phase changes cause high-amplitude seismic discontinuities as they represent abrupt density and associated seismic velocity steps. The exact pressure and depth at which these occur are dependent of temperature and composition. Therefore, deflections of the phase transitions are to be expected when cold, depleted subducted lithosphere or a warm, possibly enriched mantle upwelling are crossing the MTZ.

These depth-changes for different geodynamic scenarios is one of the most common ways to study lower-upper mantle mass exchange, commonly interpreted from receiver function images. We explore the imaging capability of receiver functions of the MTZ for different subduction and upwelling scenarios using an integrated petrological-modelling-seismological approach to create realistic receiver function images of the MTZ phase transitions. In particular, we develop self-consistent numerical models coupled to the most advanced thermodynamic databases to derive realistic densities and seismic velocities. The generated snapshots are the base for full-waveform seismic modelling and subsequent receiver function processing. Using this synthetic modelling approach, we will explore the effect of different station layouts, noise and dimensions of anomalies.

POSTER

Towards a Finnish Seismic Database – Taming the National Seismological DDSS

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Institute of Seismology, University of Helsinki (ISUH) is responsible for maintaining the Finnish national seismological network (HE). In addition to HE network, ISUH actively collects and employs continuous waveform data from other seismic networks across the Nordic-Baltic region. In addition, data is also gathered and managed from various temporary network installations and active seismic sounding projects. These data and the accompanying metadata streams are combined, analysed and processed, and later combined with the results of the neigbouring countries (where applicable), to provide data, data products and services which can be utilized by researchers, various agencies and the public.

ISUH is actively participating in the pan-European solid-earth Research Infrastructure EPOS which will set data management, licensing and distribution standards for the provided DDSS. In order to address the requirements set by EPOS and the practical necessities of managing big data, ISUH is developing a database-driven SeisComP3-compatible solution that will facilitate more diverse, standard-based access to available data and data products.

The database will also enable the development of new services and software, which will help not only in data management and curation but also in processing raw data streams into usable products. Indeed, quality of certain data & data products have already been improved and new software has entered testing during the development and implementation phase of the project.

13. High and low temperature geochemistry, cosmochemistry and geochronology:

13.1. Geomicrobiology of the past and present

ORAL

Ocean redox conditions between the Snowballs – geochemical constraints from Arena Formation, East Greenland

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The emergence of animal ecosystems is largely believed to have occurred in increasingly oxygenated oceans after the termination of the Sturtian and Marinoan glaciations. This transition has led to several hypotheses for the mechanism driving ocean oxygenation and animal evolution. One hypothesis is that enhanced weathering increased oceanic nutrient levels, primary productivity and organic carbon burial, and ultimately oxygenated the atmosphere and oceans. Another hypothesis suggests that an animal-driven reorganization of the marine biogeochemical cycles might have oxygenated the oceans. Through molybdenum (Mo), carbon, sulfur isotopes and iron speciation results from the Arena Fm, East Greenland, this study constrains ocean redox conditions after the Sturtian deglaciation and before the major radiation of animals. Carbon and sulfur isotope stratigraphy is used to correlate the Arena Fm with other formations worldwide between the Sturtian and Marinoan glaciations (~720–635 Ma). The lower part of the Arena Fm consists of black shales deposited under locally euxinic conditions as evidenced by high proportions of highly reactive iron and pyrite. These black shales display muted Mo enrichments, low Mo/TOC compared to overlying shales and Phanerozoic euxinic sediments. The δ^{98}Mo values are consistent with other Cryogenic euxinic basins and well below that of the modern oceans. The combination of low [Mo] and δ^{98}Mo suggests that widespread anoxia prevailed in the oceans at this time. These results are consistent with most other studies from this time suggesting that ocean oxygenation was not linked to Snowball Earth deglaciation, but was delayed until animals effectively entered the scene.

ORAL

Primordial cellular oxygen sensing key to animal evolution in the oxic realm

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Microbes sense environmental oxygen through mechanisms that since have been inherited through evolution all the way to vertebrate animals[1]. The inherited and modified mechanisms in animals now couple to cell responses that are crucial for the maintenance of tissue. However, to what extent an evolution of the oxygen sensing mechanisms mattered for the evolution animals remains largely unexplored.

Oxygen sensing mechanisms have primarily been explored in the field of tumor biology, since they associate with tissue hypoxia[2] and the maintenance of cancer stem cells. Cancer stem cells possess the capacity to form new tissue. In these studies, the hypoxia-inducible transcription factors (HIFs) are central, by how they are guided by ambient tissue oxygenation and how they associate to stem cell-like features (stemness)[3]. Insights from tumor biology, on

how HIFs regulate tissue formation, emphasize that refined control of primordial oxygen sensing mechanisms must play a role for large life in the oxic environment. Indeed, by acknowledging a few observations from the fields of stem cells science and tumor biology, it appears a paradox that animals renew tissue in the oxic environment at all.

Based on transdisciplinary observations regarding the role of the oxygen sensing mechanisms – inherited from microbes – I present a model of evolving stemness control that may have facilitated animals to enter and diversify in the oxic environment. The model challenges the view that an increased extent of oxic niches resulted in the Cambrian explosion. Implications of the model is compared to observations in the geological record.

ORAL

Microbial element cycling and transport: from ancient sedimentary basins to the Plastisphere

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Microorganisms play a key role in biogeochemical processes in aquatic environments, closing all major element cycles and influencing element transport and burial. Experiments with modern, model organisms have been used to constrain the role of microbes in ancient aqueous environments. Both the acquired knowledge and the analytical methods used in these studies of the Earth´s past are also useful to clarify the role of microorganisms in contemporary and future evolving environments.

The pollution of oceans through plastic debris has emerged as a new global challenge. The introduction of these synthetic particles to aquatic systems raises environmental health concerns, but these particles may also alter the transport and burial of microbial organic matter and influence global biogeochemical cycles. Both in the water column and sediment, bacteria are found as free-living cells or surface-oriented biofilms. While biofilm found on marine plastic implies a new ecological niche, named the Plastisphere, our knowledge of marine plastic-microbe interaction is still nascent. Plastic acts as a vector for microbial communities, offers a surface for abiotic and biotic element cycling, and may even be a microbial carbon source. Indeed, microorganisms may play a key role in degrading, transporting and incorporating (micro)plastic into biogeochemical cycles. In this new study, we combine microbial community profiles, bioimaging, isotope, and elemental analysis to elucidate plastic-associated element cycling. Focus on the interaction between microbes, the plastic surface and their environment, as well as the effect of transport and diagenesis will inform the influence of these particles on element cycling.

ORAL

Mechanistic insight into microbial formation of iron oxides: implications for development of banded iron formations and our atmosphere

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Microbial control over mineralization is a widespread phenomena that has shaped the near-surface mineralogy and chemistry of the earth, oceans and atmosphere. However, the mechanistic understanding of these interactions is poorly constrained. We quantitively addressed the mechanisms behind the controls that

microbial extracellular polymeric substances (EPS) exert in directing mineral formation and transformation. We captured the collective bond behavior of model and natural EPS during interaction with the two common iron oxides, hematite and ferrihydrite. Subsequently, we applied nucleation theories to the measurements and obtained information on the mechanistic controls for iron oxide formation on the polymers. One of the main findings is that EPS, as well as less complex polysaccharides, strongly bind iron species and iron oxides to such an extent that they modulate the interfacial free energy of the iron oxide-polymer system, thus promoting nucleation on the polymer matrix by decreasing the nucleation barriers. These findings have implications for mineral formation in both oxic and anoxic conditions and may explain the mechanisms behind the development of banded iron formations (Lalonde et al., 2012) and oxygen buildup during the Great Oxidation Event (Canfield, 1998).

ORAL

Pore space sealing using microbially mediated calcite precipitation: a lab to field scale study

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Microbially driven calcite precipitation (via ureolysis) has shown great potential in a wide range of applications, including solid-phase capture, concrete crack remediation, soil stabilisation and carbon sequestration. Here, this process is investigated as a means of reducing the primary porosity and/or secondary fracture porosity of host rocks surrounding nuclear waste repositories in order to control or prevent radionuclide transport. To determine a suitable field injection approach, a series of bench scale experiments were undertaken in the laboratory. First, batch experiments focused on the kinetics of calcite precipitation as a function of bacterial mass, urea and Ca^{2+} concentration and anaerobic vs aerobic conditions. Results showed that the ureolytic bacteria performed equally well under both oxygen poor and oxygen rich conditions. In the next stage, flow-through experiments in various media (sand columns, rock cores) were carried out to examine the homogeneity and extent of the pore space fill along the column / core as a function of injection strategies. It emerged that a staged injection strategy, where we alternate between bacterial and reactant injection, yields the most homogeneous calcite fill, reducing overall porosity by up to 45 %. Ultimately, this approach was tested at the field scale, led by University of Birmingham, to seal a fractured rock (dacite) at ~28 m depth, in a quarry in Leicestershire, UK. Within few injection cycles, the single fracture was substantially plugged by calcite, yielding a significant transmissivity decrease over several meters.

13.2. Bio-mineral interactions

ORAL

Crystallization kinetics of apatite model systems

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The formation of biominerals remains shrouded in mystery. A plethora of mechanisms have been proposed [1,2]. To obtain detailed insights into the formation of such minerals, we have present results of studies of apatite formation.

We use in situ X-ray diffraction to map crystallization kinetics [2-5] and found that at high pH apatite forms from amorphous calcium phosphate precursors. Choices of pH and counterions have significant impacts on crystallization kinetics and the shape of the resulting nanocrystals.

We show that using dense organic gels afford chemical garden type formation of hollow tubes with apatitic (and other minerals depending on choice of conditions) walls [6] while coupling sedimentation and particle aggregation results in large transparent nanocrystal aggregates [7]. Organic additives change crystallization kinetics and crystal size/shape [3,4,7] and may even dramatically alter the crystallization pathway by introducing metastable mesoscopic states prior to nucleation [8]. These results illustrate the complex nature of (bio)mineral formation.

ORAL

In, on or in between: tracking the persistence of proteins in the past

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It is a time of great change in the use of biomolecules in archaeology and geology. As a young lecture at the Fossil Fuels and Environmental Geochemistry Institute in Newcastle, I was used to thinking that it was small robust molecules which typified organic geochemistry. Today leading Scandinavia Archaeologist Kristian Kristiansen (Gothenburg) is arguing that his discipline is undergoing a third science revolution, in which genetics allied to isotope geochemistry and data modelling is casting aside postmodern notions and returning to older concepts of cultural change. Of these three pillars, both bigger geochemical datasets and better modelling strategies were foreseen, the explosion in genetic data was not. Genetics and proteomics are now potential tools for archaeologists and geoscientists because extraordinary technological advances, driven by the biosciences, are luckily well suited to the fragmented remains which accumulate over time. Using new genomic methods, the last decade has revealed how remarkably well large fragile organic molecules persist and can be recovered and interrogated.

Proteins survive longer than DNA - therefore if genomics has revolutionised archaeology will proteomics revolutionise geosciences...? Er, no, probably not. Nevertheless in this presentation I will explore what we know about protein survival. How long do proteins survive into geological time, where and how does they survive, and what use might they be upon recovery? As I am speaking in the bio-mineral interactions session, it probably comes as no surprise that it is minerals which seem to key to answering these questions.

ORAL

Biomimetic approach to material design

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Biomineralising organisms are experts in controlling the interplay between polymers and minerals to obtain strong and functional materials. The use of bio inspired polymers to control and direct growth of calcium carbonate, could provide a pathway towards the fabrication of novel tough and strong composite materials. An important step in this direction is to gain control of the calcium carbonate nucleation and growth processes, which requires thorough characterization of the organic/inorganic interactions.

Bio inspired peptoid polymers (N-substituted glycines) can be synthesized with precision sequence control and are known to form ultrathin two-dimensional nanosheets [1]. A recent study has shown that nanosheets with surface exposed acidic chains can template formation of stable amorphous $CaCO_3$ (ACC) [2]. This has inspired us to investigate the $CaCO_3$ nucleation rates and growth on functionalised substrates as a function of time using a custom build flow cell system. We used model systems of chosen self-assembled monolayers (SAMs) to map the effect of specific functional groups as well as studied direct nucleation and growth on immobilized peptoid polymers.

This study provides insight into the different energy barriers provided by the different surfaces. Knowledge of the kinetics and thermodynamics of the crystallisation process is an important first step for guiding the crystallization towards fabrication of bio inspired composite materials.

ORAL

Sub-micron resolution diffraction and fluorescence tomography reveals bone microstructure

Nina Wittig[1], Simon Frølich[1], Mie Birkbak[1], Jonas Palle[1], Maja Østergaard[1], Kathryn Spiers[2], Jan Garrevoet[2] and Henrik Birkedal[1]
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The structures of many materials including biominerals are highly complex. Understanding their structure is challenging and calls for methods with sensitivity across several length scales in 3D. Multimodal X-ray tomographies are such techniques [1]. Here, we apply diffraction scattering computed tomography (DSCT) to reveal the crystalline properties and fluorescence tomography (FT) to probe element distributions in bone using a 400 nm X-ray beam.

Bone displays essential structural features ranging from the nano- to macro-scale. The links between bone structure and function remain poorly understood. The osteon is a building block in human long bones. In osteons, mineralized collagen fibrils are arranged in a twisted plywood structure surrounding a Haversian canal. While it has been shown that the indentation modulus varies periodically with the osteon lamellae and that this is positively correlated with the mineral content [2], it remains uncear how the mineral phase's properties varies across the osteon. The same holds for oligo elements such as Sr. To unravel the structure of osteons, we combine DSCT and FT with sub-micron resolution. This experiment combines the capabilities of diffraction and fluorescence with those of computed tomography to allow for reconstruction of a diffractogram and a fluorescence spectrum in each volume element within the sample [1]. The resulting >1.5 million diffractograms were Rietveld refined using MultiRef [3] to obtain typical crystallographic

parameters, including unit cell parameters, profile parameters etc. This revealed distinct variations in mineral properties and element distributions with distance from the osteon center.

POSTER

Quantification of molecular bonding: Implications for origin of life and the iron cycle

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Mineral-polymer interactions are vital for many life forms have probably played a significant role in the origin of life through polymerization of nucleotides. To form functional biopolymers, the preexisting monomers had to be preconcentrated from dilute prebiotic solutions and the thermodynamic barrier to polymer formation had to be surpassed. Both these processes has been found to be encouraged by mineral adsorption. Element cycles of carbon and iron are also strongly impacted by mineral-polymer interactions. E.g. microbial production of iron oxides occurs on such a vast scale that it impacts the global iron cycle and has been responsible for major biogeochemical events such as the creation of an oxygen-rich atmosphere. Despite the significance of the polymer-mineral interaction, little insight into the thermodynamic and kinetic properties of the polymer-mineral bond is available at a mechanistic level.

Dynamic force spectroscopy (DFS) can directly capture the bond behavior of interacting bonds between molecules and mineral surfaces. We have used this atomic force microscopy technique to investigate the thermodynamic and kinetic bond parameters describing bond behavior and energetics of nucleotide adsorption and RNA polymerisation on clay mineral surfaces as well as the mechanism behind the observed enhanced iron oxide formation on bacterial polymers. Our results highlight the strength of DFS as a tool of investigating the determining mechanisms behind mineral-organic interactions.

POSTER

Using LA-ICPMS to investigate seasonality in Cod otolith microchemistry

Kristian Nielsen[1], Simon Hansen[2], Tonny Thomsen[2] and Karin Hüssy[1]
[1]Technical University of Denmark, National Institute of Aquatic Resources, [2]Geological Survey of Denmark and Greenland, Department of Petrology and Economic Geology

Fish ages are traditionally determined by visually inspecting the ring structures in fish ear stones (otoliths). These ages are important in fish stock management, e.g. when assessing fishing pressure, growth patterns or stock conditions. For the eastern Baltic cod the methods of visual age determination has always been problematic, and in recent years this has worsened, causing problems for the stock management. In this project we aim to develop an alternative age determination method using the chemical composition of otoliths. We have analysed 132 otoliths using LA-ICPMS line transects which provide a chronological record of the fish's entire life from hatch to catch. The elements analysed were Mg, P, Ca, Mn, Cu, Zn, Sr and Ba, which are the most abundant elements in otoliths. The otoliths are recaptures from a mark-recapture experiment, where cod were tagged with an external tag and an internal chemical marker by injecting SrCl2, which incorporates into the otolith during growth. During LA-ICPMS analysis, the Sr marker was detected by screening with a 3 µm laser spot size, whereas the analyses were performed using a beam size of 40 µm at 5 µm/s progressing rates. The Sr marker acts as a time stamp that allows evaluation of the LA-ICPMS elemental analysis in time. The aim is to investigate if some of the analyzed elements vary on a seasonal basis, and how well this can be used for age determination. The presentation will

include method details and preliminary results of this on-going project.

POSTER

Manganese speciation and distribution in foraminiferal calcite under varying environmental conditions

Nadine Quintana Krupinski[1], Sam Webb[2], Per Persson[1], Marit-Solveig Seidenkrantz[3], Takashi Toyofuku[4] and Helena Filipsson[1]
[1]Lund University, [2]Stanford Synchrotron Radiation Lightsource, [3]Aarhus University, [4]JAMSTEC

Benthic foraminiferal Mn/Ca, though often referred to as an indicator of authigenic contamination, has recently been suggested as a bottom water oxygen proxy. However, our understanding of Mn incorporation into benthic foraminifera is incomplete, and roles of potential contaminant phases need to be clarified. To evaluate whether Mn can indicate past hypoxia, we need to understand where/how Mn occurs in benthic foraminifera: is it incorporated into the calcite as a Mn-bearing carbonate species, and are other forms of Mn present? We also study how/whether changing environmental conditions and vital processes may affect Mn speciation and distribution.

We use synchrotron methods (X-ray absorption spectroscopy (XAS)) and micro-X-ray fluorescence (μXRF) mapping) to evaluate how Mn is incorporated into the benthic foraminifera calcite lattice (its distribution and speciation). We complement this with solution ICP-MS to determine mean Mn/Ca values for pooled foraminifera from the same samples. We use field-collected samples of living benthic foraminifera (to avoid diagenetic effects) from two oxygen conditions to evaluate whether differing environmental conditions affect Mn distribution and coordination.

Spectral data (XAS) indicate that Mn in the foraminiferal tests occurs as a Mn-carbonate, while small external debris with high Mn in these uncleaned foraminifera generally has Mn-oxide-type spectra (removable via cleaning methods). μXRF maps show that in many species, Mn is fairly evenly distributed at low-moderate concentration throughout the test, potentially suggesting stable oxygenation conditions. However, other species have specific high-Mn chambers, perhaps suggesting intervals of greater oxygen stress or a response to foraminiferal processes that alter the microenvironment.

13.3. Inorganic Geochemistry

ORAL

Microscopic view of hydrogen motion in Clay minerals from neutron scattering

Heloisa Bordallo[1]
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Neutron science is the science of everyday life, providing a microscopic view of the materials we rely on for modern life. Neutrons, similarly to X-rays, penetrate matter. However, unlike X-rays, neutrons interact with matter in a different manner, thus allowing the identification of elements with very low molecular weight, including hydrogen. For this reason, neutron spectroscopy brings unique information about hydrogen mobility and can contribute for better understanding the mechanisms that govern processes in clay dominated environments.

In this talk I will discuss on this promising approach by presenting a couple of specific examples of quasi-elastic neutron scattering experiments. The first is related to the investigation of how the transport mechanisms (of water or ions) are affected by an applied electric field. To shed light into this question, we have focused specifically on the dynamics of water in clays through investigating the origin of changes observed in water resistance under in-situ electric field stimuli. The second focus on in-situ measurements performed during controlled exposure to water vapour and how the dynamics of adsorbed water change over a large range of unsaturated conditions. Using this approach we were able to confirm that true material equilibrium at intermediate hydration states is a time dependent phenomenon. The overall knowledge acquired using neutron spectroscopy opens new possibilities in the mitigation of soil contamination and geo-environmental engineering, where the role played by water controls the system properties.

ORAL

Turbostratic disorder: Lessons learned from Fe-bearing Layered Double Hydroxides.

Knud Dideriksen[1], Laura Voigt[2], Marco Mangayayam[1], Case van Genuchten[3], Cathrine Frandsen[4], Kristen M. Ø. Jensen[1], S. L. S. Stipp[1] and Dominique J. Tobler[1]
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Turbostratic disorder exists in ordered materials with highly anisotropic bond strength (e.g., clays) and affects their properties (e.g., stability and ion exchange). It arises when sheets of strongly bonded atoms, stacked along the direction of weaker bonding, are displaced so that atomic alignment across sheets is lost. Layered double hydroxides (LDH) are composed of Me^{II}-Me^{III} hydroxide sheets separated by interlayers with water and weakly held anions. To probe short range order (1-40 Å) in synthetic LDHs in the sulphate green rust (Fe^{III}) - nikischerite (Al^{III}) series, we performed pair distribution function (PDF) analysis of high energy X-ray scattering data. Results show that structural coherence along the c axis decreases with increasing Al content, although Bragg peaks are clear for basal planes. The PDF for synthetic nikischerite is best matched by the calculated pattern for coherent scattering domains composed of a single metal hydroxide sheet. Parallel to the decrease in the structural coherence between layers, the coherence within layers also decreases markedly to ~6 nm for synthetic nikischerite. Thus, this material does not simply have unaligned, but otherwise structurally developed sheets. Instead, crystals are mosaic with coherent scattering domains that decrease in all directions. In fact, the aspect ratio of the large green rust sulphate crystals is comparable to that of the small coherent scattering domains in synthetic nikischerite. Given that the structure of

disordered material is very complicated to characterise with traditional techniques, we speculate to what degree silicate clay minerals have mosaic crystals rather than only turbostratic disorder.

ORAL

$CaCO_3$ scaling: Nucleation and growth inhibition of aragonite by $MgSO_4$

Mia Rohde Nielsen[1], Juan Diego Rodriguez-Blanco[2], Karina Sand[1] and Susan Stipp[1]
[1]Nano-Science Center, Department of Chemistry, University of Copenhagen, Denmark, [2]Department of Geology, Trinity College Dublin, Dublin, Ireland

Mg^{2+} and SO_4^{2-} are abundant in seawater and in hydrothermal fluids and are hence naturally present where calcium carbonate minerals form. Both ions are known to influence nucleation and growth of $CaCO_3$ polymorphs but reports of aragonite growth inhibition by Mg^{2+} ($\pm SO_4^{2-}$) are contradictory. We used UV-vis spectroscopy to explore the influence of Mg^{2+} and SO_4^{2-} on nucleation and growth rates of crystalline $CaCO_3$ phases and we examined the solids using scanning electron microscopy (SEM) and powder X-ray diffraction (PXRD). SO_4^{2-} promoted formation of vaterite, extended the induction time for nucleation and decreased growth rate. Mg^{2+} ($\pm SO_4^{2-}$) promoted formation of aragonite in preference to calcite. Aragonite nucleation and growth was inhibited by Mg^{2+} alone and in combination with SO_4^{2-}. Mg^{2+} clearly prolonged induction time and inhibited aragonite growth proportional to Mg^{2+} concentration. The results suggest an environmentally friendly method to inhibit aragonite scale formation, for example in desalination plants.

14. Hydrocarbon geology and energy

14.1. Geothermal energy and CO2 storage

ORAL

Assessing European geological CO_2 storage capacity

Karen L. Anthonsen[1] and Niels E. Poulsen[1]
[1]Geological Survey of Denmark and Greenland

Deployment of large scale CCS in Europe is depending on knowledge about location and storage capacity of the most attractive storage areas and thus a reliable CO2 storage atlas is a key tool for planning future CCS operations.

Since the beginning of 1990ties, several studies have attempted to map and estimate the European storage capacity for CO2. Among the most prominent are the Joule II project (Holloway et al. 1996), the GESTCO project from 2004 (Christensen & Holloway, 2004), the CASTOR project (2006), the EU GeoCapacity project (Vangkilde-Pedersen et al. 2009) and the CO2 StoP project (Poulsen et al. 2013).

These projects more or less build on one another, but there are differences between the projects with respect to number of countries included, screening parameters, classification of storage sites and assessment methodology. It is important to recognise the evolution of European CO2 assessments and the challenges related to the methodology (static or probabilistic) for mapping and estimating storage capacities in Europe.

Apart from the European EU co-funded projects, Norway has published an atlas for the Norwegian continental shelf (Halland et al. 2014) and the NORDICCS project made an assessment for the Nordic countries (Anthonsen et al. 2013) and released a joint Nordic CO2 storage web-atlas in 2015. Both United Kingdom and Spain have prepared a national CO2 storage atlas.

ORAL

Seismic interpretation of a slopping offshore potential CO2 aquifer; the Gassum Formation in Skagerrak between Norway and Denmark

Ulrik Gregersen[1], Irfan Baig[2], Anja Sundal[2], Lars Henrik Nielsen[1], Mette Olivarius[1] and Rikke Weibel[1]
[1]GEUS, [2]University of Oslo

The first phase of the project "Optimized CO_2 storage in sloping aquifers – CO_2Upslope" is seismic stratigraphic interpretation of the siliciclastic Upper Triassic–Lower Jurassic Gassum Formation in Skagerrak between Norway and Denmark. The wells Felicia-1, J-1 and 13/1-U-1 provide seismic-well ties for selected lines from eight 2D seismic surveys constituting the database. The work resulted in a detailed interpretation of the top and base of the formation and three sequence stratigraphic horizons within the aquifer (SB5, TS9 and TS10). The formation is mostly less than 100 m thick in the study area, with its thickest parts located in/near the Felicia-1 well (230 m). The formation thins towards east and north and shallows to the north where it is truncated in places. The three internal horizons approach the base of the formation towards north and only TS10 continues into the northernmost part of the study area where it ties near the base of the 13/1-U-1 well. Some minor trough-shaped seismic features within the formation may indicate channel incision. The formation is succeeded by mudstones of the Fjerritslev Formation divided by two internal horizons. Fourteen assigned faults and additional minor faults are interpreted. Most faults are normal faults trending SW–NE and some are associated with ridges/structures formed by regional tectonic events. Most faults slightly offset the Top Gassum horizon and parts of the Fjerritslev mudstones. Succeeding phases of the project involve establishment of a 3D geological model forming the basis for numerical

modelling of CO_2 injection, movement and trapping.

ORAL

A numerical investigation of combined heat storage and extraction in deep geothermal reservoirs

Marton Major[1], Søren Erbs Poulsen[2] and Niels Balling[1]
[1]Aarhus University, Denmark, [2]VIA University College, Campus Horsens, Denmark

Heat storage capabilities of deep sedimentary geothermal reservoirs are evaluated through numerical model simulations. We combine storage with heat extraction in a doublet well system when storage phases are restricted to summer months. The effects of stored volume and annual repetition on energy recovery are investigated. Recovery factors are evaluated for several different model setups and we find that storing 90 °C water at 2500 m depth is capable of reproducing, on average, 67% of the stored energy. In addition, ambient reservoir temperature of 75 °C is slightly elevated leading to increased efficiency. Additional simulations concerning pressure build up in the reservoir are carried out to show that safety levels may not be reached. Reservoir characteristics are inspired by Danish geothermal conditions, but results are assumed to have more general validity. Thus, deep sedimentary reservoirs of suitable properties are found to be viable options for storing access energy for high demand periods.

ORAL

Shallow subsurface thermal structure for onshore Denmark

Ingelise Møller[1], Niels Balling[2] and Claus Ditlefsen[1]
[1]Geological Survey of Danmark and Greenland, Denmark, [2]Department of Geoscience, Aarhus University, Denmark

Information of shallow subsurface geothermal conditions is important for number applications including exploitation of shallow geothermal energy, heat storage and cooling as well as of general geoscience interest. Available measured temperatures and thermal conductivities covering Danish onshore areas to a depth of about 300 m have been compiled and analysed. Temperature data from about 50 boreholes, 100-300 m deep and thermal conductivities measured on samples collected at 31 well-characterized outcrops and on core material from 20 boreholes are included. Temperature gradients and thermal conductivities were grouped according to details of lithology over which they were measured.

Significant thermal variations are observed. At a depth of 100 m, temperatures vary between 7.5 and 12 °C and at 200 m, between 9 and 15 °C. Characteristic temperature gradients are in a range of 1 - 4 °C/100 m. Following Fourier's law of heat conduction (heat flow = thermal conductivity x temperature gradient) a correlation is observed between temperature gradients and thermal conductivities of different lithologies, and a regional estimate of characteristic shallow heat flow in Denmark is obtained. Quartz-rich sand deposits (high thermal conductivity) show low temperature gradients, chalk and limestone intermediate gradients and almost pure clay (low thermal conductivity) high gradients. Mean thermal conductivities range between 0.6 and 6 W/mK. An estimated regional heat flow of about 37 mW/m^2 is in good agreement with local, classically determined heat-flow values from shallow borehole data. Due to long-term palaeoclimatic effect, this value is significantly below deep background heat flow.

ORAL

Understanding nature's secrets and using the new knowledge to solve society's challenges: insights for CO_2 sequestration

S. L. Svane Stipp[1] and and the Members of the NanoGeoScience Research Section[1]
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The electronics revolution has given us tools that can "see" at molecular scale, providing whole new insight into the physical and chemical processes that control the interface between natural solids and fluids (anything that flows, water, oil, CO_2, gases). By understanding how nature works, we find clues to solve some of the challenges that society faces. An important issue is to reduce the CO_2 available in the atmosphere and oceans by converting it to mineral form, where it will be stable for millennia. By understanding the processes that take place at the surfaces of minerals, we can tailor underground gas storage facilities to be more effective and we can build models to predict their safety. What we have learned about CO_2 injection into the basaltic rocks of Iceland has also inspired investigations with mineral fibre insulation and the design of nanoparticles for in situ remediation of contaminated groundwater. Our work is very fundamental and also very applied. We combine experiment with theory, in the lab, the field and at synchrotron radiation facilities.

POSTER

Regional evaluation of structural collapse in sandstone reservoirs and impact on reservoir quality, a case study from the Entrada Sandstone, Utah, USA

Nikoline Bromander[1], Sigrid Østmo da Costa[1], Elin Skurtveit[2], James Evans[3], Ivar Midtkandal[1], Alvar Braathen[1], Valentin Zuchuat[1] and Anja Sundal[1]
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In this study we examine exhumed paleo-reservoirs showing evidence of past CO_2-charged fluid accumulation to better understand processes related to geological sequestration of CO_2 in subsurface siliciclastic reservoirs. Field data was collected from the wet aeolian dune system in the Jurassic Entrada Sandstone in Utah, USA, and in particular the reservoir characteristics of the light-coloured fluvial and aeolian dune interlayers have been evaluated. Bleaching in red rocks is interpreted to have developed in response to reduction and/or dissolution of iron oxides as CO_2-charged fluids from underlying reservoirs escaped through the sedimentary succession. Some light-coloured, highly porous layers contain extensive amounts of deformation bands, which may be associated with structural collapse.

The working hypothesis is that observed reservoir collapse structures (deformation bands) in specific layers is a regional feature related to sedimentary facies. Deformation band distributions and orientations are used to document reservoir collapse. Deformation bands occur in different structural settings; clusters connected to faults cutting the stratigraphy, single deformation bands exclusively in fluvial and aeolian dune interlayers dying out in the over/underlaying facies forming small scale faults in the reservoir, as well as in major meter-scale circular collapse structures. Deformation bands were present in some specific layers throughout the field area, with frequencies from 0 to 18 per meter and the degree of structural

collapse increased towards zones of high deformation, e.g. faults. Preliminary results show that collapse structures are regional features exclusively occurring in two types of facies, with the degree of collapse locally determined by structural parameters.

POSTER

Mass estimation of CO_2 trapping in the Smeaheia reservoir

Tatiana Sacco[1], Anja Sundal[2] and Helge Hellevang[3]
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CO_2 storage in saline aquifers is an important measure to reduce anthropogenic greenhouse gas emissions. The Smeaheia reservoir (located east of the Troll field, 50 km offshore) has been proposed by Gassnova and Statoil as a suitable CO_2 sequestration site due to low leakage risk and large storage capacity. The aim of this work is to determine and quantify the temporal distribution of CO_2 in i) mineral phase; ii) dissolved in the formation water; and iii) free phase for specific layers and facies in the Smeaheia reservoir candidate.

The reservoir interval (1.2 to 1.6 km depth) comprises deposits from Middle to Upper Jurassic ages; named Sognefjord, Fensfjord and Krossfjord formations. These are heterogeneous shallow marine and deltaic sandstones. The Draupne Formation consists of marine mudstones and serves as a sealing unit. The Heather Formation comprises silty-claystones with low permeability, interfingering with sandy units.

In addition to the porosity and permeability distribution, the geochemical trapping potential for CO_2 in Smeaheia is considered in this study. The low salinity (TDS~5.6g/l) provides dissolution potential for CO_2, and favor mineral dissolution. High porosity (~30%) and permeability (~500 to 1500mD) cause spreading of a CO_2 plume. Smaller grains yield larger reactive surfaces, accelerating the dissolution of framework minerals (e.g. chlorite, feldspars, pyrite), and thus reactivity is facies dependent. Relatively low temperature (~50 ºC) and pressures (120 - 160 bar) in Smeaheia will affect mineral dissolution kinetics and the potential for subsequent CO_2 trapping through carbonate precipitation (e.g. siderite, ankerite).

POSTER

Geological constraints on the immobilization potential for CO_2 in the Upper Triassic – Lower Jurassic Gassum Formation (Skagerrak, Norway)

Anja Sundal[1], Helge Hellevang[1], Mette Olivarius[2], Rohaldin Miri[1], Lars Henrik Nielsen[2], Ulrik Gregersen[2], Odd Andersen[3], Halvor Møll-Nilsen[3], Rikke Weibel[2] and Per Aagaard[1]
[1]University of Oslo, [2]GEUS, [3]Sintef

In the CLIMIT-funded "CO_2-Upslope" project, the main objective is to improve reservoir characterization schemes to optimize geological storage of CO_2. Coupled modelling is applied to estimate trapping efficiency and migration distances in order to ensure safe storage in open-boundary, sloping aquifer type reservoirs. The Gassum Formation comprises fluvial to marginal marine sandy and muddy deposits. The prospective reservoir is located in Skagerrak near industrial, onshore CO_2 emission sources. Our estimates of the reaction potential for CO_2 in these sub-arkosic sandstones indicate significant capacity for immobilization of injected gas into fluid and solid phases. The salinity of the formation water is high, and thus the dissolution potential is limited (~0.65 mol/kg), but may be catalyzed by solid carbonate precipitation - driving further dissolution of CO_2. PHREEQ-C simulations in a reservoir setting with 20 % porosity show dissolution of oligoclase and chlorite, providing cations and facilitating precipitation of magnesite, siderite and calcite,

trapping more than 5 mol/l carbon after 1000 years. Petrography and geochronology results indicate immature sand with relatively high contents of reactive phases (i.e. feldspar, rock fragments) in the upper part of the Gassum Formation, which dominates on the Norwegian shelf, caused by a shift in provenance area towards the south during the later phases of deposition. Ongoing research activities in "CO_2-Upslope" will further improve the sedimentological, structural and diagenetic model as basis for reservoir simulations. Ultimately, a complete storage scheme tailored to the Gassum Formation and representative of migration assisted CO_2 storage in sloping aquifers will be provided.

15. Marine geology

15.1. Tectonic, geodynamic, oceanographic, and cryospheric evolution of the Arctic Ocean from Mesozoic to present day

ORAL

The Opening of the Arctic-Atlantic Gateway: Tectonic, Oceanographic and Climatic Dynamics – Status of the IODP Initiative

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The modern polar cryosphere reflects an extreme climate state with profound temperature gradients towards high-latitudes. It developed in association with step-wise Cenozoic cooling, beginning with ephemeral glaciations and the appearance of sea ice in the late middle Eocene. The polar ocean gateways played a pivotal role in changing the polar and global climate, along with declining greenhouse gas levels. The Arctic Ocean was an isolated basin until the early Miocene when rifting and subsequent sea-floor spreading started between Greenland and Svalbard, initiating the opening of the Fram Strait / Arctic-Atlantic Gateway (AAG). Although this gateway is known to be important in Earth's past and modern climate, little is known about its Cenozoic development. The opening history and AAG's consecutive widening and deepening must have had a strong impact on circulation and water mass exchange between the Arctic and the North Atlantic Oceans. To study the AAG's complete history, ocean drilling sites in the Boreas Basin and along the East Greenland continental margin are proposed. These sites will provide unprecedented sedimentary records that will unveil the history of shallow-water exchange between the Arctic and the North Atlantic Oceans, and the development of the AAG to a deep-water connection and its influence on the global climate system.

Getting a continuous record of the Cenozoic sedimentary succession that recorded the evolution of the Arctic-North Atlantic horizontal and vertical motions, and land and water connections will also help better understanding the post-breakup evolution of the NE Atlantic conjugate margins and associated sedimentary basins.

ORAL

Depositional history of the western Amundsen Basin, Arctic Ocean

John R. Hopper[1], Carlos Castro[2], Paul Knutz[1] and Thomas Funck[1]
[1]Geological Survey of Denmark and Greenland, [2]Niels Bohr Institute

Seismic reflection data collected in the western Amundsen Basin show a uniform and continuous cover of sediments over oceanic basement. An interpretation of seismic facies units shows that the depositional history of the basin reflects changing tectonic, climatic, and oceanographic conditions throughout the Cenozoic. The early history of the basin shows a tectonically influenced restricted basin that gave way in the early to mid-Miocene to a bottom current dominated environment indicated by a buildup of contourite deposits. It is suggested that this is a response to the opening of the Fram Strait and the establishment of geostrophic bottom currents that flowed from the Laptev Sea towards Greenland. These deposits are overlain by a seismic facies unit characterized by buried channels and erosional features. These include prominent basinward levee systems that suggest a channel morphology maintained by overbank deposition of muddy sediments carried by suspension currents periodically spilling over the channel pathway. These deposits indicate a

change to a much higher energy environment that is proposed to be a response to brine formation associated with the onset of perennial sea ice cover in the Arctic Ocean. This interpretation implies that the development of significant sea cover results in a significant change in the energy environment of the ocean that is reflected in the depositional and erosional patterns observed. The lack of similar high energy erosional features and the presence of contourite deposits throughout most of the Miocene may indicate the Arctic Ocean was relatively ice-free until the very latest Miocene.

ORAL

Arctic Climate Perturbations during the Early Triassic Biotic Crisis

Jochen Knies[1]
[1]Geological Survey of Norway

Fractured and kaolinite weathered basement rocks have been discovered in various wells off the Norwegian coast and inferences on timing, source to sink relationships, and environmental implications have been widely discussed. The reason for the kaolitinization has often been related to intensive chemical weathering during late Triassic to early Jurassic times. Chronological control has primarily been inferred from the overlying late Jurassic/early Cretaceous marine transgression and poorly constrained K-Ar datings from weathered basement onshore as well as climate conditions favourable for kaolinite formation.

In this study, I present evidence that the deeply weathered basement off the mid-Norwegian coast represent a complete paleosol profile formed ca 250 million years ago. The timing corroborates with the Early Triassic biotic crisis and suggest a causal relationship between intense chemical weathering, high atmospheric CO_2 concentration, extreme ocean warming, delayed biotic recovery, increased riverine flux of nutrients and widespread anoxia/euxinia in the high northern latitudes during a time of rapid global climate perturbations.

ORAL

Greenland Ice Sheet evolution and dynamics seen from the perspective of a large glacial fan system, northeast Baffin Bay

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The Greenland Ice Sheet (GrIS) is a major freshwater reservoir and a key component of the global climate system so understanding its past dynamic behaviour is crucial for underpinning climate model predictions. The long-term history of the GrIS is mainly deduced from deep ocean drilling sites while relatively little information exists from its dynamic glacial margins. Here we present mapping results, based on a dense 2D reflection-seismic grid tied to industry well data, which illuminates the stratigraphy and spatial evolution of the Melville Bugt - Upernavik trough-mouth fan system. The fan depocentres, formed by sediments eroded and transported by the northern GrIS, are constructed by sequentially organized prograding depositional units, bounded by glacial erosion surfaces that extend into steeply dipping clinoforms on the outer margin. South of the main trough, the erosion surfaces are commonly onlapped by laterally continuous strata attributed to sea-level transgressions. The study reveals eleven phases of ice stream advance over the northwest Greenland continental margin since the onset of shelf-based glaciation at around 2.8 Ma. The GrIS advance phases were interrupted by glacial retreats and sea-level rises that appear to correlate with super-interglacial periods identified in the Siberian Arctic region. Moreover, a change in ice flow configuration from uniform glacial advances to distinct trough-based

drainage points to a major change in GrIS dynamics through the Mid-Pleistocene transition.

ORAL

On the origin of the marginal plateaus north of Svalbard and Greenland

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The marginal plateaus north of Svalbard and Greenland are conjugate features with respect to the Gakkel Ridge and likely to share a geologic history.

Dredge hauls from three sites on the Yermak Plateau have recovered an abundance of metasediments and gneisses with strong affinities to known lithologies from northwest Spitsbergen. The results support the earlier idea of the plateau being a continental outlier except for its northeasternmost tip. The outlier rifted off the margin north of Svalbard and moved with the Greenland plate which implies significant Paleogene dextral shear motion close to the coast of Spitsbergen. Past coast-parallel shear is supported by observed seismic velocity anomalies in the crust characteristic of continental transform boundaries.

A seismic reflection transect across Morris Jesup Rise show an eastern flat-topped spur of undeformed west-dipping layers and a western dome-structure cored by deformed sediments, possibly an imbricate stack of thrust sheets. High amplitude rough seismic reflections interpreted as lava flows are present at depth in the 40 km wide depression between these two structures.

The shared geologic history of the marginal plateaus involve Yermak Plateau rifting off north of Svalbard at Chron 24 and the eastern Morris Jesup Spur rifting off the Yermak Plateau at about Chron 15. The Morris Jesup Spur is likely to represent the pre-Cenozoic continental slope north of Svalbard.

ORAL

Late Cenozoic paleoenvironment and erosion estimates for the northeastern Svalbard/northern Barents Sea continental margin, Norwegian Arctic

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The upper Cenozoic sedimentary succession of the northeastern Svalbard/northern Barents Sea continental margin is analyzed using available 2D seismic data. The primary focus is to better understand the glacial paleoenvironments and sedimentary processes as well as to estimate the glacial erosion of the inferred source areas. Seismic facies analysis shows three main facies; parallel to oblique parallel, contorted, and chaotic seismic patterns. These observations suggest an interplay between contour current and glacial-related mass-wasting processes. The seismic mapping shows abundant contourite deposition since the Miocene, interpreted to be related to the establishment of an ocean circulation system following the opening of the Fram Strait, similar to present conditions. The glacigenic debrites and its associated mass-transport deposits are interpreted to characterize the area in front of the troughs. This is likely related to extensive glaciations in the Plio-Pleistocene during which ice sheets repeatedly advanced to the shelf break during the full-glacial conditions. The inter trough-mouth fan areas appear to be dominated by contouritic deposits characterized by a series

of sediment waves and sheeted drifts. In the studied margin, there is an increasing trend of mass-wasting processes eastwards, while along-slope processes dominate to the west. Isopach maps of the glacial strata will be presented along with the erosion estimates using a mass-balance approach. Major sediment source areas will be discussed in relation to the late Cenozoic history of this studied margin. This contribution will be useful to better understand the dynamics of uplift and erosion events in the greater Barents Sea area.

ORAL

Enigmatic craters and giant gas flares in the central Barents Sea

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[1]Norges geologiske undersøkelse

Recent analyses of high-resolution multibeam swath bathymetry and water column data collected from the central Barents Sea resulted in over 300 new observations of active gas flares emanating from southeast Storbanken (~100-200 m below modern sea level; mbsl). Seabed fluid escape features, including pockmarks, craters, and mounds (tentatively interpreted as gas hydrate pingos; GHPs) were also mapped in this area. Interestingly, mapped fluid escape features do not coincide with the locations of the active gas flares, which is in contrast to hundreds of similar craters, GHPs, and co-located gas flares ~300 km southwest, at depths of 310-370 mbsl (Andreassen et al., 2017). The GHPs and craters observed on southeast Storbanken occur outside of the methane hydrate stability limit, indicating that the gas hydrates underlying the GHPs constitute a mix of methane and heavier natural gases, which remain stable at shallower water depths and/or warmer temperatures. The craters, most of which are immediately adjacent to the GHPs, indicate that methane hydrates (≥99.9% methane) were formerly present, but became unstable and dissociated from the seabed, likely between ~12 - 15 ka BP following deglaciation. Depending on future warming of bottom waters in the Barents Sea, the gas hydrates underlying the GHPs on southeastern Storbanken could dissociate rapidly, forming new craters and sending large quantities of methane to the sea surface and atmosphere. Such events have important implications for both seabed geohazard mapping and for climate change models, which must take into account all sources and sinks of methane, a powerful greenhouse gas.

POSTER

An automated cryogenic magnetometer at the Geological Survey of Norway for natural remanent magnetization and rock magnetism: A case study of North-East Atlantic continental margin sediments

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A new, automatically operating cryogenic magnetometer system at the Geological Survey of Norway is used to acquire natural remanent magnetization (NRM) and rock magnetic parameters from two locations, West Barents Sea (~71.6°N,16.2°E) and Vestnesa Ridge, NW Svalbard (~79.0°N, 6.9°E). The magnetometer lab setup comprises an automated robot sample feeding, dynamic measurement operation and monitoring, and customised output-to-database data handling. The setup is designed to dynamically enable a variety of parallel measurements with several coupled devices (e.g. balance, MS2B) to effectively use dead-time in between the otherwise time-consuming measurements with the cryogen magnetometer. Web-based access allows remote quality control and interaction 24/7 and enables high sample throughput.

In the studied cores the magnetic properties are combined with geophysical, geochemical measurements and optical imaging, both radiographic and colour images, from high-resolution core-logging. The multidisciplinary approach enables determination and interpretation of content and formation of the magnetic fraction, and its development during diagenetic processes. Besides palaeomagnetic age determination the results offer the opportunity to study sediment transformation processes that have implications for the burial and degradation of organic matter. The results also help to understand long and short-term variability of sediment accumulation. Chemical sediment stability is directly linked to environmental and climate variability in the polar marine environment during the recent past.

POSTER

The general seafloor morphology of the NE Greenland shelf - Insights from new marine shallow seismic and core data collected during the NorthGreen2017 expedition

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We present preliminary observations from seismic data supported by marine sediment cores from the NE Greenland shelf between 80°N and 74°N. The data were acquired in nearly ice-free conditions and consist of ~2200 km of shallow seismic subbottom profiler data as well as sediment cores from 15 different sites. The data were acquired during the NorthGreen2017 expedition in September 2017, and represent an area that has been rarely accessed due to mostly perennial sea-ice cover prior to 2017.

The data cover a wide range of different geological provinces across the NE Greenland shelf, but can roughly be subdivided into deep troughs (formed by glacial erosion) and basement highs, which also appear to be affected by glaciers. In nearly all areas, a thin cover (1-3 m) of most likely Holocene mud drapes the varying structures. Sedimentary basins (with estimated mud/clay thickness up to ca. 15-20 m) were only encountered in a few places on the shelf, primarily linked to glacier outlet troughs.

Varying seafloor morphologies can be recognized such as blocky and faulted seafloor, rugged seafloor possibly related to slope failures, potential iceberg plough-marks, basement outcrops and flat seafloor related to minor sedimentary basins. Similarly, the reflections below the seafloor show varying characteristics such as parallel high-amplitude continuous reflections and low-amplitude discontinuous chaotic reflections indicative of changing subsurface.

POSTER

Active fault systems and submarine landslides along the Eastern Sakhalin slope, the Okhotsk Sea

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Continuous sub-bottom profiling and detailed bathymetry maps obtained during international projects in 1998-2015 has first revealed areas of active tectonics and associated submarine landslides within central and northern areas of Sakhalin Island slope, the Okhotsk Sea. Active faults form two local systems within limited areas. Within the northern area the fault system contains NE and NW striking normal and strike-slip faults. In this area tectonic deformation caused displacement and destruction of a

sediment block with approximate volume of 16 km^3. NW striking normal faults form steep instable tectonic scarps up to 120 m high. Seismic survey reveals mass transport deposits with estimated total volume of 3 km^3 at the base of the largest scarp Within the central slope segment the active fault system contains NE and NS striking normal and strike-slip faults. Vertical displacements along the NE normal faults result in subsidence of sediments and form closed depressions with steep walls. Failure of one of such steep walls formed a landslide with volume of about 4 km^3. The presented data show that the active tectonics creates favorable conditions for landslides generation in the study area.

15.2. Paleo-landscape analysis based on high-resolution marine data

ORAL

The impact of a buried shear margin moraine and thermokarst landscapes on ice-stream dynamics of the SW Barents Sea revealed by high-resolution 3D seismic data

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Meter-scale glacial landforms and layers, not resolvable by conventional seismic data, comprise new information about glacier dynamics and fluid flow, which are valuable for the development of offshore infrastructure and geohazard assessments. The goal of this study is to characterize the paleo-landscape of the SW Barents Sea on a meter-scale, to correlate these structures with the sub-surface geology and to study their implications on ice-stream dynamics. The database consists of c. 200 km^2 of high-resolution P-Cable 3D seismic data and 37 gravity cores in the SW Barents Sea. The grids of the picked seabed and Upper Regional Unconformity (URU) horizons, which define the top and base of the Quaternary sediment sequence, are compared with interpretations obtained from conventional 3D seismic and multibeam echosounder data. Seabed images interpreted in P-Cable 3D seismic data show an increased resolution and sharpness compared to surfaces derived from multibeam echosounder and conventinal 3D seismic data. Hill-hole pairs and rhombohedral ridges at URU are interpreted as geological structures formed by subglacial thermokarstic processes, indicating the presence of permafrost. Reflections within the intraglacial sediment package are not visible in conventional

seismic data, and include a shear margin moraine, mass tranport deposits and soft beds. This study shows that high-resolution seismic data can be used to identify geological structures in multibeam echosounder quality of both the seabed and the shallow sub-surface. Identified thermokarst landscapes, a submarine braided river and a shear margin moraine have led to the development of a revised ice-stream model of the SW Barents Sea.

ORAL

Geological setting of Anholt Loch (Site M0060) IODP Expedition 347

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IODP Expedition 347 Site M0060 is situated in the southern Kattegat at a water depth of 34m. The background selection of the coring position was a rather coarse grid of seismic lines, that indicates an erosional valley southeast of Anholt Island in the Kattegat Sea. The valley was originally interpreted as infilled by a sequence from MIS 6, MIS 5e, and MIS 3 (Lykke-Andersen et al. 1993). Later boomer profiles and shallow cores show, that the younger parts of the infill is late glacial and Holocene age (MIS 2–MIS 1; Jensen et al. 2002).

In 2013 the IODP program core M0060 reached a total depth of 232.5m of which 0 to 9 mbsf is Marine Holocene and the range 9 to 82 mbsf covers the most recent deglaciation 14 – 18 ka BP i.e. (Bokhari 2015). On greater depths alternating sandy and silty sequences are recorded, while the lowermost 84 m consists of diamict.

Parallel to Expedition 347 a local Danish – Swedish project DAN-IODP-SEIS carried out High Resolution 2D seismics (Nørmark et al. 2014) and in spring 2017 a 3D high resolution survey was carried out in connection with the Geocenter Denmark project SEDI-TRAPS.

Correlation of the coring results and the seismic data show that the Anholt Lock is linked closely to the structural development of the Tornquist Zone strike-slip fault system and synsedimentary Late- and Postglacial depositional patterns document that reactivation has taken place.

ORAL

Postglacial paleo-landscape evolution of Aalborg Bay-Læsø Rende, northwestern Kattegat – results of a regional aggregate raw material mapping campaign

Niels Nørgaard-Pedersen[1], Jørgen O. Leth[1], Ole Bennike[1] and Steen Lomholt[1]
[1]Geological Survey of Denmark and Greenland

In 2016 a regional shallow seismic mapping campaign for aggregate raw materials took place in an 1800 km^2 area in Aalborg Bay in northwestern Kattegat. The main purpose of the study, performed for the Danish Environmental Agency, was to assess the distribution and quality of aggregate material as well as monitoring the habitat conditions in the area. Mapping of basis of the Holocene deposits in the area, representing the low stand period at about 12.000-10.000 yrs. BP, reveals a network of valley/channel systems which appear to be connected to the major drainage systems connected to inlets of eastern Jutland. Rapidly increasing relative sea level from about 10.000-7.000 yrs. BP enhanced marine transport of very large volumes of sandy material from the northwestern Kattegat in to the northern part of the study area. Elongated sand bars tens of kilometers long formed in Læsø Rende. In the mid-Holocene at about 5000-4000 yrs. BP relative sea level culminated at about 4-5 m above present sea level. Due to the continued isostatic uplift of the northern part of Kattegat relative sea level fell after c. 4000 yrs BP. The large sand bar and intervening channel systems were selectively eroded and large amounts of

sandy material were transported southward to the central deeper part of Aalborg Bay. The development of a geological model encompassing the present distribution of specific stratigraphic units and the related paleo-landscape evolution in relation to sea level changes, is an important prerequisite for predicting aggregate raw material distribution and quality variability.

ORAL

Glaciotectonic thrust complex offshore Holmsland, the Danish North Sea - New Results.

Bernhard Novak[1] and Henrique Duarte[2]
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Geological structures and seismic stratigraphy of a large-scale glaciotectonic thrust complex has been investigated in an area 5 km offshore along the coastline off the Holmsland Dunes area, west Denmark. A dense grid of seismic data combined with surface samples and boreholes information have been analyzed in a 6 by 15 km area. The base of the Quaternary (D,b) constitutes an unconformity interface to Neogene. A smooth seismic horizon (D,d) that outline ramps and flats constitutes a decollement surface beneath the thrust complex. New analysis (and data) yield evidences that the base Quaternary unconformity is unaffected by the deformation and that near horizontal parallel seismic facies onlaps D,b. The seismic unit D,0 between the horizons D,b and D,d shows medium to high amplitude parallel (onlap), mound, channel, oblique and chaotic seismic facies. This 0 to 30 meter thick seismic unit is interpreted to represent glaciolacustrine laminated sediments (parallel facies) deposited over a proglacial outwash plain environment. Analysis of thrust block dip variations above D,0 suggests a correlation to the thickness of unit D,0 and the thrust style. In areas where the unit is absent a fold/dome deformation style at the base of the complex is accompanied by steep thrust style and maximum space between thrust ridges above the folds. Our model suggests that unit D,0 function as a hydro conductive agent beneath tens of meters of glaciolacustrine deposit. Variations in the appearance of unit D,0 and lithological variations in the lacustrine deposits results in variations in thrust style.

POSTER

Paleo-river valleys near the Dogger Bank in the Danish and German sectors of the North Sea – an undiscovered tributary system to the Paleo Elbe Valley

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This study presents a new system of paleo-river valleys southeast of the Dogger Bank which has been mapped using high-resolution subbottom profiler data and sediment cores acquired during a RV Heincke expedition to the German and Danish sectors of the North Sea in May 2016.

The paleo-river system covers an area of approx. 200 km2 and is found below a thin succession of marine sediments, which indicates that the river system formed prior to the marine transgression 8000 years ago. The river system is characterised by a central, 5 km wide and up to 6 m deep NE-SW striking valley that intersects six older and smaller NW-SE striking channels.

The course of the wider central valley roughly follows the contours of the submerged Dogger Bank and the infill of the valley is characterised by well-defined subparallel and continuous reflections. This suggest a steady infilling of the valley, which may have occurred within an estuary environment prior to the marine transgression.

The six older and smaller channels have higher sinuosity and follows a course perpendicular to the Dogger Bank. These channels are interpreted to constitute an older meandering river system

dewatering the Doggerland and terminating in the Paleo-Elbe Valley east of the study area.

The six older meandering rivers can be readily linked to other similar systems mapped further southeast (Hepp et al., 2017) and there is generally a very good agreement of our new findings with the existing theories on the development of the Doggerland landscape since the Weichselian lowstand.

POSTER

Late glacial to Holocene geological development of the western Limfjord – reconstruction of a dynamic paleolandscape

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The western Limfjord in northern Denmark comprises wider water-areas such as Løgstør and Thisted Brednings, narrow straits, small islands and some larger islands with spectacular landscapes such as Mors and Fur. The Quaternary development of the fjord has been highly governed by surface processes related to changing ice-covers which has carved-out the fjord, deformed the Cenozoic succession including the Eocene Mo-clay by thrusting and folding, and generated sea-level fluctuations due to ice-melting and isostatic glacial rebound. At the same time, deep geological subsurface processes such as rising salt diapirs, tectonic faulting and fluid migration have also controlled the formation of the landscape.

In this study, we present a detailed subsurface investigation of Visby Bredning in the western Limfjord based on high-resolution seismic data and sediment cores acquired during the WesternLimfjord-expedition in May 2017. Our preliminary results show that the Quaternary paleolandscape from the seismic data as expected is very dynamic, and most likely have recorded the history from an ice-covered to shallow-water environment. The seismic data typically show a distinct transition from high-amplitude chaotic reflections interpreted as Weichselian till, to lower amplitude, semi-parallel, continuous reflections interpreted as the Holocene succession. A few places, we observe a third unit in between the glacial and Holocene units, which we tentatively suggest could represent late glacial deposits. Sediment descriptions and age dating from two gravity cores in Visby Bredning are included to address the Holocene development in more detail and unravel the changing influence of fresh, brackish and marine waters in Visby Bredning.

POSTER

The Young Sound fjord system, NE Greenland – Insights from new marine shallow seismic and core data collected during the NorthGreen2017 expedition

Lasse Nygaard Eriksen[1], Katrine Juul Andresen[1], Tove Nielsen[2], Christof Pearce[1], Tine Lander Rasmussen[3], Sofia Ribeiro[2], Søren Rysgaard[4], Hans Røy[5] and Marit-Solveig Seidenkrantz[1]

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The Young Sound fjord system in NE Greenland generally consists of an outer, up to 7 km wide, shallow water (<200 m) part and an inner narrow (2 km wide) and deeper water (300-400 m) part known as the Young Sound Deep. The fjord system have been extensively surveyed for marine, terrestrial and meteorological data since 1994 (Bendtsen 2014 et al.), but the underlying

seafloor and the subsurface sediments have to our knowledge only been mapped superficially. In this study, we present preliminary observations from seismic mapping and sediment coring within the Young Sound. The data that consist of 400 km of shallow seismic subbottom-profiler data and four sediment cores were acquired during the NorthGreen2017 expedition in September 2017 and represent the first detailed marine seismic study of the geological development of the fjord system.

We show that the central basin in Young Sound Deep is filled with a fairly thick sediment package (at least 40-50 m where thickest). There was furthermore a clear distinction in both the seafloor morphology and the subsurface geology from the inner part of the fjord towards the outer part of the fjord, which is most likely a direct representation of the similar marked changes in topography at the fjord sides. Thus, our observations from the high-resolution shallow-seismic data suggest that we can track first-order erosion and depositional processes within the fjord back in time.

POSTER

Deep geology at Vejle Fjord – Paleogene structural control of a Quaternary fjord system

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Vejle Fjord in Denmark is believed to have formed as a tunnel valley initially carved-out during the Elsterian glaciation and later reused and expanded during succeeding glaciations and inter-glaciations. Folds and thrust faults in the present-day coast-profiles of the fjord bear evidence of glacial deformation while outcrops of Paleogene and Neogene sediments have aided the reconstruction of the paleolandscape. It has however not been investigated in detail, how deeper geological structures could have controlled and effected the configuration of the pre-Vejle Fjord landscape and in turn the focus of the Quaternary glacial processes.

In this study, we interpret newly acquired high-resolution 2D seismic data and sediment cores from Vejle Fjord with the aim of mapping and investigating the deeper geological structures and their potential influence on the formation of the fjord. Our seismic data show a number of faults, which in the southern part of Vejle Fjord offset Eocene sediments presently at the seafloor. The faults can be followed down to ca. 70 m below the seafloor, with a few faults continuing even deeper. Three hypotheses for the formation of the faults are suggested: Quaternary glacial tectonic deformation, slope failure deformation, and polygonal faulting. Which of the hypotheses that are applicable have a great importance for the understanding of the early origin of Vejle Fjord and for fjord formation in sedimentary basins in general. To understand the faults, our interpretation is focused on constraining their 3D geometries and in turn their timing, activity and controlling factors.

15.3. The Quaternary geology of the North Sea Basin [co-organized with Quaternary Geology]

ORAL

The Quaternary Stratigraphy in the Norwegian Sector of the Central North Sea – A Site Survey Perspective

Björn Bohling[1]
[1]*Fugro*

Quaternary deposits of the North Sea are of particular interest for geohazard and site characterisation studies ensuring the save emplacement of offshore installations (IOGP 2013 & 2015). A coherent (litho-)stratigraphic framework is required in order to perform a reliable interpretation of geophysical and geotechnical site survey data and in order to ensure the comparability of results.

The British sector of the North Sea has been systematically mapped by the British Geological Survey. Reports and maps presenting seabed sediments and the Quaternary geology have been published (e.g. Johnson et al. 1993, Gatliff et al. 1994). Such systematic mapping has not been undertaken in the Norwegian sector of the southern and central North Sea. Therefore, the interpretation of site survey data in the Norwegian sector is often based on the extrapolation of the British stratigraphic model, leading to a considerable degree of uncertainty and inconsistency. Recent research has improved the understanding of Quaternary deposits (e.g. Buckley 2014, Ottesen et al. 2014). However, many studies focus on the early Quaternary sequence or make use of conventional 3D exploration seismic data that have a relatively low resolution and do not image the complexity of middle and late Quaternary deposits.

This presentation will highlight issues and challenges regarding the Quaternary stratigraphy in the central North Sea as seen from a site survey perspective. Examples of high-resolution data will be shown from site surveys in the Norwegian sector and in areas crossing the UK-Norway border.

ORAL

The Norwegian Strandflat - an offshore perspective

Helge Løseth[1]
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The strandflat is the picturesque world-heritage topographic low-land, island and sounds on the coast of Norway. The age and processes of forming the strandflat have been debated since first described by Hans Reusch in 1900. The objective of this work is set constrains to the age and formation processes of the strandflat by linking it to the offshore geological evolution. Seismic and well data are used to interpret the Cenozoic geological evolution of the margin while the strandflat is studied through literature and field observations.

The non-parallel tilts of the strandflat relative to offshore Cenozoic surfaces show that the strandflat was formed during the Quaternary.

The strandflat is widest, up to 50 km, on the mid Norwegian coast. The combined effect of glacial erosion (volume-vice most important) and wave erosion formed the strandflat. Wave erosion cut leveled platforms into the glacial-segmented coast. This occurred most efficiently during glacial periods when the coast was ice-free simultaneously as the land was depressed under the weight of the inland ice. During repeated glacial and intra-glacial events the platform grew wider and deeper simultaneously as the coast gradually rose and tilted westward under isostatic adjustments form onshore erosion and offshore deposition. Outside Møre and Troms the strandflat is isostaticly forced below the sea level under the weight of the two glacial depocenters, the North Sea Fan and the Bjørnøya Fan. The absence of the strandflats in Finnmark and SE

Norway I explain by offshore glacial erosion and no flexural down-bending of the coast.

ORAL

The geological history of the North Sea Basin during the Quaternary

Dag Ottesen[1], Christine Batchelor[2], Julian Dowdeswell[2] and Helge Løseth[3]
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The Quaternary sediments of the central and northern North Sea have been mapped based on a large 2D and 3D seismic database. The Quaternary North Sea basin is a N-S-trending basin, 100-200 km wide and up to 1000 m deep. The infill pattern of the basin is outlined and the depositional setting has been studied based on buried surfaces in 3D seismic cubes. The central basin is filled in by a thick, deltaic sequence deposited from the E-SE, whereas the northern basin is filled in by prograding glacigenic debris flows deposited from the east.

On top of the sediments mapped in the northern basin, west of the Norwegian Channel, an upper regional unconformity (URU) is present. This unconformity is defined by a shift from westward (below) to eastward (above) dipping reflectors, recording a major change in sedimentation (before and after the onset of the formation of the Norwegian Channel). The age of the URU is uncertain, but a timing of around 0.8 million years is suggested. Parts of the sedimentary sequence have been linked to the seismic stratigraphy on the Dutch shelf, which is dated based on palaeo-magnetic and biostratigraphic data (Kuhlmann and Wong, 2008).

ORAL

The tunnel valleys of the central and northern North Sea (56°N – 62°N): Distribution, Characteristics and Generations

Dag Ottesen[1], Margaret Stewart[2] and Marco Brønner[1]
[1]Geological Survey of Norway, [2]British Geological Survey

Tunnel valleys are km-scale linear landforms formed subglacially beneath large ice sheets. In the British and Norwegian sectors of the North Sea, offshore tunnel valleys are associated with multiple Quaternary glaciations. In this study, we use 2D and 3D seismic reflection data, and magnetic data, to map more than a thousand buried tunnel valleys in the central and northern North Sea. The tunnel valleys are generally present from the seabed to depths of around 400 metres, in a study area of 180 000 km^2 from 56°N to around 62°N. Buried tunnel valleys are well-imaged in seismic reflection data, particularly in horizontal timeslices in 3D seismic data. In magnetic data, the tunnel valleys appear as small scale magnetic lows, likely due to their infill being less compacted and potentially more porous than the surroundings.

This work provides the most extensive study of tunnel valleys in the region to date, with more than 20% of the study area containing buried tunnel valleys, and also finds the longest tunnel valley recorded worldwide, with large meandering tunnel valleys extending for more than 160 km. We also find tunnel valleys further north than previously reported, as well as a number of isolated tunnel valleys extending towards and into the Norwegian Channel. As reported by other studies in the region, the apparently extensive networks of buried valleys are found to be comprised of cross-cutting generations. In four study areas, we find between 3 and 6 generations, and relate them to potential ice sheet configurations.

ORAL

Quaternary depositional environments and glacial history of the North Sea constrained by aminostratigraphy

Benedict Reinardy[1], Hans Petter Sejrup[2] and Berit Hjelstuen[2]
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The aminostratigraphy of up to 1000 m of glacial and interglacial sediments in the North Sea Basin is compiled from multiple boreholes sites and dated using strontium isotope (Sr) analysis to provide a chronological framework extending throughout the Quaternary. The new relative and absolute chronology also ties to regional seismostratigraphy. Increasing sediment deposition rate during the Early Pleistocene reflects glacier ice advancing to the Norwegian coast. The earliest evidence of grounded ice in the investigated area comes from mega scale glacial lineations formed during the Mid Pleistocene Transition. At least one episode of diminished coarse clasts and increased foraminiferal diversity during the Mid Pleistocene suggests a progression from ice proximal to warmer, possibly interglacial conditions. Furthermore, the stratigraphically deepest generation of tunnel valleys may have formed during the Mid Pleistocene. Amino acid ratios indicate that a high shear strength till containing chalk clasts transported from the west and/or south of the study area was likely deposited during MIS6. The Late Pleistocene stratigraphy is dominated by glacimarine sediments and tills that are chronologically well constrained with amino acid data. A sand layer recovered at core top in part of the study area is interpreted to correspond to the drainage of an ice-dammed lake in the southern North Sea during the last deglaciation (MIS2). This study shows that much of the Quaternary age sediments within the northern North Sea were deposited relatively rapidly during short periods of time probably leaving significant hiatuses within the stratigraphic record.

POSTER

Near-shore seafloor depressions in the Western Limfjord, Denmark – potential geohazards?

Anders Dahlin[1], Katrine Juul Andresen[1], Kasper U. Kjeldsen[2], Hans Røy[2] and Marit-Solveig Seidenkrantz[3]
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Pockmarks which are circular to semi-circular seafloor depressions formed due to fluid venting, is a well-known geological phenomenon that in several cases have proven to represent geohazards particular in relation to safety and cost implications for the integrity of seafloor constructions and pipelines. During the venting, fine-grained sediment is removed from the venting site leading to an excavation of the seafloor.

In this study, we present preliminary observations of 7 large-scale seafloor depressions in the shallow waters (<20m) of the western Limfjord, Denmark. The depressions are tentatively interpreted as pockmarks and have been mapped using a new multibeam and high-resolution 2D seismic subbottom profiler survey and sediment cores acquired during the WesternLimfjord research expedition in May 2017. The depressions are characterized by a complex circular to elongated map view morphology, a width of 40-500 m, and typical depths of ca. 3 m with very steep sides (11°) and flat to rugged bottom morphologies. In total, the depressions cover an area of roughly 425.000 m^2 and can be associated with the removal of ca. 850.000 m^3 of sediment, which may have taken place through violent fluid expulsions or slow seepage.

If the depressions are indeed pockmarks they would represent a rare case of near-shore pockmarks which is very important to study in order to constrain their formation, timing, duration and present-day activity and to understand their potential geohazard risk;

particularly whether similar structures may form in the future.

POSTER

Morphology of the southeast Skagerrak (Denmark) from a new geophysical dataset

Matthew Owen[1], Zyad Al-Hamdani[1], Jørn Jensen[1], Jørgen Leth[1], Katrine Andresen[2] and Lasse Eriksen[2]
[1]Department of Marine Geology, Geological Survey of Denmark and Greenland, [2]Deparment of Geoscience, Aarhus University

As part of the Danish marine habitat mapping programme an extensive geophysical dataset including multibeam bathymetry, side scan sonar and Innomar sub-bottom profiler has been acquired in the Danish Skagerrak. Approximately 2200 line km of data were acquired in an area of approximately 2600 km^2, extending between Skagen in the east and Hirtshals in the west and from 4 m water to 190 m in the deeper Skagerrak some 50 km north of the Danish coast. This new dataset allows the first detailed morphological analysis of this area and the first major study since the mid-1990s. A number of morphological features are noted that both confirm previous observations and provide new insights. In deeper water these include: outcropping strata in the west, where the Jutland current erodes the seabed; sub-parallel wavy Innomar reflectors indicating contourite deposition; grooves eroded into Holocene sequences, showing bottom current pathways; a variety of depression morphologies coupled with a strong gas front indicating gas release and pockmark formation. Where the gas is absent the Innomar signal provides evidence of vertical chimneys and images reflectors previously associated with late Pleistocene ice-proximal glacimarine deposition: below a Holocene sequence tens of metres in thickness. In shallower waters a large variety of bedforms, from ripples to 4 m high sand waves, are present giving strong evidence of the across-shelf sediment transport. These observations have significant implications for seabed habitats, the carbon and sulphur cycle, as well as the region's glacial history, palaeoclimate and oceanography.

POSTER

Buried Valleys in the Danish Central Graben

Lasse Krogsgaard Prins[1], Katrine Juul Andresen[1] and Ole Rønø Clausen[1]
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The Danish Central Graben has been subject to extensive seismic surveying (both 2D and 3D) during the past four decades. The 3D seismic data has mainly been used for oil and gas exploration, but in the last decade, these data sets have proven very useful for investigating the Quaternary sediments and especially erosional channels. Geotechnical data such as CPTu logs have furthermore proven very successful in determining sediment types and by incorporating geotechnical data we can optimize our geological models and create a geotechnical stratigraphy. In this study, we have utilized both 3D and 2D high-resolution seismic data sets together with geotechnical borehole data to interpret the Quaternary landscape evolution in the Danish North Sea. The emphasis is on the morphology, infill and relative age of buried Quaternary valleys. We describe the differences between the seismic expressions of buried river valleys and tunnel valleys. The present study combines extensive mapping of these channels from 3D seismic data with detailed seismic analyses of high-resolution 2D seismic site surveys in order to validate the mapping from 3D time-slice analyses. This gives us a better understanding of the sediment distribution in the different channels and their relative age. This study is part of the DHRTC (Danish Hydrocarbon Research and Technology Centre)-funded project "Seismic Acoustic Methods: A tool for refining the 3D geotechnical models in a mature hydrocarbon producing area" in which the goal is to create a

geotechnical stratigraphy for the Danish Central Graben.

15.4. Open session

ORAL

EMODnet Seabed Habitat, an ambitious project for mapping benthic habitats in European waters. The Danish contribution.

Zyad Al-Hamdani[1], Nicky Witt[1] and Matthew Owen
[1]GEUS

EMODnet (The European Marine Observation and Data Network) is funded by DG-MARE and in its third phase is composed of eight thematic "Portals" aiming at producing a multi-resolution seabed digital map for the whole European waters that include bathymetry, geology, chemistry, biology, physics, human activities, seabed habitat mapping and the recently added Data Ingestion Portal.

The aim of the Seabed Habitat is to produce a broad scale seabed habitat map of all European waters. A cost effective method to obtain full spatial coverage seabed habitat maps uses environmental layers such as sediment types, bathymetry, photic depth etc., as proxy to model the seabed habitat was adopted.

In the Phase I seabed habitat maps were produced with 1km resolution, in Phase II the resolution was increased to 250m and in the current Phase III the aim is to produce 100m resolution broad-scale habitat maps for all European waters. Additionally, individual habitat maps from national surveys and point datasets from national monitoring programs will be collated and standardised (INSPIRE), also habitat distribution models. The final habitat map is converted into EUNIS classification as the common classifier for European waters habitats.

To achieve this member states need to provide available information gathered through mapping endeavours and point sampling.

Denmark has contributed in all EMODnet Phases. We present the latest habitat mapping project performed by GEUS/Orbicon in the North Sea.

ORAL

When did the Danish/German/Swedish straits form?

Ole Bennike[1], Jørn Bo Jensen[1] and Niels Nørgaard-Pedersen[1]
[1]GEUS

The timing of the formation of the Danish/German/Swedish straits and the first marine influence in the Baltic Basin has been much debated. Here we present new radiocarbon ages from sediment cores retrieved from Danish waters. Most ages are based on shells of marine molluscs, which means that the ages are uncertain because we do not know the reservoir age in the past. We use a reservoir age of 400 years, which is based on dating of museum specimens collected before testing of nuclear bombs starter. It is clear from the ages that the Great Belt (Storebælt) was inundated before the Sound (Øresund). The oldest ages from the northern part of Great Belt are about 8700 cal. years BP. From the central part of the Great Belt the oldest ages are about 8100 cal. years BP and in the south-western Baltic Basin ages varies from 7200 to 7600 cal. years BP. Sediments deposited prior to the occurrence of marine molluscs contain brackish-water ostracodes (Cyprideis torosa and Cytheromorpha fuscata); the sediments are usually laminated and non-bioturbated. The brackish-water phase may have lasted 500 to 1000 years.

POSTER

EMODnet Geology – a gateway to marine data in Europe

Jørgen O. Leth[1], Bjarni Pjetursson[1], Matthew J. Owen[1] and Zyad Al-Hamdani[1]
[1]GEUS

Rapid access to reliable and accurate information is vital in addressing threats to the marine environment, for developing policies and legislation to protect vulnerable marine areas and in understanding trends and forecasting future changes such as the effects of climate change. The access to an effective pan-European marine data infrastructure will also enable effective and efficient marine spatial planning and legislation for environment, fisheries, transport and defence.

The European Marine Observation and Data Network (EMODnet) is a network of more than 160 organisations assembling marine data, products and metadata to make the fragmented resources more available to public and private users relying on quality-assured, standardised and harmonised marine data, which are interoperable and free of restrictions on use. All marine data users including marine industries, decision-making bodies, scientific research and the public in general, benefit from the overall philosophy of the EMODnet data infrastructure "collect once and use many times". GEUS has been involved in EMODnet-Geology since the start in 2009. EMODnet-Geology has successfully compiled harmonised offshore data across the European seas including: sea-floor geology, seabed substrates, rates of coastline migration, geological events and probabilities and mineral resources. The products are available via the EMODnet Geology Portal. In its third phase (2017-2020), the existing data products is further developed with higher resolution (1:100.000) including more thematic themes such as, seabed geomorphology and Quaternary and submerged landscapes. New services are being built, so users now can investigate and search for borehole data and seismic survey data using interactive maps and tools.

16. Geomorphology

16.1. Remote Sensing - Digital mapping, remote sensing and 3d models in Earth Science

ORAL

The 2017 eruption of Erta 'Ale volcano, Ethiopia: a case study in monitoring remote volcanoes with satellites.

Talfan Barnie[1], Ashley Davies[2], Gezahegn Yirgu[3], Moore Chris[4], Simon Carn[5], David Pieri[2], Clive Oppenheimer[6], Juliet Biggs[7], Tim Wright[4] and Andy Hooper[4]

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Most volcanoes on Earth are not monitored by local sensor networks, but we can potentially track all subaerial eruptions using spaceborne sensors. Here we investigate the prolonged fissure eruption of Erta 'Ale volcano in northern Afar, Ethiopia, which began in January 2017. We are unaware of any local installations of monitoring equipment despite the longevity of the eruption and the geodynamic significance of the volcano, which lies on an axial volcanic range of the Red Sea rift system. The volcano is of particular importance, as over the past 15 years or so the behaviour of the lava lake(s) in the summit caldera have apparently tracked or even heralded volcanic and tectonic activity witnessed across the broader Afar-Red Sea region since the early 2000s. Using a suite of routinely-, manually- and automatically-commissioned satellite image acquisitions, we have been able to follow the eruption with high-temporal resolution. In particular, we have been able to reconstruct time series of gas and lava emissions, and ground deformation. We have also been able to document variation in activity at the lava lake itself, monitoring lava level and tracking individual overflows on time scales of tens of minutes. Integrating observations of both the lava lake and vent, which represent two windows into the magmatic system, provides an unusual opportunity to contains the behaviour of a magmatic system during an eruption.

ORAL

A 10-year series of surface kinematics of periglacial sorted circles from SfM close-range photogrammetry

Ivar Berthling[1], Luc Girod[2], Andreas Kääb[2] and Radmil Popovic[1]

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Sorted circles are one type of periglacial patterned ground, created by large-scale cryoturbation due to freezing and thawing of the active layer. It is one of the most conspicuous types of patterns created by geomorphic processes on the earth surface, and widely used as an example of emergence in complex systems.

Since 2007 we have attempted to document the spatial pattern of displacements going on in sorted circles at 79°N on Kvadehuksletta, Ny-Ålesund, Svalbard using Structure-from-Motion (SfM) photogrammetry and feature-tracking. Published results (Kääb et al. 2014) show the applicability of this method in terms of gaining high-resolution information on vertical and horizontal displacements within the sorted circle system. This presentation will document a decade of displacements within these sorted

circles, but also comment on challenges and possible solutions for long-term SfM monitoring of sorted circles.

During 2007 and 2010 campaigns, we acquired the images from a portable ladder. In 2015, 2016 and 2017, images were shot from a camera attached to a long pole via a wifi connection to the camera. The design was set up to yield a theoretical resolution of the digital elevation model of around 1 mm.

ORAL

Combined visualisation of 3D outcrop and related geoscientific data using LIME

Simon J. Buckley, Kari Ringdal, Bowei Tong, Benjamin Dolva, Nicole Naumann, Tobias H. Kurz

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Digital representation of the earth's surface topography, using techniques such as digital photogrammetry, laser scanning and publicly available digital elevation models, is now commonplace in geology and other areas of the geosciences. High resolution and accurate surface models aid quantitative mapping, interpretation and analysis, acting as a framework for compiling project data. In addition to 3D modelling, complementary imaging techniques (e.g. multispectral, hyperspectral and thermal imaging) add colour and spectral information that can be used for interpretation of patterns, texture, object material properties and distributions. Integrated 2D–3D analysis can provide powerful synergy when applied to problems in geoscience. Furthermore, compiling 3D spatial datasets with supplementary spatial and non-spatial information in a single graphical environment aids interpretation and communication of study data to students, collaborators and other stakeholders.

Despite the current ease of acquiring digital 3D models, the increasing access to publicly available data, and the wealth of disparate ancillary information sources, software tools for advanced co-visualisation, interpretation and data sharing are non-standard and rely on custom solutions for different applications. As a means of addressing this imbalance, the current contribution presents LIME, a lightweight, high performance software package for viewing and interacting with 3D models and related spatial and non-spatial data sources. The software focuses on the novel integration of a variety of geospatial and field data, such as 3D models, georeferenced images and maps, logs, interpretation panels, and hyperspectral images. In addition, measurement and interpretation can be carried out by digitising in the 3D scene. A key component is the generation of high quality visual products, such as by projecting image and 3D data onto photorealistic models to generate novel overlay layers. These features are exemplified through case studies in hyperspectral imaging, geophysical data integration and digital outcrop mapping.

ORAL

Crystal-scale magnetic anomalies revealed by scanning magnetic microscopy

Nathan Church[1] and Suzanne McEnroe[1]
[1]NTNU, Trondheim, Norway

Scanning magnetic microscopy (SMM) maps the magnetic field generated by petrologic thin sections or polished rock surfaces at the sub-mm scale, creating the possibility to resolve the contribution of individual grains and mineral phases to bulk magnetic signal. The instrument developed at NTNU has the capability to measure both remanence properties and, uniquely, the magnetic response in a field of known magnitude and direction. A series of case studies are presented to examine the capabilities of the microscope and to describe applications to the study of crustal magnetism. The use of well-characterized samples allows signals in magnetic scans to be attributed to grains of known

composition, including the discrimination of signal associated with discrete oxides and assemblages of exsolved oxides in silicates, which can be observed to have differing directions of magnetisation. The ability of this instrument to image in fields mimicking those experienced in the crust allows the observation of the induced magnetic response, both qualitatively in the form of changes in magnetization direction, and quantitatively by varying experimental conditions. This capability gives SMM the ability to map both remanent response and generate a map of susceptibility, and provides a powerful new tool for the examination of bulk magnetic response in the Earth's crust.

ORAL

3D modelling and visualising of resource deposits in Norway with UAV technology and 3D MOVE

Iain Henderson[1], Morgan Ganerød[1], Espen Torgersen[1] and Tom Heldal[1]
[1]Geological Survey of Norway

This study combines detailed terrain models and orthophotos of resource deposits in Norway with geological information underground. The terrain models are constructed using photogrammetry from a DJI Phantom4 drone and Litchi Mission Hub software. Individual flight plans are uploaded to the autonomously flying drone leading to better model construction and more efficient use of drone battery time. Point cloud data is uploaded to the Agisoft Photoscan Professional software, where the 3D mesh representing the ground surface is created and control points are added. The resultant georeferenced mesh is exported to 3D MOVE and integrated with underground geological data, producing a fully integrated terrain-geological 3D model. We have constructed several, widely different models: the Høgtuva Be-deposit i Nordland, the Kleivan slate mine in Oppdal, and the marble deposit at Fauske in collaboration with Norwegian Rose AS. A number of valuable products have beeen developed: Full digital 3D-models, volume calculations and mapped volumes, contour maps (depth to layer/volume) and volume thickness. These products contribute to a better understanding of the geology, a more effective running of the deposits and, not least, are attractive products for financial contributors and decision makers. This project is regarded as a development project where we have created the workflow required from initial drone flight planning, drone flying, point cloud management to model integration in 3D MOVE. This project is an initiative of the Mineral Resources Division at the Geological Survey of Norway in collaboration with several Norwegian Mining companies and is partly financed by Mineralklyngen Norge.

ORAL

ASPECT spectral imaging CubeSat for planetary studies

Tomas Kohout[1], Antti Näsilä[2], Tuomas Tikka[3], Mikael Granvik[4], Antti Kestilä[5], Antti Penttilä[4], Janne Kuhno[3], Karri Muinonen[4], Kai Viherkanto[2], Esa Kallio[5] and Jaan Praks[5]
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ASPECT (Asteroid Spectral Imaging Mission) is a 3U (30 x 10 x 10 cm) CubeSat concept designed for deep space exploration of small Solar System bodies. The payload of ASPECT is a miniaturized visible - near infrared (500-2500 nm) spectral imager. The primary scientific task of ASPECT is orbital high resolution compositional mapping of the target surface with a meter resolution. The obtained compositional maps can be used to study space weathering and impact processes, as well as in evaluation of areas for subsequent sampling or in-space resource utilization (ISRU). ASPECT is proposed to be part of European HERA mission to asteroid Didymos or Japanese MMX mission to martian moon Phobos.

ORAL

Environmental mapping and monitoring of Iceland by remote sensing (EMMIRS)

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Iceland is exposed to rapid landscape changes caused by natural processes and man-made activities, which impact and challenge the country. Fast and reliable mapping and monitoring techniques are needed on a big spatial scale. However, currently there is lack of operational advanced information processing techniques, which are needed for end-users to incorporate remote sensing (RS) data from multiple data sources. Hence, the full potential of the recent RS data explosion is not being fully exploited.

The project Environmental Mapping and Monitoring of Iceland by Remote Sensing (EMMIRS) bridges the gap between advanced information processing capabilities and end-user mapping of the Icelandic environment. This is done by a multidisciplinary assessment of the Hekla area, which encompass many of the rapid natural and man-made landscape changes that Iceland is exposed to.

An open-access benchmark repository providing high-resolution LIDAR topography and hyperspectral data for land-cover and landform classification is under construction. Furthermore, a multi-temporal archive stretching back to 1945 allows a decadal evaluation of landscape changes by the development of automated change detection techniques.

The development of pattern recognition and machine learning-based approaches to image classification and change detection is one of the main tasks of the EMMIRS project, aiming to extract and compute earth observation variables as automatically as possible. Ground reference data collected through a field campaign will be used to validate the implemented methods, which outputs are then inferred with geological and vegetation models. Here, preliminary results of an automatic land-cover classification based on hyperspectral image analysis are reported.

POSTER

Safeguarding long records of geomorphological measurements using Structure-from-Motion from ground-based images

Ivar Berthling[1], Bernard Hallet[2] and Radmil Popovic[1]

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Modelling of the Earth System response to climate change benefits from records documenting sub-system response across climatic perturbations. For many of the processes that today are incorporated within an ESM, we do not have this advantage. One example is cryoturbation, the overturning of soil in permafrost areas, suggested highly relevant for the carbon budget. The process itself leaves no proxy records, except a mixture of soil organic carbon of variable age beneath the ground

surface, so recorded values of soil surface displacements through time is needed for this purpose.

During the 1980'ies, before the onset of accelerated climate warming in the Arctic, Bernard Hallet initiated measurements on the stone circles on Kvadehuksletta, Svalbard. The stone circles are a remarkable example of the effects of large-scale cryoturbation. Although these measurements are not continuous, the installations are partly still in place. They were re-measured in 2010, 2015, 2016 and again in September 2017. The purpose of this presentation is to document our work on safeguarding the remains of these installations, and to transform the methodology using Structure-from-Motion from ground-based images, to enable continuing these measurements into the future. Our goal is to document how ground surface movements and cryoturbation have responded to the amplified effects of global warming at high latitudes, and to understand this response.

POSTER

UAV topographic survey of a migrating dune – pitfalls and first results (Sylt, southern North Sea)

Benjamin Eberhardt[1] and Sebastian Lindhorst[1]
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High resolution topographic information is instrumental in analyzing sand transport processes on active coastal dunes. Unmanned aerial vehicles (UAV) greatly facilitate the on-site collection of aerial images and structure-from-motion (SfM) algorithms allow producing detailed topographic models from UAV-based photogrammetric surveys. First results from a SfM case study from an active (but partly vegetated) migrating dune (dune height up to 30 m) are presented including survey design, georeferencing issues and applied data processing steps. Aim of this study is to test the applicability of UAV-based topographic surveys to quantify sand transport volume along the slipface of the dune. The model comprises 2500 images with a resulting ground-sampling distance of 1.67 cm/pixel over an area of 550 x 530 m. Special attention is given to the identification of artifacts caused by the less structured, uniform sand areas.

POSTER

UAV photogrammetry to monitor stability of rock climbing sites

Axel Hellman[1], Mark D. Johnson[1] and Anne Hormes[2]
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Monitoring of steep rock faces and documenting their geostructural character to evaluate stability is a difficult task from the bottom of a steep rock face. Unmanned aerial vehicle (UAV) sensors and technology have seen a rapid development over the last five years. They can enable surveying and monitoring of rock-slope failures and detached blocks in areas previously inaccessible and hazardous (Boccali et al., 2017). For this project, we study two frequently visited rock-climbing crags in Sweden and Austria, both with documented rock-fall activity. In Sweden, a recent rock-fall destroyed a well-known climbing route in Fjällbo, Gothenburg. In Austria, Engelswand is a very popular climbing crag in Ötztal, where we counted 70 climbers on one Saturday, with reoccurring smaller rock-falls and occasionally larger blocks occurring in the spring during the melting period.

Our study explores the accuracy of UAV photogrammetry for the analysis of rock-fall hazards. In Austria, we tested a rough acquisition workflow deploying handhold GPS points as ground control points together with aerial imagery and telemetry data. We aim to compare the accuracy of this quick method with the more resource and cost-inefficient method of using a

differential GPS and triangulation points to acquire a high precision of ground control points.

The UAV imagery is processed in different software packages for compilation and comparison of accuracy. 3D models, digital terrain models (DTMs) and point clouds are produced and will be used for kinematic analysis. Preliminary 3D model results suggest that the rough workflow provide accurate and detailed outputs.

POSTER

Classification of block fields in Norway using Machine Learning

Mads Nedergaard Paulsen[1] and David Lundbek Egholm[2]
[1]Aarhus universitet, [2]Aarhus Universitet

The origin of Scandinavia's extensive block fields has been a subject of debate for some time. One hypothesis suggests that the block fields mainly formed by pre-Quaternary warm-climate chemical weathering (Paasche et al 2006), while another hypothesis uses Late-Cenozoic cold-climate physical weathering mechanisms to explain the block fields through long-term periglacial landscape evolution (Goodfellow et al. 2014, Egholm et al. 2015). Several field studies have mapped the extent of selected block fields in Scandinavia, but the full distribution of block fields has not yet been studied.

In this master-degree study, we aim to use Machine Learning to map the distribution of block fields in Scandinavia. The vast amount of public available LIDAR data provides us with the opportunity to study distributions of landforms, e.g. along climatic gradients set by latitude or elevation. However, the shear data volume and the need for consistent objective mapping call for automatic classification methods based on topographic features such as elevation, surface slope, curvature, and roughness. We discuss the applicability of selected Machine Learning algorithms, such as k-means clustering, SVM, boosting gradient and Neural Networks, we evaluate pros and cons of the different algorithms.

16.2. Holocene coastal morpho-sedimentary systems: Archives, processes and forcing mechanisms

ORAL

Did cuspate foreland formation trigger large-scale barrier coast retreat?

Mikkel Fruergaard[1], Lasse Sander[2], Jérôme Goslin[1], Thorbjørn Joest Andersen[1], Peter Johannessen[3], Lars Henrik Nielsen[4] and Morten Pejrup[1]
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The stratigraphic evolution of barrier systems is controlled by the ratio between rate of sea-level rise and rate of sediment supply from external sources. Because of increasing coastal erosion and flood risk caused by the global rising sea level, many studies on barrier system evolution are focused on understanding the impacts of sea-level changes despite changes in sediment supply are equally important controlling coastal evolution. In this study we investigate how changes in sediment supply influenced the large-scale coastal evolution of the Danish Wadden Sea barrier coast. This coast is wave-dominated and angular wave approach generates a large southward-directed littoral drift. The Wadden

Sea is bounded towards the north by the cuspate foreland of Blåvands Huk and the shallow marine shoal of Ulven. Based on detailed sedimentological and chronological investigations of ~60 km barrier coast we present several stratigraphic evidences that the coast experienced region-wide flooding and coastal erosion between 4500 and 1400 years ago. New chronological data suggest that coinciding with the flooding and erosion, sediment accumulation and accretion took place in the area directly north of the Danish Wadden Sea. We suggest that the retreat of the coast was related to the construction of cuspate foreland of Blåvands Huk that largely trapped the littoral drift from the north, preventing the sand reaching the Wadden Sea coast and thus shifted the depositional locus northward from the Wadden Sea. The study indicates how sediment supply and large-scale morphology of the coast can control coastal evolution.

ORAL

High-resolution Holocene windiness and storminess over the North Sea: insights from Filsø lake, Western Denmark.

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Possessing long and accurate archives of past storm events is one key towards a better understanding of the atmospheric patterns driving these latter and of how coastal systems reacted in the past to changing forcing mechanisms. During the last decade, several Holocene storminess chronologies have been based on aeolian influxes within coastal lakes and mires (e.g. Björck and Clemmensen, 2004; De Jong et al., 2006; Nielsen et al.; 2016; Orme et al.,2016).

This study presents a high-resolution (pluri-annual) history of Holocene past windiness and storminess over the North Sea reconstructed from a coastal lake of Western Denmark. Past aeolian activity and storminess are reconstructed using aeolian sand inputs preserved within the organic-rich lake sediments.

Our data demonstrate high-frequency variations of aeolian sand influx between ca. 5000 and 2200 yrs B.P. that we believe adequately reflect the changes in past wind-climate and storminess. Impressively cyclic pluridecadal-scale "breathing patterns" in storminess activity are observed between ca. 5000 and 4300 years B.P. A massive sand invasion is then observed around 4300 yrs B.P., in accordance with the first period of dune building obsreved along the west coasts of Denmark (Clemmensen et al., 2001; 2009) and simultaneousl to a period of climate deterioration widely recognized elsewhere in Europe and globally. The signal then progressively slowly fades-out, most probably reflecting coastal progradation and dune fixation.

These results will allow us to discuss potential internal and external climate forcing mechanisms, as well as to question the interdependencies between aeolian activity, sedimentary dynamics and relative sea-level.

ORAL

Detailed dynamic development and sedimentary architecture of a Holocene to Recent micro-tidal barrier-island, Danish Wadden Sea.

Peter Niels Johannessen[1], Mikkel Fruergaard[2], Lars Henrik Nielsen[1], Lars Nielsen[2], Ingelise Møller[1], Thorbjørn Joest Andersen[2], Stefan Piasecki[1] and Morten Pejrup[2]
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The Rømø barrier-island is 14 km long, 4 km wide and the Holocene deposits c. 15 m thick. It is a very sand-rich system as it receives coastal drift

sand from north and south along the shoreface. It is separated from the mainland by a 8 km wide lagoon. Average tidal range is around 1.8 m. During strong westerly storms, the water level increases considerably, up to 5 m above mean sea-level.

The barrier-island formation started for c. 8000 years ago and is still active, which allows detailed studies on recent sedimentary processes. Stacking geometries of different sand units have been unraveled based on: Seven c. 25 m long sediment cores, 35 km ground penetrating radar (GPR) reflection profiles, and dating of 70 core samples using optically stimulated luminescence (OSL) providing a unique stratigraphic framework.

Due to the detailed knowledge of the stratigraphic framework, depositional environments and precise ages, a detailed palaeo-geographic reconstruction of the Rømø barrier-island has been carried out. The barrier-island initiated as a short and narrow island. The first 5000 years the barrier island sand aggraded because sedimentation kept pace with the relative sea-level rise. The last 3000 years the barrier-island prograded seawards, as the rate of relative sea level rise decreased. This aggradational-progradational development has resulted in a thick and broad reservoir sand body.

This study shows that if there is a surplus of sand, a barrier island can aggrade and even prograde during a sea-level rise, creating thick barrier-island deposits.

ORAL

Was the 4th largest Danish Lake (Mossø) once much larger?

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Water levels of freshwater lakes can lower during the course of an interglacial and sedimentation can infill basins. Besides, wave actions develop spit systems in larger lakes by longshore sediment transport that may cuts of smaller basins. Here, we show combined effects of spit development, wave actions, antecedent topography and lake level changes on the Holocene development of the present-day Danish lake, Mossø. A variety of methods were used: coring, intensive profile digging and remote sensing, geophysical mapping by seismic reflection and electromagnetic induction, and dating by radiocarbon and optically stimulated luminescence. We find that Mossø has undergone water level changes of perhaps 6 m and shore erosion has varied accordingly. The sediment supply for spit formation depended of the vigor of erosion, on wind direction and strength and on building up of the platform in front of the spits. Strong spit activity was identified during three periods: c. 10 ka, 4.2 ka and 2.5-2.0 ka. The location of spit formation was determined by changes in lake level and also local bathymetry and sediment transport patterns. Two spits connected and were reinforced by a beach barrier by 2.5 ka, today constituting the eastern shoreline of present-day Lake Mossø. The data suggests presence of an early Holocene large palaeo-lake Mossø with a 25 km east-west extent from the present-day lakes Skanderborg Sø to Salten Langsø. Confirmation of this paleo-lake requires more investigations, as later erosions at the thresholds that connects Mossø to the adjacent lakes, and to river Gudenå, remains uncertain.

ORAL

The occurrence and formation of wash-over deposits along the shores of the inner Danish Waters

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Wash-over deposits occur along many beaches fringing the inner Danish Waters. They are often located on the Holocene barrier islands and spits and they are important accumulative features with a relatively high preservation potential. The barrier islands and spits are formed by alongshore driven wave-induced currents and they partly get their sediments from adjacent eroding glacial cliffs. Wash-over fans are often present at the landward side of the barrier or spit crest and they are formed during storms under a combination of high water levels and onshore directed high waves. The high water levels are however not always caused by wind set-up during storms in the inner Danish waters. The joint probability of water levels and waves shows that under 30% of the high water levels have large waves. This means that the frequency of occurrence of wash-over fan events is far less than extreme water level statistics would suggest. In the present paper, we will address the spatial occurrence of different types of recent wash-over fans in east Denmark using satellite images and lidar observations. We will also show the driving forces behind wash-over fan formation and show the frequency of occurrence of these driving forces.

ORAL

Polar gravel beach-ridge systems – sedimentary architecture and use as climate archive (South Shetland Islands, Antarctica)

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The sedimentary architecture of polar gravel-beach ridges is presented and it is shown that ridge internal geometries reflect past wave-climate conditions.

Ground-penetrating radar (GPR) data obtained along the coasts of King George Island (South Shetland Islands, Western Antarctic Peninsula) show that beach ridges unconformably overlie seaward-dipping strata of the strand plain. Whereas strand-plain progradation is interpreted to result from swash sedimentation at the beach face under enduring calm conditions, ridge construction reflects enhanced wave action at the beach due to elevated storminess or reduced nearshore sea ice. The internal sedimentary architecture of individual beach ridges is interpreted to reflect maximum wave-runup height during the time of ridge construction. Ridges at sheltered parts of the coast exhibit either seaward-dipping beds, interpreted to result from swash deposition, or an aggradational stacking pattern being the result of wave overtopping. At exposed beaches, larger ridges develop composed of seaward- as well as landward-dipping beds. Development of individual beach ridges is seen to result from multiple storms rather than single events.

The number of individual ridges which are preserved from a given time interval varies along the coast depending on the morphodynamic setting: Sheltered coasts are characterized by numerous small ridges, whereas fewer but larger ridges develop on exposed beaches.

Data show that even ridges at higher elevation can be subject to later reactivation and reworking. This questions sea-level reconstructions based solely on morphology and dating of polar beach ridges and advise careful investigation of the stratigraphic architecture prior to sampling for dating purposes.

POSTER

Stratigraphy and sedimentary architecture of polder fills along the North Frisian Wadden Sea (southern North Sea) – potential archives of sea-level and climate variability (project SEASTORM)

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During the past millennium the North Sea coast was altered by sea-level and climate fluctuations as well as by the onset of human land reclamation. Polders, areas embanked along the coast during the last millennium, bear unique sedimentary archives of coastal evolution during different time intervals. These archives are so far unread.

As a first result of the ongoing project SEASTORM, stratigraphy and sedimentary architecture of selected polders on the German Eiderstedt peninsula are presented. The peninsula has been shaped by land reclamation since the 10th century, and since the 12th century the history of polder embankment is documented. The sedimentary successions were investigated on the basis of a sedimentological dataset (grain size, XRF, core description, X-radiographic images, and radiocarbon ages); depositional geometries were imaged by means of ground-penetrating radar. A LIDAR-based high-resolution digital terrain model allows for geomorphological investigations.

The sedimentary succession preserved in the polders documents the complex geological evolution of the area comprising multiple phases of salt-marsh growth, re-flooding and erosion. Correlation of sedimentary successions in different polders aims on overcoming local-scale effects to reconstruct changes in sea level and climate oscillations.

POSTER

Chronology and late Holocene evolution of Caleta de los Loros, NE Patagonia, Argentina

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Caleta de los Loros is a coupled beach ridge and tidal lagoon system located on the northern shore of San Matías Gulf, Patagonia, Argentina. The study is based on remotely sensed data, sediment cores and a comprehensive dataset of ages determined using optically stimulated luminescence (OSL). We present observations on the geomorphology, sedimentology and chronology of the field site and propose inferences on the drivers behind its late Holocene evolution. Caleta de los Loros is located in a topographical depression within a cliffed shoreline composed of friable sand and gravel stones. The oldest marine deposits of Holocene age formed in the inner part of the depression around 2300 yr ago. Between 1000 and 500 yr ago, an up to 4 km wide strandplain formed in the exposed southern part of the system. The tidal lagoon subsequently experienced a period of increased sedimentation between 500 and 100 yr ago. The system is hence much younger than similar coastal environments in Patagonia and shows no apparent relation to changes in the rates of mid- to late Holocene sea level change (Schellmann & Radtke, 2010). However, stages in the morphosedimentary evolution of Caleta de los Loros are concurrent with proposed changes in humidity and wind regime for northern Patagonia as well as with changes in human occupation and subsistence strategy (Favier-Dubois and Kokot, 2011; Marcos et al., 2012). Caleta de los Loros presents a new example of the potential importance of sensible environmental changes for the rapid and non-linear development of coastal systems.

very low detail. The aim of the study was to 1) develop a procedure for processing topobathymetric lidar data and generating Digital Elevation Models (DEMs) in coastal zones, 2) automatically classify morphological units, and 3) investigate the potential of mapping shallow water vegetation. We show results from two locations with different environmental settings: the Knudedyb tidal inlet system in the Danish Wadden Sea and Rødsand lagune in the inner Danish waters.

16.3. Lidar in Geomorphology

ORAL

Mapping morphology and vegetation in shallow water using topobathymetric lidar

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The coastal zone is under pressure from human exploitation and climate change, which leads to a need for sustainable coastal zone management – a challenge which requires high resolution mapping and monitoring. Historically, there has been a gap of information in shallow water, however, the emerging technology of airborne topobathymetric lidar has proven capable of simultaneously capturing topographic and bathymetric elevation information, resulting in a seamless coverage of the land-water transition zone. The new technology also provides a potential for detailed identification and classification of shallow water morphological units and vegetation – which was previously impossible to map, or at best it was mapped in

ORAL

Morphologic mapping and monitoring of sediment transport using high resolution topobathymetric Lidar in manifold geomorphic settings: Examples from Isar river in Munich and Wadden Sea in Denmark

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Fluvial and coastal/tidal environments are valuable ecosystems under pressure due to globalization and/or climate change. Their detailed mapping is required to manage river courses and coastal zones in a sustainable way. Traditionally, the transition zones between land and water were difficult or impossible to map and investigate in high spatial resolution due to challenging environmental conditions. The new generation of airborne topobathymetric LiDAR potentially enables full-coverage and high-resolution mapping of land-water transition zones. Repeated surveys provide the opportunity for geomorphologic mapping, monitoring and quantifying fluvial and coastal sediment-

transport. We first present results from two repeated topobathymetric surveys along the Isar river in Munich, Germany, to quantify and map river-bed changes related to a large flood (June 2013). We evaluated river-bed elevation differences between the survey before (October 2011) and after (July 2013) the flood yielding elevation differences of several decimeters to meters due to erosion and sedimentation of bed-material. The detailed analysis provides new possibilities to better manage inner-city river structures and support future planning on restoration along the Isar river. In a second study, we performed a topobathymetric LiDAR survey in the Knudedyb tidal inlet-system in the Danish Wadden Sea (April-May 2014). This dataset was used for detailed geomorphic analysis on the intertidal drainage-network and bedforms, and was further compared to a topographic LiDAR survey (2011) to evaluate and quantify morphodynamics, e.g. sediment-transport directions. Our results demonstrate that high resolution topobathymetric LiDAR is an efficient, widely applicable tool to monitor and measure fluvial and coastal sediment-transport and geomorphic processes.

ORAL

Active rock glaciers at sea level in Finnmark, Northern Norway?

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Rock glaciers are geomorphological expressions of permafrost presence. Their state of activity indicates occurrence of current or former permafrost. A series of rock glaciers emerging at sea level have been identified in Nordkinnhalvøya, Northern Norway, and have earlier been classified as relict landforms (Lilleøren & Etzelmüller, 2011). However, a recently published permafrost model of the Nordic countries (Gisnås et al., 2016) simulates permafrost at similar elevations elsewhere in Finnmark, but mainly in mires as palsas.

We have now surveyed one of these rock glaciers, situated in Ivarsfjord, by repeated drone imagery (2016-2017) and Terrestrial Laser Scanning (2017). Digital elevation models (DEMs) were compiled from aerial photos from 1975, 1982 and 1992, and a network of miniature data loggers was employed over the rock glacier surface to evaluate near surface temperatures. Two short ERT (Electrical Resistivity Tomography) profiles were established from the top to the front slope of the rock glacier.

Our first results indicate both thermokarst development and front position advances since 1975. This implies that the rock glacier is active, but currently degrading. The ground surface temperature network indicates above 0˚C temperatures as an annual mean. We therefore believe that permafrost can be present even at coastal sites in Finnmark in special settings, indicating sporadic (palsas) to more wide-spread (rock glaciers) permafrost, but in a state of degradation at present.

With large-scale permafrost thaw occurring in the Arctic at present, this area could serve as a time-space substitute of High-Arctic landscapes like Svalbard or Siberia in a changing climate.

ORAL

Better Visualisation of Air-borne Laser Scanning for geomorphological and archaeological interpretation

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Digital elevation models derived from high-precision Air-borne Laser Scanning (ALS or LiDAR) point clouds are becoming increasingly available throughout the world. These elevation models presents a very valuable tool for locating and interpreting geomorphological as well as archaeological features in the landscape. The elevation models are, however, not always

directly useable, because the variations in elevation in the models often are orders of magnitude larger than the features of interest, which makes these hard to see. It is therefore usually necessary, and always advisable, to enhance (transform, improve, manipulate) the visual appearance of the elevation model, so that the features of interest are more clearly shown. In this paper, we discuss the usefulness of several advanced visualisation techniques for locating and interpreting a.o. fossil beach ridges, paleo-lake shorelines, sub-glacial meltwater courses, Iron Age Celtic field boundaries, and various other geological and archaeological phenomena under Danish conditions.

POSTER

EcoMap Project: Baltic Sea environmental assessments by innovative opto-acoustic remote sensing, mapping, and monitoring.

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Remote sensing and classification of the seafloor are required to obtain a comprehensive view on the marine environment. It allows for analysing spatio-temporal dynamics, monitoring of natural seabed variations, and evaluating possible anthropogenic impacts, all being crucial in implementing marine spatial planning for sustainable use of the sea that leads to the economic growth of the region.

The EcoMap project will develop a remote sensing catalogue documenting the feasibility of latest opto-acoustic methods for improved Baltic Sea habitat monitoring. This catalogue will be developed in close co-operation with authorities to meet their requirements and will allow stakeholders with different interests to quickly judge which remote sensing method is ideally suited for respective monitoring tasks of specific habitats. EcoMap commenced in September 2017 and will continue for three years. The project is part of the BONUS Programme, co-funded by national research funding agencies of the three project partner countries Germany, Poland and Denmark. .

16.4. Open session in Geomorphology

POSTER

Landslides in northwest Iran: a case study on the landslide hazard zonation in Baleghluchai watershed in Ardabil using AHP Fuzzy method

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Landslides and slope instabilities are among the important natural hazards, which cause human and financial casualties and loss of economic resources every year. The northwest of Iran is prone to the occurrence of landslides due to its mainly mountainous topography, complex geology, abundance of tectonic activities and earthquakes and variable climate. These hazards mostly occur in natural slopes or those manipulated by human. This contribution includes a case study on the landslide potential zonation within the Baleghluchai watershed in NW Iran. First, the main factors including the slope and its direction, geology, soil, climate, distance from the road and river and land usage were determined. The method of current investigation was Fuzzy AHP in the GIS environment, based on which, after preparing data layers using the above-mentioned parameters and giving weights to them in the GIS

environment, the landslide potential map, as well as classification was carried out by Fuzzy AHP method.

According to the final zonation map, the watershed was divided into 5 classes. Results showed that the largest part of the watershed (32.21%) has low landslide potential, while about 13.5% of it has very high potential. Areas with very high and high landslide potential (327.39 km^2 area) are mainly located in the northwest of the watershed, with some small areas distributed in the south and east, while areas with very low and low potential (504.06 km^2) are mainly found in the central to northwestern and southern parts of the watershed.

17. Education, preservation and outreach

17.1. Education, communication, preservation and Geoheritage

ORAL

Geology Day in Sweden, lessons from 17 years

Nelly Aroka[1]
[1]*Geological Survey of Sweden*

Geology Day is a Swedish non-profit organization. Our aim is to spark curiosity among the public and to highlight the benefits of basic knowledge of geology and earth sciences to society. Every year since 2001 our organizers invite the public to take part in a nationwide celebration of geology in September. At the 17 year mark we ask ourselves; what have we learned, what are our challenges and how do we continue working to promote earth sciences throughout the year?

ORAL

Challanges in conveying geology to society. - Examples from Danish landscapes traced by a Norwegian geologist, in order to create curiosity for geology and explain geological processes.

Thorbjørn Kaland[1]
[1]*University of Bergen*

Though schools at all levels are teaching geology and science, we are facing frequent lacks of knowledge leading to misunderstanding of basic geology.

Teachers, journalists, bureaucrats and politicians may need to upgrade knowledge in geology.

Geologists need to meet the challenge and share their interests for earth science.

But how?

The best way of making people search for the answers of everything's genesis, is to take them out of their rooms, and rediscover nature.

Scandinavian and German tourists drive through Denmark to see everything, - but geology. They disregard the most beautiful jewels of Denmark.

Most sites have got a geological story to tell.

How may we make the local society understand their local landscape? New visual tools may bring back the ice cap with its drain and movement.

How may social media tell more than any geologist?

Trolltunga is a cliff in Western Norway, lying lonely for 10.000 years.

After a few foreign hikers dropped into the site and posted their picture on Facebook, Trolltunga = Norway. Yearly more than 100.000 hikers walk the 9 hour mountain walk to take their selfie at Trolltunga.

This story reveals some interesting challenges:

- Where do we find "Trolltungs"?
- Do we really want to share them with the rest of the world?
- How can local community benefit the site?
- How may we plan for massive traffic in a sustainable way?

The presentation will show examples from Danish landscapes, with the objectives to create curiosity for geology and geological processes.

ORAL

What do we actually teach students in the field?

Rie Hjørnegaard Malm[1]
[1]*University of Oslo*

Fieldwork has a central position in the geosciences and is typically an integrated part of the study programme, where it is considered by many as a crucial part of the learning process and linked to the process of becoming a professional geoscientist (King, 2008; Raab & Frodeman, 2002). Fieldwork is suggested to be an effective learning arena to teach the scientific method and reasoning (Mogk & Goodwin, 2012). Educational research shows great opportunities for learning, but how do we know what the students learn? And how does our teaching in the field affect the students' opportunities to learn?

In this piece of research I follow students closely in the field and explore how and what they learn. By seeing teaching from the students' perspective I am able to show in detail how the organization of teaching has an influence on the learning potentials for the students.

When the students are given the freedom to explore and collect data on their own they experience a learning situation that simulates an authentic research situation. In this process it proves to be crucial that the students are allowed

to make mistakes and are given enough time to discuss their data collection. If we only show students how to work in the field great learning opportunities are lost. I present results from my research on students working in the field in mainland Norway, Svalbard, the Orkney Islands, and the Spanish Pyrenees and discuss how we can construct teaching in the field that promotes learning.

ORAL

Generalized bedrock map of Finland and related material

Perttu Mikkola[1]
[1]Geological Survey of Finland

In most countries the laymen's typically have limited understanding of geological concepts and processes. Reasons behind this are multiple, but one recognised factor, at least in Finland, is the lack of suitable teaching material that could be used in elementary and high schools. To answer this need Geological Survey of Finland (GTK) produced in 2016 a generalised 1:1 000 000 scale bedrock map (Mikkola et al. 2016), which is based on the same database as the "professional" version compiled by Nironen et al. (2016). The generalisation was done in association with geography teachers to ensure that for example terminology used is understood by the target group. Although the map is available as a print ready pdf-file, the most important distribution channel is an online map service. In this service user can open short information boxes by clicking on the map objects. These include for example the age of the formation, its distribution in Finland, in what kind of environment it was generated and one or two photos of representative outcrops or samples. Readymade slide packages on the larger geological entities, e.g. the Archean in Finland, were also distributed to the geography teachers. The idea in these was that individual teacher could use the one, or ones, containing information about the bedrock in his/her area. The produced material is naturally highly usable in popularising geology to any non-professional target group.

ORAL

Rock Fossils on Tour – Zoological nomenclature at its coolest!

Jesper Milàn[1], Mats E. Eriksson[2], Achim G. Reisdorf[3], Esben Horn[4] and Rune Fjord[5]
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Zoological nomenclature, the science of naming extant and extinct organisms can seem like a dull field with little public appeal. However, a new travelling exhibition "Rock Fossils on Tour", dealing with just that theme, has managed to attract a wide international audience and reach far beyond the normal palaeontological circles, and straight into the heart of rock fans!

The exhibition portrays fossils that are named after rock, punk, pop, jazz and heavy metal stars, and features exclusive lifelike sculptural reconstructions of the animals. In addition, the musicians who lent their names to science are presented alongside amusing anecdotes from the scientists responsible for this unusual etymology. Many of the items have been signed by the rock stars. The exhibition has gained extensive attention in the media and news groups worldwide, and has been very well received by both music and fossil fans in the six European museums it has visited so far.

This is the story of how the exhibition came to be, from a spontaneous capricious idea, its rise to success, and the plans for its future expansion.

ORAL

Knowledge Exchange for Resource Management and International Trust – Aleppo case study

Rodney Stevens[1], Mohamed Alkridi[1] and Michael Kouro[1]
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The KERMIT project deals with research and capacity-building targeted at two, related groups with academic backgrounds: 1) refugees in Europe and 2) local populations in the stressed regions from which people are fleeing. Although the long-term focus is aimed at raising the competence and capacity for sustainable resource management in stressed regions, the refugees with academic backgrounds involve both new challenges and opportunities with related objectives. These refugees need complementary study to adapt their educational background to European conditions, and at the same time they can provide valuable expertise and knowledge of specific regions and general conditions where resource conflicts and management have increased migration. Utilizing the connections to the local academic community and the existing infrastructure, project activities explore the dual and complementary goals to increase human capacity, thereby strengthening the hope for positive, short-term and long-term developments for both groups.

Cooperative projects and educational activities with partner institutes in stressed regions are the distinctive profile of the KERMIT project. These activities build upon our international networks and the multidisciplinary research from the cooperative projects, utilizing earlier results and emphasizing the exchange activities for knowledge transfer in all directions. One on-going case study deals with water-management strategies for Aleppo, Syria, and considers the increased pollution loading on agricultural areas along the river due to continued irrigation during the war while the water-treatment plant has not functioned. In addition, urban pollution sources, transport pathways, and recipients are modeled using system structural analysis and relative risk ranking methods.

POSTER

GIS - an appropriate tool for undergraduate field mapping?

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Geographic information systems, GIS, are key tools in the industry and geological surveys, increasing the efficiency of mapping and data collection in the field. Though GIS usage is widespread, there is little focus on GIS in the field parts of the geology program at the University of Oslo. The focus lies on learning basic field skills and traditional mapping methods. We are often met with the argument that we need to hold a basic knowledge of traditional methods before advancing to more complex digital systems. Here we report use of Arcmap Desktop to digitally map an area in the inner Oslofjord as part of our bachelor capstone course. To implement ArcMap

data files were created to record mapping observations, together with DEM/DSM files constructed from laser data. Computer files were interpreted and analysed during fieldwork to find areas where more observations were needed. This resulted in a high learning outcome in use of ArcMap. Comparing traditional mapping to GIS

mapping highlights advantages of using digital tools. Data collection increases greatly in speed, quantity and quality. Potential downsides include battery life of devices and vulnerability to weather. Both objections are easily mitigated by using water proof cases and power banks. Digital mapping greatly improved the quality and precision of our map and geological understanding of the field area. We conclude that GIS is a teaching aid that should be utilized in field work, having the potential to improve the geological understanding of students and prepare them for the work life.

POSTER

Soapstone from Nuuk: Communicating scientific and commercial value of a local resource

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The Soapstone from Nuuk project bridges the gap between scientists and people by anchoring research into society and showing its relevance to daily life. Our goal is to inform the citizens of towns and villages in Greenland about the potential for small-scale mining of soapstone and to engage local community in using the opportunities soapstone holds; for small-scale mining, geo-tourism and local rock collectors and for archaeological investigations. In order to engage a broad spectrum of the population in the project we decided to work on 3 communicative levels: i) A practical level - we hosted an in situ citizen science workshop to teach the participants how to see the landscape and the rock formations in the Nuuk area through the geologists' and archaeologists' eyes; ii) An engaging level - we hosted exhibitions and a public event with the purpose of showing different possibilities of making a living out of soapstone as well as communicating this message through the press; iii) A teaching level - we have communicated the results of the project through talks, a film and a website about the project. By mixing traditional scientific outreach with elements of involving communication and a focus on direct relevance, we reached new types of audience. By focusing on direct relevance and by involving several stakeholders representing authorities (municipality level), business (business council and business support), art (museums and artists) and tourism (tourism organisation and operators), we have created a better understanding of how to use our research among locals.

POSTER

Stevns Klint, Denmark – UNESCO World Heritage Site and how to conduct geological research at the site in the future.

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The UNESCO World Heritage Site, Stevns Klint, in the eastern Denmark represents the best exposed Cretaceous–Tertiary boundary section in the world. The boundary clay layer is easily recognizable beneath a pronounced topographic overhang, which separates the soft Cretaceous chalk from the overlying, harder Paleogene limestone. This makes the boundary layer visible even to the inexperienced eye. Furthermore the exceptional complete marine fossil record present at Stevns Klint makes the site among the best localities worldwide for studying marine biotic turnover across the K-Pg boundary, and the discovery of the iridium anomaly in the boundary clay layer in 1978 made the site a key locality in the scientific debate about an impact vs. volcanism related cause for the End Cretaceous

extinction. The management of Stevns Klint as UNESCO World Heritage Site is developed in order to secure protection of the site in a manner that encompasses the opportunity for sampling for scientific purposes and encourages continued research activity. According to the agreed guidelines sampling in the cliff face for scientific purposes may be permitted by the local geological museum, Østsjællands Museum. Who will help, ensure that the sampling are constructed in a manner that both ensures the scientific purpose of the sampling, and minimizes the impact on the protected cliff site.

Østsjællands Museum invites all interested researchers to contact the museum to obtain permits for sampling, and also to participate in the effort to communicate the scientific importance of the site to the general public.

POSTER

GEARS: Geological heritage in inner Scandinavia

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The goal of the project is to record, manage and create values based on the region's common geological heritage. Achieved results will be a common framework for geological surveying, registration and descriptions of geo resources in selected areas in Indere Scandinavia. Other results are the testing of new methods for information on geological heritage through the use of new dissemination technology (VR / AR technology), obtaining material about the geology of the region aimed at the public and residents and organizing an international seminar on geological heritage.

Expected effects are increased local and regional awareness of the importance of geological heritage as a resource for tourism and business development. Increased cooperation between tourism and nature management, increased awareness and pride of local landscapes, as well as shared cultural and historical identity. Better environmental management, better and new products for the tourism industry, better tourist experiences, development of new tourist sites and better education in the region.

In the interreg project GEARS (2017-2019) ,are SGU project owners and NGU have project management. In addition, several other regional institutions and companies from Norway and Sweden participate in the project.

Interreg project Sweden and Norway (2017-2019): SGU is project owner, NGU is project manager In addition, several other regional institutions and companies from Norway and Sweden participate in the project.

POSTER

Detailed mapping of the polydeformed Gressholmen and Rambergøya islands, Oslo Rift - a capstone course project at Oslo University

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The small islands of Gressholmen and Rambergøya, situated in the Inner Oslo Fjord within the Oslo Rift, were mapped in 1:5000 scale as part of the bachelor capstone course at Oslo University. The islands comprise mid-Ordovician to earliest Silurian sediments, recording the local expression of the global upper Ordovician regression and early Silurian transgression. The rocks are dominated by shales, nodular shales and limestone, locally fossil rich. In the Silurian, the sequence formed part of the Caledonian fold and thrust belt. Repetition of layers and calcite filled thrusts (locally with slickensides) are common, indicating top-to-southeast displacement. The islands themselves form a large scale overturned southeast verging anticline with numerous parasitic folds of different orders. The compressional structures

are overprinted by north-south trending sub-vertical extensional faults, commonly with sub-vertical slickenlines. Dikes of different compositions, mainly striking north, are present on the islands. Both the faults and the dykes are parallel to the nearby eastern Oslo rift margin, and are consistent with east-west Permian extension associated with its formation. The limited extent of the study area and the complex tectonic evolution of the islands make them highly suited for undergraduate mapping projects. In particular, successful mapping of the island requires integration of the various sub-disciplines that make up the bachelor program, including sedimentology, paleontology, mineralogy-petrology and structural geology, within a tectonic framework. The mapping project provides a natural laboratory for revising, testing and developing field skills in an authentic context that prepares students for independent geological work in their later careers.

POSTER

Field-based education in the high Arctic – how digital tools can support active learning in Geology

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The University Centre in Svalbard, UNIS, is Norway's national high Arctic research and education hub located in Longyearbyen, Svalbard at 78°N. In Arctic Geology UNIS offers BSc, MSc and Phd- level courses and semester packages (30 ECTS) in geology and physical geography. All courses at UNIS include a significant field-based component, and the natural environment provides the "lab" facilities for the courses. Even in this location Arctic field work can be logistically demanding. Similar to any program in geology, it is beneficial to increase the students' exposure to hands-on and realistic exercises, in order to prepare them for field work. Increased exposure also allows students to continue practicing field skills after returning to the classroom.

We are active pioneers of emerging technologies such as virtual outcrops and virtual reality as relevant tools to be used in the classroom. Use of tablets in the field provides access to data, models and previous work (including classroom-based preparation exercises) during the field work, and allows for a more coherent learning experience between field- and classroom time. The aim of the digitally supported learning environment is to increase student learning and increase the use of formative feedback. In addition it allows us to do hands-on, field relevant teaching year-round, including during the 4 month long dark season.

In this contribution we share our experiences of using these emerging technologies in a harsh Arctic environment in the framework of the recently revised BSc package offering at UNIS using active learning.

18. Other topics

18.1. Other Sessions

ORAL

Beyond Classification – Managing Resources Sustainably

Sigurd Heiberg[1], Per Blystad[2], Kerstin Brinnen[3], Charlotte Griffiths[4], Tom Heldal[5], Janne Hokka[6], Erika Ingvald[7], Kaj Lax[7], Hannu Makkonen[6] and Harikrishnan Tulsidas[4]
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Successful resource management requires relevant information on the resource base, adequate framework conditions set by Governments and society and enterprising capacity, also termed integrative dynamic capabilities in the public, private and financial sectors. We begin by addressing how the United Nations Framework Classification for Resources (UNFC) is built to house resource inventories and the guidance provided for applying this to minerals in Finland, Norway and Sweden. The information is carried by the project, not the deposit. Focus is on the quantities that the project will yield in the form of sales and non-sales production and how much will be left in the subsoil. Inventories are constructed by categorising separately the economic and social conditions for development, their industrial status and the uncertainty with which the quantities are defined. The projects themselves carry other important management information such as time series of production, costs, labour etc. The classification is mapped (bridged) to other key classifications such as the CRIRSCO template, the SPE PRMS and the new Russian classification for oil and gas (RF2013). This facilitates the reporting of a UNFC inventory in these classifications.

Being a project based resource classification, the UNFC has been adapted not just to fossil energy and mineral resources, but also to renewable energy, including geothermal, and injection projects for CO2 storage and other purposes.

The presentation will open for a discussion on how best to develop guidance for the use of the UNFC in the Nordic region for the commodities it has been developed for.

POSTER

DETERMINATION OF PALAEOPRODUCTIVITY USING CARBON QUALITY IN AN END MEMBER MIXING MODEL

Justin Fadipe[1] and Maarten Felix[1]
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To improve our understanding of the global carbon cycle as well as the impact of anthropogenic contributions to this cycle, it is important to understand the link between palaeoproductivity and the amount of carbon that is ultimately buried. There has been much debate regarding the fate of organic matter (OM) during its transition to the sea floor, and about the quantification of OM remineralisation and preservation within subaqueous sediments.

This study applies a kinetic model with the aim of quantifying the decay of organic matter in both the water column and during the early stages of sedimentation. Laboratory derived decay rate constants for different constituents of organic matter together with the duration required to settle through the water column, were used to produce a quantitative estimate of carbon flux to the sediment. The approach demonstrates its validity when compared to measured trap data from literature. In addition, a comparison between the modelled flux and empirical equations showed similar outputs for both. The model results also compared well with (more limited) measured sediment column data.

Estimating palaeoproductivity utilising the proposed kinetic model, necessitates the distinction of the relative contributions of marine and terrigenous sources to total organic carbon (TOC). Bulk geochemical measurements of TOC and hydrogen index (HI) are used in an end member mixing model, whereby the degraded marine end member values are obtained by applying the kinetic model. Application of the kinetic model to carbon quality provides reasonable estimations of degraded HI end-members.

POSTER

Surface kinematics of sorted circles using Structure from Motion photogrammetry in Juvfonne and Juvasshøe

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Sorted circles are a form of periglacial patterned ground that are recognized by characteristic geometric shape. Sorted circles are believed to have an important function as a carbon reservoir in high latitudes.

This research project is looking at sorted circles close to Juvfonne and on Juvasshøe, Norway, using Structure from Motion photogrammetry (SfM). The aim of this study is to understand the changes of sorted circles during one melting season at two different locations. Changes in the circles will be traced by tracking features in the orthoimages.

POSTER

Frequency-magnitude analysis for landslides in Sogn og Fjordane

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The county of Sogn og Fjordane in Norway has a climate and topography which makes it vulnerable for debris avalanches, debris flows and slush flows. The recently established landslide forecasting service at NVE (www.varsom.no) is able to predict their spatial and temporal occurrence. However, a better understanding of these processes, their spatial distribution, dimensions, mechanisms and dynamics is needed to improve the performance of the service, especially at local scale.

The main objective of the study is to investigate if the landslide warning for the county can be improved by considering the landslide magnitude. The analysis implies mapping of landslides and an analysis of meteorological and sedimentological conditions of which the events were triggered from. The analysis focus on landslides in soil (debris avalanches, debris flows, slush flows) from 2011 and throughout 2017. A sample from the landslide events will be visited in field to perform analysis on landslide volume, thickness of deposit and some other landslide parameters.

The study will also implement an analysis of the events that had a corresponding landslide warning level associated with it. A validation will then be performed to compare the predicted outcome with the resulting outcome of the meteorological event. This part of the master thesis might clarify challenges the landslide warning service has today. It may also enlighten improvements or adjustments that is needed to increase the landslide warning service accuracy.