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# ABSTRACTS

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# ORAL ABSTRACTS

# Direct dating of marine sediments using optically stimulated luminescence techniques: Insights from ODP cores 658B and 659A.

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Chronologies for marine sediments are usually constructed by tuning marine proxies for global ice volume ($\delta^{18}O$) to the well understood variations in the Earth's orbit, by the identification of event horizons (e.g. tephra or biostratigraphic markers) and/or by radiocarbon dating. However, these techniques are not universally applicable. Optically stimulated luminescence dating (OSL) is potentially widely applicable to marine cores and may offer significant advantages over more conventional chronometric techniques. However, methodological considerations regarding the application of OSL techniques have yet to be systematically explored. Using material from Ocean Drilling Program (ODP) cores 658B and 659A, we assess the applicability of OSL dating to deep ocean sediments. For these cores, severe uranium-series disequilibrium is found, but the cause and character of this disequilibrium is spatially and temporally variable. Uranium-series disequilibrium causes the environmental dose rate to vary over time, and an iterative dose rate calculation is required to generate accurate ages. For the last glacial-interglacial cycle, these calculations yield OSL ages which are in good agreement with independent age estimates, suggesting that the application of luminescence dating techniques to deep-sea sediments merits further investigation.

# The history of charge deposition in quartz and feldspar and its effect on luminescence production

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Luminescence production models invariably assume charge neutrality during irradiation and stimulation so there is always an equal number of trapped electrons and holes. However, there is macroscopic evidence from the gemstone industry (Nassau, 1985) and from scanning electron microscopy (e.g. Vigouroux et al., 1985) that quartz and feldspar may acquire a net charge during irradiation with electrons. We have previously shown that charge imbalance is predicted for 50 µm spherical grains in the laboratory and in nature (Autzen et al., submitted) and argued both from modelling and using experimental evidence that this can affect luminescence output. In this work, for the first time we couple the output of a radiation transport model (GEANT4) to a standard luminescence production model (Bailey, 2004; Pagonis, 2007); this coupling assumes that all electrons and holes in a grain have some probability of being trapped, independent of whether they result from the creation of an electron/hole pair or whether they are injected into the grain from the external radiation field. This model is first used to predict dose deposition, ionisation rate and charge imbalance for a number of geometries relevant to luminescence dating, and for a range of grain sizes. We then use the luminescence model to show that the relationship between dose and luminescence is significantly dependent on grain size, mineralogy and irradiation history. These predictions are supported by experimental observations that the apparent beta dose rate to quartz and feldspar is significantly different (Hansen et al., 2018) and by new results showing that the dose-dependent luminescence output in the MGy region varies with incident electron energy.

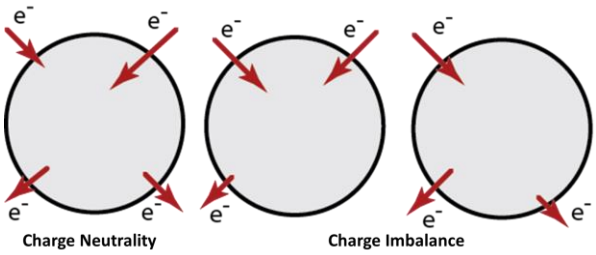


Diagram illustrating different situations of charge deposition in grains.

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# A NaI(Tl) scintillator-based gamma spectrometer for the determination of burial dose rates in OSL dating

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A recent inter-comparison study (Murray et al., 2015) has brought attention to variability in the measurement of dose rate between luminescence dating laboratories. Part of this variability indicates the difficulties in homogenising and dissolving samples so that the <500 mg used in e.g. ICP-MS and NAA is representative. In order to achieve a representative and thus more accurate dose rate, high resolution gamma spectrometry is an obvious alternative because it can measure samples 100-1000 times larger. However the instrumentation is low-throughput, high capital and running cost, and requires skilled personnel to maintain operation over many years.

A recent study (Bu et al., 2018) revealed that traditional NaI(Tl) scintillator-based gamma spectrometers are also able to accurately determine dry dose rates in the natural geological samples, at a considerably lower cost. Based on a 3"×3" NaI(Tl) scintillation crystal, they reported minimum detection limits (MDL) for $^{40}$K, $^{238}$U, and $^{232}$Th activity concentrations of 25, 4.8, and 2.5 Bq/kg, respectively; these data were obtained using a 250-300 g sample and an improved 3-window spectrum analysis approach. Even though these MDLs (especially for $^{40}$K) lie about or below those found in most natural sediments, lower MDLs, especially for $^{238}$U, and $^{232}$Th would be desirable to achieve lower uncertainties in the derived burial dose rates.

In this study, we investigate the potential of a new approach, i.e., a full spectrum analysis (FSA) method (Hendriks et al., 2001) to reduce the MDLs. The FSA uses a weighted least-square regression to fit three calibration standard spectra ($^{40}$K, $^{238}$U, and $^{232}$Th) to the unknown spectrum (after subtraction of an appropriate background spectrum). Thus the FSA approach uses considerably more statistical information from each spectrum, and as a result MDLs are reduced down to 12 Bq/kg, 0.7 Bq/kg, and 0.6 Bq/kg, respectively for $^{40}$K, $^{238}$U, and $^{232}$Th, between 50 and 85% lower than those obtained with the 3-window approach. The analyses compare favourably with reference values from high-resolution HPGe gamma spectrometry (Murray et al., 2018). With this new approaches, 19 natural samples have been measured and analysed, and all activity concentrations lie within 7% of the reference values; the average ratio of dose rates measured on our NaI(Tl) scintillation spectrometer to those from HPGe spectrometry is 1.033±0.009 (n=19).

We conclude that this simple scintillation spectrometry system featuring the FSA is a useful alternative laboratory method for accurate and precise determination of burial dose rates at a significantly lower cost than high resolution spectrometry. This, combined with the large (and so more representative) sample size makes it a strong competitor to other analytical methods used in OSL dating.

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# A source of variability in single and multiple grain measurements of equivalent dose

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Accurate measurements of equivalent dose ($D_e$) underpin the use of luminescence methods for retrospective dosimetry and dating. In the last 20 years new protocols have been introduced for measurement of quartz and of feldspar, almost entirely based upon single aliquot approaches. The ability to make replicate measurements of $D_e$ using different aliquots derived from a single sample made it possible to examine the distribution of $D_e$ values. Many researchers have studied the spread of these $D_e$ values and either used the pattern to make inferences about the sample (such as the extent to which it was bleached at deposition, the impact of microdosimetry, physical mixing or bioturbation), or have applied statistical models to extract an appropriate value for age determination.

A consistent theme of research throughout the last 20 years has been a debate about the extent to which variations in $D_e$ can be attributed to differences in the trapped charge population in the sample (i.e. the dose) and the extent to which the differences arise from aspects of the protocol or the instrument used for measurement. Instrumental causes of variability in $D_e$ are already known (e.g. the inhomogeneity of some beta sources used for irradiation, Ballarini et al. (2006)). However, other instrumental sources are not well documented and are often simply grouped under the collective heading "Instrumental uncertainty" (Duller et al. 2000; Thomsen et al. 2005).

This presentation describes one source of this instrumental uncertainty, and demonstrates that the magnitude of this effect varies between different readers. A simple method of assessing the magnitude of this effect is described, coupled with a means of correction to remove this source of uncertainty from datasets. The variability observed is difficult to detect as part of routine instrument operation, but will impact both multiple grain and single grain datasets if uncorrected.

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# Late Quaternary landscape change around the Indus Civilisation site Rakhigarhi

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A range of palaeoclimatic and palaeoenvironmental evidence suggests the Asian sub-continent experienced phases of arid-humid alterations on centennial and millennial scales during the Holocene, which were set against a backdrop of insolation-driven weakening of the Asian Monsoon system. These oscillations would have affected fluvial regimes on the plains of northwest India, which were occupied by the Bronze Age Indus Civilisation during the mid-Holocene. It has been suggested that a decline in regional river systems contributed to the decline of the urban Indus at ~4 ka (e.g. Giosan et al., 2012, Singh et al., 2017), although in a recent study Orengo and Petrie (2017) identify a complex network of buried channels on the Sutlej/Yamuna interfluves, and Durcan et al. (in press) have highlighted complexity in the response of regional geomorphic systems to climatic/environmental change. Further work is required to understand the spatial and temporal dynamics of regional hydrological systems in order to assess the importance of changing climate and/or environment in the decline of the Indus Civilisation

Rakhigarhi is the largest and potentially most important Indus Civilisation site in northwest India (Singh et al., 2009). Located in Haryana state in northwest India, the site is at least 50 km south of the Ghaggar-Hakra palaeochannel, and closer to a much smaller, separate and presumably monsoon-fed palaeo-system. There is, however, a lack of geomorphological and chronological data confirming the existence and timing of this river system, which Singh et al. (2017) cite as a significant unresolved issue, meaning that the relationship between Rakhigarhi and its surrounding landscape is unresolved. This paper presents optically stimulated luminescence dates from palaeochannel sediments and associated dune deposits in the area around the Rakhigarhi site to reconstruct Holocene geomorphological and palaeoenvironmental change. This will allow a better understanding of the relationship between changing landscape and archaeology in the area around Rakhigarhi.

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# A reassessment of the OSL geochronology for the Erdut loess-palaeosol profile, Croatia

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Loess-palaesol sequences provide one of the most detailed and well-preserved terrestrial archives of environmental and climatic change. However, to fully utilise and interpret the information recorded in loess complexes, a robust geochronology is required. The development of the post-infrared infrared stimulated luminescence signal (pIR-IRSL) for dating (e.g. Thomsen et al., 2008; Buylaert et al., 2009) has provided an opportunity to investigate palaeo-environments and climates extending beyond the last interglacial. There is particular scope for its application to loess-palaesol sequences because they often cover multiple glacial-interglacial cycles, providing an opportunity to revisit previously investigated sites and extend the dated age range. In Europe, loess–palaeosol sequences in along the Danube River hold some of the most complete and longest terrestrial records.

This study presents a reassessment of the chronology of the Erdut loess-palaeosol complex in Croatia. Previous luminescence dating at the site utilised additive dose protocols and the $IR_{50}$ signal for the dating of the fine grain polymineral fraction (Galović et al., 2009), and suggested an age range of 19.8 ± 2.1 - 61.5 ± 6.2 ka for the upper part of the profile. In this study, we measure the $pIRIR_{225}$ signal using single aliquot regenerative dose protocols. Commonly performed tests to assess the reliability of the signal, such dose recovery, residual, and fading tests were also carried out. Fading tests suggest an average fading rate of ~2.15 %/decade for the $pIRIR_{225}$ signal, and $pIRIR_{225}$ ages were compared with quartz OSL ages in the upper part of the sequence. Dating using the pIRIR225 signal suggests that the penultimate glacial-interglacial cycle is preserved at the site with ages ranging between 74.6 ± 5.2 and 194.4 ± 11.66 ka. These results allow a reassessment and reinterpretation of a suite of environmental proxies in the context of the regional loess records.

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# Preliminary investigations on the application of infrared photoluminescence (IRPL) to sediment dating

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Prasad et al. (2017) demonstrated that Stokes-shifted near-infrared (NIR) emission allows direct, non-destructive measurement of trapped electron population in feldspar; they identified a single, broad IRPL emission peak at ~1.30 eV (955 nm) using laser excitation at ~1.40 eV (885 nm). Subsequently, Kumar et al. (2018) have shown that there exist two IRPL emissions at ~1.41 eV (880 nm) and ~1.30 eV (955 nm) by shifting the laser excitation energy to ~1.49 eV (830 nm). The peaks are well resolved at low temperature (7K) but merge into one broad peak at room temperature (295K). The two emissions can be discriminated in the Risø TL-OSL reader using pulsed laser excitation, and IRPL detection through a combination of bandpass interference filters (880/10nm or 950/50nm) and appropriate NIR photomultiplier tubes (Kook et al., 2018). What still remains to be tested is suitability of the two IRPL emissions for sediment dating.

Since IRPL is non destructive and has high sensitivity because of repeated excitation of the same trapped electron, it is possible to integrate it into the existing SAR protocols developed for infra-red stimulated luminescence (IRSL) and post-IR IRSL (pIR-IRSL); this allows both simultaneous dose measurement using IRPL/IRSL/pIR-IRSL as well as monitoring of changes in the trapped electron population during different SAR cycles. Here we present a combined IRSL-IRPL SAR protocol and discuss the results obtained from a variety of K-feldspar sediment extracts having independent age control. We test the potential of IRPL by examining the dependence of equivalent dose on emission energy (1.41 vs. 1.3 eV), excitation energy (~1.49 vs. ~1.40 eV), and the measurement protocol. Finally, we discuss the pros and cons of IRPL dating.

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# Establishing OSL chronologies for drill core sediments to infer the avulsion history of palaeo-Yamuna River in northwestern India

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Discussion concerning an eastward avulsion of the Yamuna River in northwestern India to its present course has been ongoing for some time but this discussion has lacked chronological constraint. The avulsion has, *inter alia*, been linked to the decline and abandonment of Bronze-Age Indus valley urban centres ~4.2¬3.9 ka ago; a westward-flowing Yamuna has been postulated to be an important tributary of a large Sarasvati River during this period. The surficial present-day traces of westward courses of the palaeo-Yamuna River have been mapped using remote sensing techniques but their subsurface existence and the timing of fluvial activity are still debated. Here we present detailed sedimentological and chronological information to help unravel the stratigraphy of the buried channels and the time period of activity and abandonment of a west-flowing Yamuna River system. Six sediment cores were drilled down to ~50 m across the sequence of palaeochannel traces of the Yamuna in the Haryana plains, northern India. Around thirty sediment samples were taken from different depositional units in the cores to determine OSL ages using both feldspar and quartz grains. Based on the sedimentary characteristics, facies association and depositional discontinuities, we identified distinct, thick sedimentary units in each core that correspond to high-energy fluvial channel activity. Combining the drill core data with groundwater well lithologs and resistivity surveys, a detailed alluvial architecture was generated which confirms the subsurface existence of a large palaeochannel network in this region. The preliminary OSL ages from these buried sedimentary bodies suggest that the avulsion of the Yamuna River from a west-flowing tributary of the Sarasvati to an east-flowing tributary of the Ganga occurred more than ~10 ka ago, significantly prior to the Bronze Age Indus Valley Civilization.

# Insights into stability of trapped electrons in feldspar from infrared photoluminescence (IRPL)

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The dosimetric signal from feldspar is typically measured using infrared stimulated luminescence (IRSL) which relies upon electron-hole recombination (Hutt et al., 1988). IRSL shows varying thermal and athermal stability across samples of different compositions and provenance. It is not clearly understood whether it is the electrons or the holes that determine the apparent stability of the dosimetric signal. Recently, it has been shown that trapped electrons in feldspar can be measured non-destructively using intra-defect transition within the principal trap (Prasad et al., 2017). The measurement of the resulting IRPL signal does not involve trapped holes; thus, IRPL has the potential to provide direct assessment of thermal and optical stabilities of trapped electrons. This information is important for evaluating the accuracy of optical dating (including thermochronometry) using feldspar as well as for designing laboratory procedures for the measurement of equivalent dose.

Here, we investigate on the two IRPL emissions (~1.41 eV (880 nm) and ~1.30 eV (955 nm)) produced using ~1.49 eV laser excitation (Kumar et al., 2018) in a set of feldspar samples studied previously by Prasad et al (2017). IRPL emission was not detectable in Ca- feldspar. We examine in detail the thermal and optical stability, optical trap depth, excited state lifetime, and correlation between IRSL and IRPL in K- and Na-feldspar. The results from these investigations are discussed with a view to characterize the electron-trapping center (principal trap) and its environment in feldspar.

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# The suitability of post-IR IRSL methods for dating alluvial and colluvial "cut and fill" sequences in the Great Karoo, South Africa

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Headwater valleys of the Sneeuberg, South Africa contain alluvial and colluvial "cut and fill" deposits of varying thickness, extent and pedogenic overprinting. Determination of their age structure in the Wilgerbosch catchment has been problematic due to: (i) a lack of organic remains for $^{14}C$ dating; and (ii) the unsuitability of quartz for luminescence dating. We present an investigation of the suitability of K-feldspar (kfs) post-IR IRSL methods at three representative outcrops exposed in a low-order tributary (Africanders Kloof), focusing on: (i) the performance of the post-IR IRSL (pIRIR) protocol; and (ii) the extent to which the post-IR IRSL signal is adequately bleached.

The single aliquot pIRIR protocols yield consistently good recycling, good dose recovery and low recuperation. A key concern, given the sedimentary context and previous studies using pIRIR signals in such environments, is the issue of adequate bleaching. Here, two published quartz ages (Oldknow and Hooke, 2017) were used to assess the reliability of the K-feldspar and reveal good overlap for $IR_{50}$, $pIRIR_{150}$ and $pIRIR_{170}$ ages: (i) LV509: 8.2 ± 1.5 ka (quartz); 8.5 ± 0.8 ka ($pIRIR_{170}$); (ii) LV515: 17 ± 2.5 ka (quartz); 14.6 ± 1 ($pIRIR_{170}$), with $pIRIR_{225}$ and $pIRIR_{290}$ ages showing a tendency to overestimation. Measured fading rates for the $pIRIR_{170}$ remain quite small (0.1-1.6% per decade) relative to the $pIRIR_{225}$ and $pIRIR_{290}$ and thus the former was used to establish a new chronology comprising 23 $pIRIR_{170}$ ages. These ages are all (within 1σ error) in correct stratigraphic order. To further assess the extent to which the $pIRIR_{170}$ ages are sufficiently bleached, particularly for older samples without additional age control, $IR_{50}$ ages were measured and corrected for fading (Huntley, 2006). The resulting age ratios (corrected-$IR_{50}$/$pIRIR_{170}$) are within ±5% of unity with the exception of a late MIS4 (LV506: 1.25) and MIS5 (LV513: 1.64) alluvial sample whereby the $pIRIR_{170}$ overestimates the corrected-$IR_{50}$.The impact of poor bleaching on the MIS4 and 5 samples ($D_e$> 300 Gy) relative to the late-glacial (LV515) and Holocene (LV509) test samples might be expected to have a proportionally lower impact on age estimation. In conjunction with the otherwise good agreement between the quartz ages, fading corrected-$IR_{50}$, $pIRIR_{150}$ and $pIRIR_{170}$ ages, the source of this over-estimate is presently not clear. Aliquot size was also investigated to further assess the sources of $D_e$ variability and the impact of this on age estimation will be considered.

The resultant chronology reveals four major phases of net aggradation: (i) 2.6 m of sediment accumulated from 58-40 ka followed by a phase of soil formation; (ii) minor incision followed by a further 2 m of floodplain aggradation from ~39-37 ka; during which an elevated water table resulted in the formation of wetlands; (iii) 1.6 m of sediment accumulated from 30-25 ka; and (iv) approximately 4 m of sediment accumulated at or just before 14.6 ka. These phases of aggradation (with the exception of ii) were interrupted by at least two phases where incision exceeded the thickness of the accumulated sediment at: (i)37-30 ka resulting in the drainage of the wetland; and (ii) 25-17 ka. During the Holocene, infilled palaeogully architecture (e.g. LV627: 5.7 ka) attests to phases of incomplete incision with subsequent refilling. This study demonstrates the potential of the $pIRIR_{170}$ protocol for constraining past geomorphic and hydrological change in a hitherto unexplored area of the Karoo; a region where quartz-OSL is highly problematic.

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# Identifying the best-bleached cobbles in heterogeneously bleached environments

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**Abstract:** In sediment dating, the extent to which luminescence signals of individual grains are reset on deposition can vary in different environments (Duller, 2008). Where heterogeneous bleaching of sediment grains occurs, it is critical to assess and extract the population of well-bleached grains for calculation of the sediment age. However, selection of the appropriate model to identify the 'correct' age is subjective. In contrast, in rock luminescence dating the degree of bleaching can potentially be revealed objectively, by examining the luminescence signal with increasing depth into the rock to derive a luminescence-depth profile (e.g. Frieseleben et al. 2015; Jenkins, et al., 2018). Well-bleached rocks show identical luminescence ages through the upper part of the profile, whilst poorly-bleached rocks show growing or saturated ages with depth. Equivalent dose can be used as an indicator of age where the dose rate of rock slices is similar. However, determining the age or the equivalent dose of multiple rock slices from each cobble is time consuming, and much of the data collected may potentially prove to be unsuitable for dating if a large proportion of the cobbles collected are from a deposit containing poorly-bleached cobbles or cobble faces. Rapid assessment of the equivalent dose allows screening to identify well-bleached rock samples for further measurement and poorly-bleached ones can be discarded, thus saving laboratory measurement time.

This study develops the screening method of Jenkins et al. (2018), by exploring measurements of the normalised natural luminescence signal ($L_n/T_n$) and the normalised response to a given radiation dose ($L_1/T_1$) for the upper several millimetres of a core from each cobble. The degree of bleaching of the cobble prior to deposition is inferred by comparing the $L_n/T_n$ to $L_1/T_1$ ratio, and building a luminescence-depth profile. The potential of a standardised growth curve (SGC) approach (Roberts and Duller, 2004; Li et al., 2015) for rapid assessment of the equivalent dose of rock samples is also explored, comparing different cobbles from the same section, and also using cobbles of different origins.

**Key words:** Rock luminescence dating; bleaching; standardised growth curves; cobble

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# Dose rate offset in γ spectrometry due to $^{222}$Rn leakage

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High resolution γ spectrometry is widely used for environmental activity measurements. In trapped charge dating this is used to assess the annual dose rate.

In this work we investigate and quantify how gastight the beakers commonly used in γ spectrometry are. The measurements were performed using two low background, high resolution HPGe γ spectrometers with resolutions at full width at half maximum of 1.8 keV and relative efficiencies of 25% and 40% at the energy of 1332 keV. Analyses were carried out using Genie™ 2000 software distributed by Canberra and Tukan 8k developed by Polish National Centre for Nuclear Research. We assess this by injecting $^{222}$Rn rich air into various beakers and next we trace the abnormal decrease of $^{222}$Rn daughter isotopes, $^{214}$Pb and $^{214}$Bi. Fig. 1 shows one of such measurements in Marinelli beaker where the theoretical and measured $^{222}$Rn decays do not agree. Measured decay times are used to estimate the $^{222}$Rn the leakage from several commercially available beakers. We also investigated the influence of the additional beaker sealing. However, an additional beaker sealing can only slightly reduce $^{222}$Rn escape. This leads to the dose rate underestimation and thus overestimation of age in trapped charge dating.

The work is the result of the research project No. DEC-2011/03/D/ST10/05788 funded by the National Science Centre.

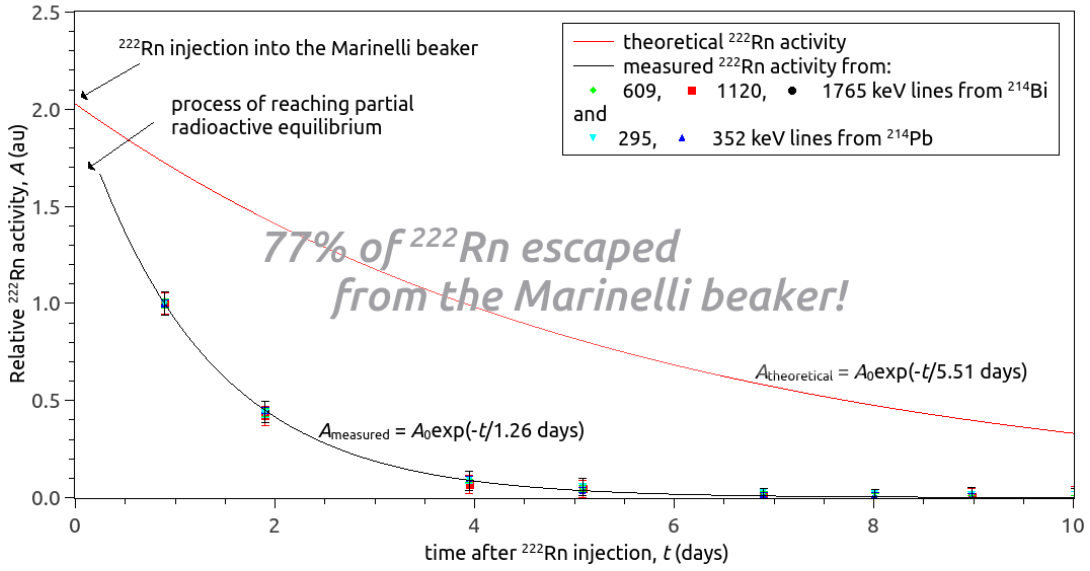


Fig. 1 Comparison of theoretical and measured relative $^{222}$Rn activity in one of the Marinelli beakers after radon injection.

# Finding the most suitable moraine boulders for dating using luminescence-depth profiles

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Moraine deposits can be very difficult to date by currently available methods such as cosmogenic nuclide (CN) or radiocarbon dating, because of problems with inheritance, lack of exposure and/or lack of suitable (organic) material. Rock surface luminescence burial dating has the potential to be used for dating glacial moraines, but selecting the most appropriate sampling strategy for such deposits is not a trivial matter. The major advantage of rock surface luminescence burial dating to more standard luminescence dating using sand-sized or smaller grains is that a clast is large enough to record internally the degree of bleaching prior to burial. Thus, clasts that have been sufficiently bleached prior to burial can be unambiguously identified by the shape of the luminescence-depth profile beneath their surface. Unfortunately, only a fraction of moraine clasts has received such light exposure, and one of the main challenges in the application of the method is the efficient identification of the most light-exposed clasts.

In this study we set out to sample a broad selection of mostly granitic boulders of different sizes and shapes, including different angularities and sphericities, in order to test whether these characteristics can be used to discriminate in favour of the most light-exposed boulders, and so minimize measurements on non-exposed boulders. In the absence of post-depositional reworking, the main factors influencing the suitability of boulders for dating are (i) the length of the pre-burial exposure to daylight, and (ii) the possible subsequent erosion of the profile, either during transport or after deposition. These factors can presumably be associated with a specific shape of the boulder. A boulder exposed to the sun in a proglacial river will tend to be rounded, whereas a boulder exposed on the hillslope will, in general, be more angular. On the other hand, the angularity will also be low if a boulder has been severely eroded during the glacial transport, while it may be high if the boulder was plucked from bedrock under the ice and transported without further erosion.

The Vimmerby moraine was chosen as the test site - this is a prominent and fairly accessible landmark in southern Sweden and has been dated by CN dating to 14.4 ± 0.9 ka[1]. Despite this apparently successful CN study, the luminescence-depth profiles measured in the buried surfaces of the sampled clasts indicate that ~50% of these moraine boulders were exposed to light before final deposition, implying some (presumably small) CN inheritance; some of these boulders were sufficiently bleached to be useful for rock surface luminescence burial dating. In this presentation we discuss the correlations of luminescence signal bleaching with boulder size and shape. The potential of rock surface luminescence profiles to explore glacial transport pathways are also outlined.

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# Dating of fault-related fluvial sediments in New Zealand

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Single grain K-feldspar post-IR IRSL has been used to date sites on four major sub-parallel strike-slip faults in New Zealand, in order to help derive a chronology for the complete movement along a major tectonic plate boundary over the past 10 to 15 thousand years. This is the first time that such a detailed chronology has been constructed, and the application of luminescence to date relatively high energy fluvial terrace deposits that record slip events but rarely contain preserved organic matter represents a significant achievement. Samples were collected from pits dug vertically into terrace surfaces; geomorphic offsets were identified using high resolution airborne LiDAR. As phase one of this research effort, funded by the NSF (USA), draws to a close, and phase two, funded jointly by the NSF and NERC (UK) is starting, this presentation will reflect on observations of the luminescence characteristics, and on lessons learnt.

From the start, a relatively large number of closely spaced sediment samples was collected. This was in part because it was often impractical to return to sites to collect further samples (though this was done to help resolve chronological problems at three sites), but also because of the nature of the sampled sediment, ranging from high energy gravels composed dominantly of boulders with only small volumes of sand between them to fine sands and silts from channel fill and overbank deposits. It was foreseen that some samples might not be well zeroed, so closely spaced samples offer possibilities when some samples do not provide tight chronological constraints.

In order to make best use of the relatively large numbers of closely spaced age estimates, a two stage Bayesian age model was used at each site (Zinke et al., 2017). This approach becomes particularly rewarding when the data are closely spaced in time and have well-established lithostratigraphic and morphostratigraphic relationships. It is useful to consider the concept of a "data density threshold"; beyond the threshold, the degree of consistency between many age estimates can be assessed, providing valuable insights into the veracity of individual ages, and helping to identify landscape development features not clear from the surface geomorphology alone.

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# Optical measurement of band-tail width, depth and excited state energies of the IRSL trap in feldspar

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Luminescence dating is increasingly being used to determine rock thermal histories (e.g. Guralnik et al., 2015; King et al., 2016). Such applications require accurate constraint of the parameters that govern thermal decay for bedrock cooling histories to be extrapolated over geological timescales, however these parameters remain poorly constrained. We investigate the parameters that are thought to determine the thermal stability of infrared stimulated luminescence (IRSL) in a suite of 13 compositionally different feldspar samples using optical probing. We focus specifically on the excited and ground state of the principal trap and the width of the sub-conduction band-tail states. Excitation spectra measured at room temperature result in approximate trap depth of ~2 eV and an excited state at 1.44 ± 0.02 eV, irrespective of feldspar composition. Fitting the non-resonant rising continuum of the excitation spectra suggests that the band-tail states accessible from the ground state of the trap (ΔE, Poolton et al., 2009; Kars et al., 2013) have widths ranging from 0.21 to 0.47 eV at room temperature. Photoluminescence measurements are used to constrain the full sub-conduction band-tail width (Urbach width, Eu) using the excitation-energy-dependent emission (EDE, Prasad et al. 2016; Prasad and Jain, 2018), resulting in values ranging from 0.26 to 0.81 eV. While the depth of the principal trap and its main excited state seem to be independent of feldspar composition, a difference between ΔE and Eu potentially indicates that K-content is related to band-tail state accessibility from the ground state of the trap. The similarity in the kinetic parameters across the samples investigated potentially indicates their independence of composition and we therefore hypothesis that the defect giving rise to IRSL is located on the aluminosilicate framework, which is (almost) the same across the alkali feldspar series.

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# Developing a new generation of standards for dose rate measurements for luminescence dating

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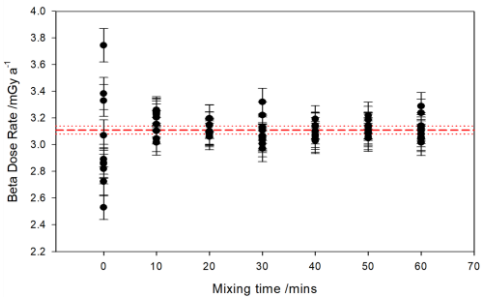
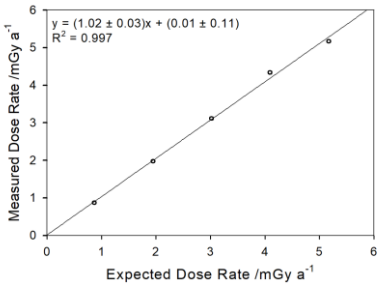
Regardless of which methods are used for dose-rate analysis for luminescence dating there are ongoing needs for both internal and external reference materials for sensitivity determination and quality control purposes. At SUERC a combination of field gamma spectrometry with thick source beta counting (TSBC), high resolution gamma spectrometry (HRGS), NAA (up until 1995) and occasional mass spectrometry or alpha spectrometry has been used for more than 30 years for dose rate analyses of heated materials or sediments undergoing dating. The data have been used to estimate effective dose rates in combination with microdosimetric models and water content corrections. Internal activity has been determined using NAA or ICPMS. Geostandard reference materials have generally been used in setting up or validating the analytical methods, but internal standards are used for routine analysis. These comprised geo-standard spiked orthoclase, used in TSBC, and also a Shap granite reference material, originally homogenised in 1986, and later used for routine control of TSBC and HRGS analyses. The working values of the Shap Granite were determined to high precision relative to Canmet and NBL reference materials. As the remaining quantities have diminished, new work has been undertaken to develop a set of replacement materials.

Residual quantities of Granulite and Basalt obtained in bulk from known Scottish quarry sources in 2015 to prepare new 1.2 m cube "rockboxes" for calibrating field gamma spectrometers provided the input material. Approximately 200 kg of each of these materials was initially ground in a mixer mill, and work undertaken to characterise the homogeneity of kg and 20 g sub-samples using HRGS and TSBC respectively. ICPMS analysis was also undertaken with 100 mg samples. A BSc study was then undertaken using HRGS to evaluate the necessary mixing times and methods required to produce homogenous mixtures of the materials, and 40 kg of each of the pure end members and mixtures at 25%, 50%, and 75% were then prepared. TSBC and HRGS results confirmed bulk homogeneity and the expected dilution series, but excess variation was observed in the ICPMS data from small samples, particularly from the granulite. Further milling and sieving of all materials has been subsequently conducted to further reduce the grain size distributions prior to bottling numbered sets of each material, random re-sampling and replicated determination of working reference values. We now have multiple sets of materials prepared under reproducible conditions and covering a range of beta dose rates from 0.6 to 4.4 mGy $a^{-1}$, and gamma dose rates from 0.8 to 2.4 mGy $a^{-1}$.

The presentation will discuss the preparation methods, the results of homogeneity determinations, the ways in which these materials will be used internally and their potential for interlaboratory work.




Mixing results (50:50% sample) (from Doran, 2018)




Initial beta dose rates (from Doran, 2018)

**Reference**

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# Time-resolved optically stimulated luminescence of quartz in the nanosecond domain

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Time-resolved optically stimulated luminescence (TR-OSL) in combination with pulsed excitation is an established tool for obtaining information on luminescence centres in natural minerals. While for specific cases TR-OSL might be superior to continuous wave stimulation for dating purposes, the method mainly adds to understanding the processes leading to luminescence emission as a function of thermal and optical treatments as well as irradiation. The key information obtained from TR-OSL spectra are the so-called 'lifetimes', which were reported to range from a few µs to ~150 µs for quartz, with a principal lifetime between 30 µs and 40 µs (Chithambo et al., 2007; Ankjærgaard et al., 2010). It has been suspected that short quartz OSL lifetimes (<5 µs) are linked to low OSL-sensitivity in crystalline rocks (Chithambo et al., 2007), and the study by Bailey (2000) implies that the slow component(s) of quartz OSL might be associated with short-lived phosphorescence due to direct donor-acceptor transitions.

Here we report on TR-OSL results for a range of quartz samples from different geological origin obtained with new equipment specifically designed to record TR-OSL spectra with a time-resolution down to 2.5 ns. This extension for the Freiberg Instruments *lexsyg research* reader creates stimulation pulses with a decay time of the falling edge of ~10 ns, allowing lifetimes >50 ns to be recorded without distortion. A number of samples indeed showed hitherto undetected short lifetime components in the range of 100–300 ns beside the principal lifetime, which were extracted from the bulk TR-OSL spectra by fitting single-exponential decays using the **R** (R Core Team, 2018) function fit_OSLLifeTimes() (Kreutzer and Schmidt, 2018). Our contribution discusses whether recording the TR-OSL spectra with a log-scaled time axis with increased time-resolution at the beginning of the off-time period is beneficial and whether a correlation of these short lifetimes with the presence of slow components in the OSL signal exists. Furthermore, we explore if the observation of such short quartz OSL lifetimes is consistent with the picture of direct donor-acceptor transitions.

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# Luminescence dating of Travertine deposits: a potential tool for dating faults activity.

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One of the most important topic for geologists is to establish the temporal framework of tectonic activity and earthquakes series. These are related to active geodynamic settings and influence the Earth surface evolution. Travertines are terrestrial carbonates that precipitate from $CO_2$-rich fluids pumped along active crustal faults and thus are necessarily syntectonic deposits.
Radiocarbon and U/Th are the most chosen methods for dating such deposits. However, weathering, presence and/or accumulation of secondary materials (older carbon or detrital Thorium) along with U-chain disequilibrium frequently have hampered the feasibility of these methods.
Despite the usual low content of terrigenous sediments, wind-blown and/or water-flowed quartz and feldspar grains might be enclosed in travertine deposits and thus luminescence methods could potentially be applied for dating.
In this contribution, luminescence and U-Th dating have been applied on impure syntectonic travertine deposits to establish the latest period of fault activity in NW Sardinia Island (Italy).
The island has been considered tectonically stable since the last 1 Ma and often used as reference to define sea level fluctuations occurred during the late Pleistocene. However, the studied master fault offsets two paleo-beach systems dated to MIS5e ($pIRIR_{290}$ 136 ± 8 ka) and MIS7 ($pIRIR_{290}$ 230 ± 8 ka) respectively, and it provides evidences to support a post-MIS5e (125 ka) tectonic activity in NW Sardinia.
U/Th dating of travertine associated to main fault gave uncorrected ages of 33±8 ka and 32±4 ka. Nevertheless, these were considered as maximum ages because of the diffuse presence of detrital Th in the system.
The SAR-OSL, $IR_{50}$ and $pIRIR_{150}$ protocols were applied on quartz and k-rich feldspar coarse-grains (90-180 µm) extracted from travertines.
Quartz grains show fast-dominated OSL signal, good recuperation, and absence of thermal transfer but a modest recycling ratio. Quartz paleodose (6.6 ± 0.2 Gy) calculate on accepted multi-grain aliquots is far from saturation, leptokurtic distributed with an overdispersion (OD) of 22%. However, dose recovery test highlights that quartz dosimeter systematically overestimates the given dose of ~30%.
On the other hand, $IR_{50}$ and $pIRIR_{150}$ protocols show good performance of dose recovery and recycling ratio, both close to unity, and recuperation less than 5% of natural. Average natural $IR_{50}$ and $pIRIR_{150}$ paleodoses are 5.1 ± 0.4 Gy and 10.8 ± 0.7 Gy respectively. Both paleodoses show positively skewed platikurtic distributions with an OD of 60% and 44% respectively. G-value for $IR_{50}$ and $pIRIR_{150}$ signals are 2.2 ± 0.23 and 1.6 ± 0.05 (%/decade).
Quartz paleodose was corrected for the 30% of De overestimation and gave an age of 3.6 ± 0.2 ka. Corrected for fading $IR_{50}$ age is 3.7 ± 0.5 ka and fading corrected $PIRIR_{150}$ age is 6 ± 0.5 ka. The fading-corrected $IR_{50}$ and OSL ages are clearly in perfect agreement, whilst the fading-corrected $pIRIR_{150}$ age overestimates them. Difference in estimated feldspar ages are likely related to different rates of bleaching of signals in nature. Exposure to light prior burial was sufficient to reset completely the OSL and $IR_{50}$ signals, but partially the $pIRIR_{150}$ one.
The studied syntectonic travertine formed 3.7 ka ago. This supports, for the first time, the Holocene faults activity in Sardinia. In conclusion, luminescence dating seems to be a powerful tool to date impure travertine and to assess the recent activity of faults system.

# Reducing the uncertainty in luminescence dating caused by the internal geochemistry of feldspars

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Feldspars form a solid solution series from orthoclase (K-rich) to albite (Na-rich) to anorthite (Ca-rich), which includes perthites composed of different phases; thus, grains of feldspar can contain variable internal concentrations of K, Rb, U and Th. The internal composition of grains emitting blue-violet signals can vary from 0 – 14 % K (e.g. Smedley et al. 2012), and from 0 – 3 ppm U and 0 – 16 ppm Th (Smedley and Pearce 2016). The variability in the internal geochemistry of feldspar can still add significant uncertainty into ages determined, especially for single grains (Smedley et al. 2012; Smedley and Pearce, 2016; Buylaert et al. in press). This is because different feldspar can emit blue-violet signals, even though the peak emission of Na-feldspar is yellow (~570 nm), and perthites have wide emission bands (Krbetschek et al. 1997). To date, our understanding of emission spectra from different feldspar is solely derived from museum specimens, rather than sand-sized feldspar grains from nature. There is a lack of studies investigating the relationship between different emissions of single-grain feldspar and their internal geochemistry, and none have yet considered exploiting this to ensure that dating is only performed on K-feldspar. Here we investigate the link between emission window and the geochemistry of sand-sized feldspar grains, and work towards devising a new, robust luminescence procedure to ensure that only K-rich feldspar grains are used for age calculation.

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# Mass movements: can they be dated using rock-surface luminescence?

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Mass movements such as rockfalls, landslides and debris flows pose a serious hazard to human population and infrastructure in mountainous areas. At least 300 million people are exposed to mass-movement risk globally [1] and every year there are tens of reports of major mass movements around the world; these cause human fatalities, destroy buildings and damage transportation corridors. The occurrence of such disastrous events seems to be on the rise [1]. Understanding the mechanisms by which these processes initiate slope failure enables the development of robust site-specific models necessary for proactive intervention aimed at risk mitigation. Moreover, mass movements are one of the major processes of slope erosion and thus a significant component of landscape evolution; as a result, they have become one of the most studied processes in engineering geology and geomorphology. Knowledge of the return frequency of mass movements lies at the heart of these studies and is a key to understanding their forcing mechanisms. However, the measurement of this return frequency on a scale longer than the historical record has been greatly hampered by a lack of reliable geochronological tools to date past mass movements. Recently, rock surface luminescence dating has been successfully used to determine the age of a rockfall event in Utah, USA [2], as well as the burial of colluvial and fluvial cobbles elsewhere [e.g. 3,4]. The great advantage of this new technique over the established methods such as radiocarbon dating and cosmogenic nuclide is that i) it is directly applied to rock surfaces and ii) it is equipped with an internal record of the degree of pre-burial inheritance (if any) in the chronometric signal; this is preserved in the luminescence-depth profile in the target surface.

Here we present the application of rock surface burial dating to cobbles collected from four illustrative mass-movement sites: i) debris-flow deposits, Bailong river valley, China, ii) abandoned floodplain deposits, southern Pyrenees, NE Iberia, iii) megaflood deposited gravel bar, Montana, USA and iv) rockfalls, Central Iberia. The luminescence signal characteristics and depth profiles are measured in several cobbles from each site. The observed luminescence-depth profiles show that despite the unsuitable bleaching conditions in these depositional settings, finding cobbles whose surfaces were sufficiently bleached prior to burial is likely. The bleaching of the cobble surfaces most likely takes place on the hillslopes and before entrainment in the mass movement.

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# OSL dating of rocks from Holocene beach deposits, Disko, W. Greenland

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Several Holocene mean low-tide sea level markers (down-lap points) have been identified recently in the sedimentary structure of gravelly beach ridges on the west coast of Disko Island, West Greenland (Souza, Kroon, & Nielsen, in press); the deposition time of these ridges is unknown. The very limited amount of sand-sized grains in the open matrix increases the risk of sampling grains that have migrated downwards after deposition; this restricts the application of standard luminescence dating methods. Here, we date the burial time of cobble surfaces collected from the subsurface (ca. 70 cm deep) of four sequential beach ridges. At least five rocks > 15 cm in diameter and of various compositions (quartz and/or feldspar rich) were collected from each pit to increase the likelihood of finding suitable material for dating. Whole rock slices (~10 mm in diameter and ~1.2 mm thick) were cut from cores drilled into the surface of the cobbles and mounted directly on the carousel of a Risø TL-OSL reader for all measurements (e.g. Sohbati et al., 2011). Initial tests show that most rocks provide infrared stimulated luminescence (IRSL) signals at 50° C. IRSL-depth profiles measured from one side of various cobbles show that the surfaces have been reset by bleaching to various depths. For the cobbles identified as well-bleached prior to deposition (i.e. bleaching depth > 2 mm), the dose response curves of the outer two slices and the two innermost slices were constructed for equivalent dose and saturation dose estimations, respectively (Rades et al., in review). The field-to-laboratory saturation ratios show that the IRSL signal in our samples fades less than ~20%. Clast specific dosimetry, based on beta counting and gamma spectrometry of gamma cups made of each clast and of its surrounding matrix (ca. 20 cm), is used to derive apparent ages for individual clasts. We discuss the implications of the resulting ages with respect to relative sea level variations in the study area during the Holocene.

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# A new method of increasing dose rate precision with correlated uncertainties in the µDose system

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The µDose system (Tudyka et al., 2018) records α and β particles along four decay pairs arising from subsequent decays of $^{214}$Bi/$^{214}$Po, $^{220}$Rn/$^{216}$Po, $^{212}$Bi/$^{212}$Po and $^{219}$Rn/$^{215}$Po. Under the assumption of secular equilibrium this allows to assess the specific radioactivities of $^{238}$U, $^{235}$U, $^{232}$Th decay chains and $^{40}$K. This measurement provides results whose uncertainties are correlated. This creates the necessity to develop a methodology of error estimation that takes this fact into account.

Here we present and discuss two different approaches to uncertainty propagation, namely a Monte Carlo and a probabilistic method. Both approaches produce statistically identical results and allow obtaining significantly better dose rate precision than when the correlations are not accounted for (or in measurements when they are non-existent).

The development of the pulse analyzer used in the µDose system was supported with the grant LIDER/001/404/L-4/2013 by the Polish National Centre for Research and Development. Currently the project is co-financed by the Ministry of Science and Higher Education from "Incubator of Innovation+" programme within the framework of the Smart Growth Operational Programme, Action 4.4 Potential increase of human resources of the R&D sector.

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# Poor bleaching of OSL signals; a novel tool to reconstruct fluvial sediment pathways

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It is well known that incomplete resetting of luminescence signals ('poor bleaching') may result in overestimation of burial age. Given limited light exposure during fluvial transport, approaches to overcome poor bleaching have received abundant attention in the fluvial community. In most cases, problems can largely be overcome by using quartz OSL signals, focussing on the most light-sensitive part of the signal ('fast component'), in combination with advanced statistical interpretation of equivalent dose distributions obtained using small aliquots, or even single grains.

Here we treat poor bleaching not as a nuisance, but as a novel tool to investigate sediment provenance and transport processes. We build on the notion that the bleaching degree depends on the dose acquired during previous burial (the age of the source material), the duration and intensity of light exposure, as well as the number of sediment recycling steps. These attributes will differ for different fluvial systems, and may also change over time.

In recent years, several authors have investigated luminescence bleaching as a proxy for sediment transport in contemporary systems (e.g. McGuire and Rhodes, 2015; Reimann et al., 2015). Here we explore how similar approaches can yield information on changes in sediment transport over time, investigating bleaching degree of fluvial deposits from the geological archive. For this purpose, we have developed and tested several methods to quantify the degree of bleaching. These methods include: 1) The comparison of different luminescence signals with different bleachability (quartz OSL, feldspar IRSL and pIRIR signals); 2) Characteristics of equivalent dose distributions, obtained on small aliquots or single grains of quartz or feldspar; 3) Differences between mean equivalent dose and best-estimate palaeodose obtained using minimum age models.

We report on our experiences with these methods for a wide range of systems, from a large incising terraced river in New Zealand, to a small low-energy river in the Netherlands, and the megadeltas of the Mississippi and Ganges-Brahmaputra. We show that the different systems require different approaches, reflecting their own unique geomorphic attributes, the type of sediment and the luminescence characteristics of local quartz and feldspar minerals. Moreover, we demonstrate that analysis of bleaching provides insight into changes in sediment transport over time. Although still in its infancy, these results clearly show the potential of this novel tool to fingerprint the routing of sediments through fluvial systems.

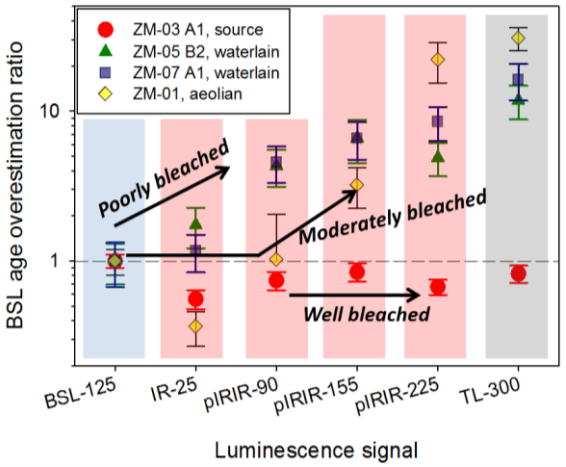


**Figure:** Comparison of palaeodoses obtained from signals of different bleachibility may provide information on the degree of bleaching, and hence the depositional environment and transportation history of grains. Signals are plotted from easily bleached on the left, to very difficult to bleach on the right. Figure adapted from Reimann et al. (2015).

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# POSTER ABSTRACTS

# OSL dating of Middle Palaeolithic occupations in the Jubbah basin (Saudi Arabia)

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The Arabian Peninsula occupies a critical location at the interface of Africa and Eurasia, as well as being an area that witnessed dramatic past environmental oscillation. The environmental and archaeological records of Arabia are therefore very informative on processes of early human dispersals, and the response of human populations to environmental change. While surface scatters of stone tools have been known for decades and indicate the richness of the prehistoric record for Arabia, the chronological and environmental context of these assemblages has been unclear. To better understand the chronology and nature of these occupations new excavations were lead by an international and interdisciplinary team in the Jubbah basin in the southern part of the Nefud desert (Saudi Arabia). Two sites named Jebel Umm Sanman-1 (JSM-1) and Jebel Katefeh-1 (JKF-1) showed evidences of different assemblages of Middle Palaeolithic stone tools. Single grain OSL dating suggest that these tools were made by two different early humans populations which lived in the Nefud desert during MIS 3 and MIS 5.

# Luminescence Characteristics of Quartzite and Granite Cobbles from Terrace Surfaces in Wadi Sodmein, Egypt

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Recent developments in optically stimulated luminescence (OSL) dating enables the study of burial and exposure events of rocks. The method has proven useful to provide chronological context to archaeological sites (e.g. Sohbati et al., 2015). If properly developed, luminescence dating of rocks could potentially be widely applied to settings where other dating methods are not suitable. One such setting are the surfaces of terrace remnants of Wadi Sodmein in the Eastern Desert, Egypt. Despite the erosive characteristics of the environment in this desert, remnants of Pleistocene wadi terraces have been preserved. The terraces are covered with desert pavement made up of coarse clasts of varying lithologies, many of which are coated with desert varnish. Artefacts of varying ages (Middle Stone Age to Neolithic) have been discovered on the surfaces of several of the terraces (Kindermann et al., 2018). No artefacts have so far been found interbedded in the terrace sediments, which indicates that the terrace surfaces pre-date the oldest artefacts. The terraces are located in close proximity to the Sodmein Cave (e.g. Van Peer et al., 1996) and the Sodmein Playa (Kindermann et al., 2018), two sites with human occupation during the Pleistocene. Our goal is to investigate the possibility of using OSL dating techniques in order to determine burial and exposure ages for quartzite and granite cobbles and boulders from the terrace surfaces. Assuming that these surfaces have remained stable since the deposition of the oldest artefacts, a successful attempt would provide a maximum age for our ancestors' footprint on the terraces. Cores from quartzite and granite cobbles were extracted and cut to ~0.7 mm thin slices. The single aliquot regenerative (SAR) protocol was used to measure the luminescence intensity and estimate an equivalent dose. The quartzite slices were heated for 100 seconds at 220 °C, followed by a 30 second paus, and then the slices were stimulated with blue light at 125 °C. Each SAR cycle was finished with a hot-bleach blue light stimulation at 280 °C to reduce recuperation. The granite slices were measured with infra-red stimulation at 50 °C, with the protocol used by Sohbati et al. (2018). Preliminary results from quartzite cobbles (~60 mm thick) indicated that the signal had been bleached all through the cobbles, which makes the quartzite unusable for dating. The absence of a signal in the cobbles is coherent with the results of Gliganic et al. (2018), who showed that a century of exposure to daylight can erase the signal until 2 cm of depth in translucent quartzite. The lack of signal is likely due to long exposure to daylight and translucency of the mineral grains. Preliminary results from a granite cobble displayed an IR50 signal from a core which was extracted from the buried surface. Thus, the results from granite cobbles are more promising, wherefore we will continue to investigate this signal further.

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# Exo-Electrons from Single Grains of Quartz

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OSL/TL results from the initial trapping and subsequent release and recombination of charge in a suitable crystal structure such as quartz or feldspar; these luminescence signals can be used to estimate the dose absorbed by the crystal and so the time since the traps were last emptied. During such processes, electrons are also emitted from the crystal surface; these exo-electrons provide information regarding the trapping process, as well as an alternative method of measuring trapped charge. Ankjærgaard et al. (2006, 2008, 2009) have previously shown that it is possible to measure a dose-dependent exo-electron signal from naturally occurring quartz at the multigrain level. A flexible, modular exo-electron attachment for the Risø reader (Risø Exo-Electron System (REES) has recently been characterised by Autzen et al. (submitted) using multi-grain quartz and salt samples. Here we explore the sensitivity of the system by extending our investigations to individual grains. Such measurements have the potential to give important new insights into grain-specific trapping and recombination probabilities since the emission of exo-electrons competes with the recombination process. By pulsing the applied high voltage during OSL stimulation we deconvolute the "true" OSL signal from the UV photons generated by exo-electrons during acceleration (Townsend avalanche). As a result, we are not only able to measure, for the first time, exo-electron signals from individual grains of quartz, but also to compare these with the OSL emitted at the same time.

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# On the relationship between K concentration, grain size and dose in feldspar

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Previous work has been unable to establish a relationship between K concentration and $D_e$ in single-grains of feldspar. Here we use four well-bleached sediments with low external dose rate (typically ≤1.5 Gy ka−1) to investigate this relationship. Single and multi-grain pIRIR measurements and μ-XRF analyses are made on Na and K-rich extracts; μ-XRF is directly applied to grains sitting in single-grain discs to minimise uncertainty in grain identification. Micro-XRF is shown to be sufficiently precise and accurate and luminescence instrument reproducibility is confirmed using dose recovery measurements on heated feldspar. We are again unable to establish any correlation between single-grain De and K concentration, even in feldspar grains for which the internal dose rate should dominate. We also measure highly variable Rb concentrations in these grains and are unable to detect, at the single-grain level, the correlation between K and Rb previously observed in multi-grain investigations. Nevertheless, these results are unable to explain the lack of De correlation with K. Finally, we investigate the dependence of De on grain size (isochrons). Linear correlations are observed but slopes are inconsistent with model prediction. We conclude that this surprising absence of the expected relationships between dose and K concentration and grain size does not arise from analytical precision, incomplete bleaching, sediment mixing or fading. It appears that we cannot measure feldspar doses in these samples as accurately as we thought.

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# Palaeoenvironments of the western Nefud Desert, Saudi Arabia during Marine Isotope Stage 5

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Marine Isotope Stage (MIS) 5 is a critical time period in the history of our species, as fossil and archeological evidence increasingly support the idea that *Homo sapiens* successfully dispersed from Africa and into Eurasia during this period. The Nefud Desert, Saudi Arabia is located in a key geographical position for such dispersals as it lies just ~550 km southeast of the Sinai Peninsula, the only terrestrial route out-of-Africa. The Nefud Desert is currently arid to hyper arid and presents a major barrier to overland movement. However, the region has periodically been accessible to humans during humid phases driven by precession cycles. Humid phases are represented in the Nefud Desert by numerous interdunal lacustrine, palustrine and calcrete sediments. Reconstructing the nature of the water bodies represented by these sediments is key to understanding Hominin dispersals from Africa and into Arabia. Here, we apply a multi-proxy analysis to four interdunal carbonate or silicious diatomite beds. Two palaeolake beds are dated to early MIS 5 and two to the latter half of MIS 5 through optically stimulated luminescence (OSL) dating. A combination of sedimentology, micromorphology, diatom palaeoecology, and oxygen and carbon isotope analysis demonstrate that the Nefud Desert contained interconnected, freshwater and perennial interdunal lakes during two separate humid phases within MIS 5. This provided a habitable landscape through which *Homo sapiens* could disperse upon leaving Africa.

# Violet stimulated luminescence: Comparison of single- and multiple-aliquot measurement protocols

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The natural violet stimulated luminescence (VSL) signal in quartz has been shown to grow in nature over the range from 200-2000 Gy (Ankjærgaard et al. 2016). This makes VSL an enticing prospect for dating as it has the potential to extend the age range of quartz luminescence through the Quaternary. Different measurement protocols have been used for VSL, including the single aliquot regenerative dose (SAR) protocol (Colarossi et al. 2018, Porat et al. 2017, Ankjærgaard et al. 2013) and the multiple aliquot additive dose (MAAD) protocol (Ankjærgaard et al. 2016), with mixed results. Before routine application of VSL measurement to samples can be realised, further investigation into the nature of the signal and the mechanisms behind the measurement protocols need to be undertaken.

In this study three protocols, the SAR, SARA (single aliquot regeneration added dose) and MAAD, are investigated using two samples from St Paul's, KwaZulu-Natal, South Africa. The samples were selected based on their equivalent dose ($D_e$) values; (i) a very young sample (Aber215/STP09) with a $D_e$ of 3.00±0.16 Gy determined by single grain quartz OSL and (ii) an old sample (Aber215/STP01) with an expected quartz $D_e$ of 354±30 Gy based on single grain K-feldspar post-IR IRSL measurements. The VSL SAR protocol gave a $D_e$ of ~4 Gy for the young sample, which is comparable to the expected $D_e$ value from quartz SAR, whilst the VSL SARA and MAAD protocols gave similar, but larger, $D_e$ values of ~13 Gy and ~14 Gy respectively. For the old sample, the VSL SAR $D_e$ was ~124 Gy, only 35% of the expected $D_e$. In contrast, the SARA and MAAD protocols gave $D_e$ values comparable to the expected $D_e$ value for the old sample, ~325 Gy and ~407 Gy respectively. Although these data represent preliminary measurements, they are encouraging and further investigation into the merits of the SARA and MAAD protocols for the VSL signal is ongoing.

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# Debris-flow cobbles as chronometers of mountain glaciation

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Debris flows and other mass movements are usually difficult to date by OSL, because resetting of grains during transport is unlikely. Alternative dating methods rely on the sporadic occurrence of datable material in the bracketing sediments. However, the development of rock surface dating makes it feasible to date cobble-rich debris flows directly. Cobbles and boulders have a high probability of being exposed on hillslopes and stream beds for prolonged periods, so may have their luminescence signals reset prior to transport. Furthermore, a record of the bleaching history of a clast can be read by measuring the OSL signal with depth, and this provides an internal check on the degree of bleaching.

Here we investigate the debris-flow sediments of the upper Baksan valley in the Causasus Mountains. The valley contained a major glacier during Pleistocene glaciations, and has evidence of smaller, presumably Holocene glacier advances. The area is prone to debris-flows and avalanches, with many destructive debris flows observed in the last few years. The numerous debris fans in the valley must post-date the last valley glaciation. Dating of these debris fans serves a double purpose: first, to help understand the recurrence intervals and causes of the debris flows; second, to place a chronology on glacier retreat in the Caucasus.

Initial IRSL measurements of granite cobbles show that roughly 30 % of clasts have at least one surface that was well-bleached prior to burial, with deposition occurring in the late Holocene. We also investigate the use of infrared photo-luminescence (IRPL) imaging to identify well-bleached clasts. IRPL signals are more difficult to bleach, but have potential to provide bleaching profiles of very high resolution, without the need for an irradiation step.

# Using a portable luminescence reader for a rapid age assessment of lake shoreline sediments

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Portable luminescence readers (POSL) have been demonstrated to provide an extremely useful first-order estimate of inorganic sample burial age. This allows for sites and sequences to be interpreted *in situ* and permits more targeted field sampling strategies. In southern Africa, thus far, this device has been used predominantly in the analysis of dune settings (Stone et al., 2018). Here, we present data from ~100 lake sediment samples from the middle Kalahari (Burrough et al., 2007; 2009), broadening the environmental settings for which the applicability of this device has been investigated.

We present data on the regression between POSL blue stimulated signal and the full SAR-protocol OSL burial ages from the published lake sample datasets (Burrough et al., 2007; 2009). We also investigate what sample characteristics may be influencing the strength of this regression. Finally, we compare this data with the region-specific calibrations that have already been produced for southern African aeolian sediments (Stone et al., 2018).

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# Age and Extent of Proglacial Lake Pickering

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During the Late Devensian, the Vale of Pickering, North Yorkshire, was the site of a large proglacial lake, and until recently, the conceptual model of Lake Pickering has lain with P.F. Kendall's 1902 publication *A System of Glacier-Lakes in the Cleveland Hills*. Kendall describes the Vale of Pickering at the Last Glacial Maximum (LGM) as filled with a large proglacial lake (70 m O.D.) bounded by the North Sea Lobe (NSL) in the east and the Vale of York Lobe (VoYL) in the west and south.

Revisiting Kendall's Lake Pickering after 116 years enables new technology to investigate the accurate age and extent of Glacial Lake Pickering. A suite of samples taken from natural exposures, via hand auguring, and by percussion borehole coring across the Vale of Pickering were dated using optical stimulated luminescence (OSL) via small aliquot with one single grain date. The resulting data shows several iterations of Glacial Lake Pickering preceding the LGM with the 70 m O.D lake level likely to be Pre-Devensian.

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# HOLOCENE WILDFIRE ACTIVITY AND DUST DYNAMICS IN WEST GREENLAND

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The largest wildfire ever observed in Greenland raged through the tundra of West Greenland during august 2017. Wildfires can affect erosion, dust activity, carbon cycling, aerosol emissions and surface albedo in the climate-change sensitive Arctic. However, fire activity in Greenland has largely been ignored by researchers. Here, Holocene aeolian sediments are characterized and used as archives for paleoenvironment, dustiness and fire activity by analysis of charcoal content, magnetic properties and grain size distributions. Ten sections are dated independently by OSL and $^{14}C$.

The sources of the aeolian sediments are the glacial outwash plains in front of the ice sheet which is now situated just kilometers from the study sites; this has probably remained largely unchanged throughout the late Holocene. The nearby gneiss source was expected to provide relatively insensitive quartz, and short transport distance increases the likelihood of poor bleaching, especially if transport takes place during the long, dark winter. OSL results indicate that the quartz signal is indeed very weak. Preheat plateau tests using the coarse feldspar fraction (250-300 µm) indicate that a low preheat temperature (around 200°C) is to be preferred and so we have adopted a $pIRIR_{180,50}$ SAR protocol. Preliminary results suggest that at least the $IR_{50}$ signal is well bleached giving youngest ages of ~400 years. The challenges of dating Arctic sediments proximal to their source will be discussed, and the implication of the OSL chronostratigraphy for these Greenlandic sequences considered.

# The dependence of apparent feldspar dose on sample processing

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In luminescence dating, considerable effort is employed to extract feldspar with a high potassium content for dose determination. This is because the feldspar equivalent dose ($D_e$) should be dependent on the internal K concentration; thus sodium rich feldspars are expected to have a $D_e$ approximately the same as that of quartz whereas a 200 µm grain of pure (14 %) K feldspar should have a $D_e$ about 30 % larger (for typical external dose rates). However, Sohbati et al. (2013) have shown that even Na-rich extracts often have a $D_e$ more similar to that of K-rich feldspar rather than that of quartz, when measured using blue filters. This has been attributed to the more intense blue emission from K-rich compared to Na-rich feldspars (Baril and Huntley, 2003); the former presumably dominate the IRSL signal even if only present at low concentrations. This suggest that the feldspar $D_e$ is not strongly dependent on the purity of the feldspar extract; this hypothesis leads to the present study.

Here we use 15 sediment samples of various geographical and sedimentological origins. The IR stimulated signal and the derived $D_e$'s from quartz-rich extracts, Na- and K-rich extracts and acid-cleaned but unseparated grains are examined for each sample, all sieved to same size range. The major element concentrations of these various extracts are also measured using the XRF attachment to a Risø reader.

Based on these data we discuss the need for feldspar separation when dating using K-rich feldspars. The potential of $D_e$'s based on the internal feldspar contamination of quartz grains is also considered.

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# Towards dating prehistoric rock art from central Iberia using luminescence from rock surfaces

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Rock art is notoriously difficult to date numerically using established geochronological techniques. Recently, optically stimulated luminescence (OSL) rock surface dating has been used successfully to constrain the age of a Native American rock art in Utah, USA (Chapot et al., 2012). In this study, we follow a similar approach to constrain the age of two important rock art sites in the Iberian Peninsula: i) a Levantine Style rock art (Peña del Escrito, Villar del Humo, ~300 km SE of Madrid) characterised by naturalistic depictions and scenes of people and animals interacting, and ii) a Schematic rock art (Peña Escrita, Fuencaliente, ~400 km S of Madrid) of a more abstract style with human- and animal-like figures and more abstract elements as the main features. The time frame of the Levantine Style is controversial with dates proposed from before and after the Neolithic. In contrast, the Schematic Style is traditionally considered to be of Chalcolithic or Bronze Age. At both sites, rockfall has removed a part of the rock art and buried it on the toe of the cliff.

For luminescence measurements, we collected three samples from the pigmented buried rock face at the sandstone Levantine Style site and a similar one from the quartzite Schematic Style site, together with corresponding dose rate samples from the underlying sediment/rock. Whole rock samples were cut in the usual manner and the luminescence signals measured as a function of depth. The sandstone samples have a weak fast-component OSL signal but are dominated by IRSL. In contrast, the quartzite sample is dominated by a strong fast component OSL signal with only weak IRSL. As expected, the observed OSL and IRSL profiles all show evidence of light exposure prior to burial. We present these profiles and relevant luminescence characteristics for the two styles of rock art.

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# Quartz OSL and K-feldspar post-IR IRSL dating of Tell al-Magass, Jordan

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In this study we test the applicability of luminescence dating to geo-archeological sediments from "Tell" (mound) formations. Combined quartz optically stimulated luminescence (OSL) and K-feldspar infrared stimulated luminescence (IRSL) dating were applied to eight sediment samples taken from the Tell al-Magass archaeological site in southern Jordan. The site is made up of a stratigraphic sequence of different sandy and ash layers covering architectural features of stone and mudbrick. The uppermost unit is composed mainly of alluvial sand built up by debris flows from Wadi Yutum. The second unit is a mixture of stone and mudbrick walls with thick sandy and ashy layers. The sand is assumed to be aeolian, and the ash is taken to result from fire following an earthquake (Khalil, 2009; Korjenkov & Schmidt, 2009). OSL samples were collected from layers that were previously dated by $^{14}C$ from an open pit in the north-western part of the section through Tell al-Magass.

Both quartz and alkali feldspars (KF) were measured using, for quartz, blue OSL and, for feldspar, $IR_{50}$ and $pIRIR_{290}$ signals. The $pIRIR_{290}$ signals required the subtraction of residual doses (measured using prolonged stimulation in a daylight simulator); in contrast the $IR_{50}$ signals did not include a significant residual dose, but did require correction for anomalous fading. The resulting agreement of the ages from the two IRSL signals with those from quartz confirms that the quartz was fully reset before or during the last daylight transport event. This is further confirmed by the satisfactory comparison with previous published $^{14}C$ dates from the same section.

Keywords: OSL, IRSL, Tell al-Magass, Jordan.

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# Exploring sediment and OSL stratigraphies of urban-hinterland archaeology; historic landscape management in the Wadi Suf, Jordan

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The site of Jerash, Jordan, occupied from the Hellenistic to the Islamic period, is one of the major cities of the Roman Decapolis. Bisected by the River Chrysorrhoas ('the river of gold', now Wadi Suf), the city's wider significance is related to its location in one of the fertile areas of the northern highlands of Jordan. The recently completed *Danish-German Jerash Northwest Quarter Project (2011-2017)*[1] provided an understanding of the domestic, everyday activity in Jerash before and extending beyond 749 CE when the region was hit by a devasting earthquake. Geoarchaeological investigations of the wider urban area and its surrounding hinterland identified late Holocene colluvial and fluvial deposits on the lower slopes of the city and along the Wadi Suf, linked to Hellenistic-Roman-Islamic land use and management. This sedimentary archive provides an insight on the sustainability, resilience and degradation of the agrarian landscape through short- to longer-term changes in climatic and environmental conditions.

As part of the *Northwest Quarter* Project, three profiles in the Upper, Middle and Lower reaches of the Wadi Suf were examined; 4-5km upstream and immediately downstream of the ancient city, and at the intersection with the Wadi Dayr. These sections were sampled for OSL dating in 2015 and 2016, with the analyses performed at SUERC in early 2017[2]. These early investigations showed that significant volumes of sediment were mobilised through the Wadi Suf from the mid 7th century AD to early 15th century AD, both prior to, and after the 749 CE earthquake. Although significant in defining the evolution of the wadi, the temporal and spatial resolution of these data are insufficient to resolve the historical dynamic between city and hinterland, and thus assess the sustainability of land management practices in different periods.

In 2017, we returned to the 2015-16 sections to retrospectively sample for OSL profiling, providing more detailed stratigraphies for each; and, using these relative chronologies expand the investigations into the wider landscape. This has allowed us to more fully appraise wadi formation processes at the catchment scale, and identify new linkages between the natural course of the wadi, the historical exploitation of this water resource and the terraced agrarian landscape. Our catalogue of temporal data on the evolution of the wadi continues to develop, from the late Pleistocene development of the Cambisols ubiquitous through the region, to the early Holocene Fluvisols accumulating adjacent to the wadi, prior to urbanisation in the Hellenistic period. Critically, evidence of fluvial sedimentation from the 2nd-3rd centuries BC to the 7th century AD remains elusive, which may suggest effective management of the water resource at this time. From the beginning of the 6th century, the wadi begins to back-fill, and in the absence of additional chronological data, this may imply a decline and loss in land/water management.

Coupled to this, geoarchaeological investigations of the wadi's soils and sediments are providing information on early land management practices, from land allocation, to its use and modification. The history of Jerash is in many ways representative of other ancient cities in the semi-arid Near East, which rose to prominence and then declined due to climatic and environmental change, catastrophic events and geopolitical situations. Therefore, our observations on the early urban-hinterland exchange provide insight and significance beyond Jerash, with relevance to theoretical and practical issues of long-term urban and hinterland management elsewhere.

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# Using luminescence signals to fingerprint glacial oscillations

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Single grain optically stimulated luminescence is a well-established method for dating the last time sand grains were exposed to sunlight prior to burial by deposition and has been used for dating ice margin retreat with some success (e.g. Bateman et al., 2018). In glacial environments the luminescence palaeodose signal often has a skewed distribution indicative of partial bleaching. Typically, research has looked for ways to pick out the palaeodose which is thought to be related to bleaching at the final deposition event, and the remaining data is ignored. We hypothesise that some of this ignored data may represent earlier sediment transport and exposure events in the lifetime of the sand grains (Livingstone et al., 2015). The premise being that at the base of ice sheets sediment is recycled as they fluctuate, and therefore sand grains that are not reset by exposure to sunlight record previous phases of ice free conditions. If such signals can be distinguished, there is the potential to document ice sheet oscillations beyond the last depositional event, to include ages of initial ice advance (glaciation onset) and important retreat-readvance sequences related to climate switches or instabilities. Here we present results of a pilot study using single grain palaeodose signals from sites in and around the Irish and Celtic seas (Smedley et al., 2017a,b; Chiverrell et al., 2018). Using Finite Mixture Modelling we note encouraging coincidences in $D_e$ component which give age clusters at ~20 ka, 27-35 ka, ~50 ka, 70-80 ka and 90-100 ka. Could these represent periods of ice-free conditions? Building on these data, we identify a framework for further testing of our hypothesis and outline key challenges that remain if luminescence signals are to be used to constrain ice sheet oscillations.

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# Determining the timing of Mega-blowout initiation in QTP

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Mega-blowouts are very large -scale deflationary landforms formed by wind erosion on a pre-existing palaeodunes. They are abundant in the Gonghe basin, northeast margin of the Qinghai-Tibet Plateau (QTP) and little is known about the initiation and evolvement. Here we report on mega-blowouts dating results and its expansion rate and control factors. Four different sized blowouts (small, medium and mega) from three areas in QTP have been dated in the luminescence laboratory in the University of Sheffield. New sedimentological data and OSL dates indicate that the age of mega-blowouts varied, with the oldest (B2) in Gonghe Basin dating to ~260 years and the youngest blowout in Zoige area dating to ~60 years. The biggest mega-blowouts show the oldest ages, reflecting good relationship between its maturity and age. The initiate of mega-blowouts coinciding with the Little Ice Age (LIA) climate event when northwest winds are known to have intensified in the north-eastern QTP. The historical average expansion rates of areal change in erosional basins approximated 650 $m^2 a^{-1}$, 80 $m^2 a^{-1}$ and 40 $m^2 a^{-1}$ for the mega, medium and small sized blowout based on the dating results. The Sediment characteristics, water erosion, and freeze-thaw processes all play a part in mega-blowout initiation and expansion. However, the relative roles that these factors play may differ according to a blowout's different evolutionary stages and different areas. A large proportion of sand patches and small blowouts around the mega-blowouts are still developing in QTP which proves that land degradation is still ongoing on this inland high-altitude region with global warming. To understanding the initiation mechanism and its dynamical evolution feedback to the climate change, long term in-situ monitoring and large portion of dating work need to undertake in future.

**Figure 1.** Aerial view of the mega-blowout in QTP.

# Dating overdeepened valley fills from Switzerland: challenges and approaches

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During the Pleistocene, extensive and repeated glaciations have carved the forelands of the European Alps and left deeply incised trough structures, overdeepened valleys, behind. Subsequently, these valleys were infilled with subglacial to proglacial sediments and often partially re-eroded during later glaciations. To better understand the evolution of these landscapes and to assess whether their timing was in accordance with global glaciation pattern, the development of local chronologies is crucial.

Previous studies from Northern Switzerland have shown the complexity of dating pro-glacial deposits especially beyond the radiocarbon dating limit. Conventional luminescence (i.e. BSL, $IR_{50}$) dating methods have been found to be the most suitable/feasible, however, age estimates above ~150 ka have been proven difficult. $D_e$ values close to saturation and the complex response to high doses are most challenging for dating such samples. However, recent development in measurement protocols and OSL reader equipment have opened new options for the age determination. Pulsed IRSL and pBSL VSL protocols are believed to be promising alternatives for dating samples with high $D_e$ values. For this study, these measurement protocols will be tested on samples from overdeepened valley fills taken at several sites in Northern Switzerland.

# Testing the combined effects of test dose size and IR LED stimulation time on dose recovery performance using the post-IR $IRSL_{50,170}$ protocol.

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Reliable monitoring of sensitivity change during the single aliquot regenerative dose (SAR) protocol is a prerequisite for successfully dating both quartz and K-rich feldspar. The assumption that the IRSL signal is reduced to a stable background level at the end of the regenerative ($L_x$) part of the sequence has been shown to be questionable (Colarossi et al., 2017). In their study using the post-IR $IRSL_{50,225}$ protocol on single grains of K-feldspar they showed that increasing the test dose size was more effective at reducing the dependence of the $T_x$ signal on the magnitude of the preceding regeneration dose than extending the LED stimulation time. The principal aim of this study is to explore the effects of different IR LED stimulation times (100, 200, 500, 800, 1100, 1400s) on: (i) mitigation of charge carry over; (ii) sensitivity change; and (iii) the form of the dose response curve (DRC). Preliminary results are presented from three dose recovery experiments using the post-IR $IRSL_{50,170}$ protocol carried out on single aliquot coarse-grained (63-125 μm) loess from Tadjikistan. Given dose (GD) was kept constant (38 Gy) but the test dose was varied for each experiment (5, 12 and 20% of GD). The effects ofvarying the LED stimulation time were explored by examining the: (i) overall performance of the dose recovery test; (ii) $T_x/T_n$ ratio; (iii) IRSL signal from the first channel (0.3s) of the test dose ($T_x$) plotted as a function of the last channel of the prior regeneration dose ($L_x$); and (iv) the $L_x/T_x$ ratio from the high regeneration dose (76 Gy).

Dose recovery performance declines for the smaller test dose sizes (5%). For the 5% test dose, notably the 500s and 1100s stimulation times were relatively successful (ratios 0.93-1.03 and 0.91-1.06 respectively) and a well-ordered decline in sensitivity change with stimulation time up to 1400s was observed. The magnitude of $L_x/T_x$ showed a well-ordered increase with stimulation time especially at the 76 Gy regenerative dose point. The IRSL signal from the first channel of the test dose ($T_x$) plotted as a function of the last channel of the regeneration dose ($L_x$) in general showed an inconsistent trend with stimulation time and also large inter-aliquot variability, though the slope of the regression line was on average improved at the 1100s (0.8x) relative to 500s stimulation (1.47x). For the intermediate (12% and 20%) test doses, the apparent impact of $L_x$ on $T_x$ increased with stimulation time. Though dose recovery was good (85-89%), the dose ratio tended to be >1 for the 12% test dose but <1 for the 20% test dose, accompanied by increased inter-aliquot variability with increased stimulation time. The results of this study so far indicate that increasing the LED stimulation time at least partially mitigates sensitivity change for single aliquots of loess when a small test dose is used. The increased $L_x/T_x$ ratio at the 76 Gy regenerative dose point for the longer IR stimulation times raises the prospect of extending the dating limit of the post-IR $IRSL_{50,170}$ protocol when a small test dose is used. Furthermore, the deteriorating performance of dose recovery (and dose ratio within ±10% of unity) at the higher test doses with increased stimulation time may be indicative of "charge retrapping" and should be avoided.

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# The potential of the TT-OSL signal to extend the chronology at Florisbad, South Africa

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The optically stimulated luminescence (OSL) signal from quartz has been successful in extending our knowledge of the chronology of human evolution through parts of the Middle Stone Age (MSA) beyond the range of radiocarbon dating. However, its saturation typically limits its applicability to deposits with equivalent doses ($D_e$) up to ~150 Gy, and depending on the dose rate this may limit the use of this signal to the last ~100 ka. Florisbad, a MSA site in South Africa primarily known for the discovery of a well-preserved cranium of a late archaic modern human, is thought to contain a record dating back to the last ~280-300 ka (Grün *et al.*, 1996). However, the quartz OSL signal shows saturation on both single aliquot and single grain scales at ~100 ka. Therefore, the use of an alternative chronometer is explored.

The thermally transferred optically stimulated luminescence (TT-OSL) signal in quartz has the potential to extend the age range of luminescence dating by an order of magnitude compared to the quartz OSL fast component. However, its applicability to dating has had mixed success, and highly variable lifetimes have been reported for the TT-OSL signal. It is unclear whether existing lifetime calculations are universally applicable, or whether there are inter-sample variations in the stability of the TT-OSL source trap. Initial observations on older samples at Florisbad using TT-OSL show underestimations in the expected equivalent dose. It is possible that this is due to thermal instability of this signal. Following work by Arnold and Demuro (2015), this study explores the use of the preheat temperature to isolate more reliable TT-OSL signals, and the subsequent implications for extending the Florisbad chronology using the TT-OSL signal.

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# Luminescence dating of Holocene soil erosion (Lublin Upland, E Poland): testing new approach to dose rate determination

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Less is a widespread Quaternary sediment in the world (about 10% depending on the definition of loess). In Poland loess covers main parts of the Polish Uplands, the Sudetes-Forelend, the Lower Silesian Lowland and the Carpathian Foreland. These covers are made of different age layers dominated by the the youngest (Vistulian) loess. Due to their properties loess areas were used for agriculture since the beginning of Neolithic. Loess covers are the most susceptible to mechanical denudation associated with atmospheric precipitation. As the result of intensive denudation, at the foot of the slopes and in the bottoms of dry valleys the series of redeposited loess-soil materials have been accumulated. This colluvial materials is reaching up the thickness to several meters. The colluvial sequence is mainly composed of non-homogenic Holocene sediments of various ages and lithology (older soil material and non-carboniferous loess).

This work presents the results of Optically Stimulated Luminescence (OSL) dating of Holocene slope sediments from the Kolonia Celejów site (Nałęczów Plateau, Poland). The loess profile modified by soil processes as well as deposits filling the fossil gully were investigated. For luminescence dating 14 samples from two sediment profiles were collected. The blue light luminescence dating and SAR protocol were applied to the 90-125 μm quartz fraction. In addition, sediment samples were collected for precise dose rate measurements. The subject of studies is a loess-soil sequence in a huge gully system on western part of loess plateau. The selected sediment profile was modified by pedogenic processes, postpedogenic redeposition and secondary accumulation as the colluvial layers. In this study simultaneously with luminescence measurement were done detailed pedoligical and micromorphological studies. Those additional analysis allow to recognize the litho- or pedological microfeatures in the examined sections and thus improve the interpretation of the luminescence dating results. The top of the sediment was measured also by γ spectrometry to assess the $^{137}$Cs isotope which is a marker of modern sediment (no older than 60 years).

Three methods were used to determine dose rates: high purity germanium (HPGe) γ spectrometry, TSAC (thick source alpha counting) and μDose system. The results obtained with HPGe and μDose system are in agreement. Values obtained from TSAC are statistically higher showing signs of so called overcounting. Dose rates were calculated using conventional method and μDose build-in module for dose rate determination. This allowed to combine measurements, apply necessary corrections and obtain more precise and accurate results.

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# OSL dating of cataclysmic glacial outburst flood deposits in the Channelled Scablands of North America

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The largest known floods in Earth history are thought to have occurred in north-western USA, as Glacial Lake Missoula drained catastrophically when the ice dam which impounded it failed (e.g. Baker and Bunker, 1985; Balbas et al., 2017). The flood-water released covered an area of more than 7500 km$^2$ (equal to 40 % of the area of Wales). During these floods, parts of the area were submerged under a fast moving (up to 38 m/s) water column up to 400 m deep (Liu and Baker, 2018). These cataclysmic floods left behind an impressive footprint in the landscape. Beside large-scale geomorphological features, such as coulees, house-height current ripples and cataracts, the floods also deposited extensive sediment sequences. During these mainly post-last glacial flood events, volcanic activity of the Cascadian Volcanoes (i.e. Mt. St. Helens and Glacier Peak) resulted in multiple ash falls over the study area of Washington State, preserved as tephra layers within the flood sediment sequences.

The aim of this project is to develop a clear understanding of the nature, frequency, and timing of these floods, by developing a high-resolution chronology of cataclysmic glacial outburst flood deposits by application of optically stimulated luminescence (OSL) and tephrochronology. The magnitude of these floods and the depth of the water column limit the likelihood of the suspended sediment load being well-bleached. Thus, the application of OSL dating to these sediments might be challenging. First tests in this study are therefore made on aeolian sand anticipated to be of a similar composition and age as the flood sediments, and taken from the research area in Washington State. This aeolian material is not only likely to be well bleached, but also contains multiple tephra layers, which provide independent age control for the OSL ages generated. Once successfully applied to aeolian sediment, and equipped with better knowledge of the luminescence behaviour of these sediments, the flood deposits are then the main target for OSL dating in this study. The main goals are (i) to establish a chronological record of these flood deposits and (ii) to infer different flood paths based on the timing of the recorded deposits throughout different sampling locations. Whilst the tephra units preserved within the flood sediments will serve as an important independent cross-check on the luminescence ages generated, in some settings there are also opportunities for OSL ages bracketing the tephra layers to be used to refine the current age estimates of the ash falls (Mullineaux, 1986), thereby improving our knowledge of the eruptive history of Cascadian Volcanoes.

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# Identifying archaeological "firesetting" evidence by luminescence protocols at the La Turquesa mine in Catalonia, Spain.

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The copper ores of the Turquesa mine from Cornudella de Montsant (Priorat, province of Tarragona), Catalonia, Spain were exploited in Prehistoric times (Chalcolithic and the Bronze Age) and during XIX century (Rafel *et al.* in press). The primary minerals were chalcopyrite and pyrite disseminated in milky quartz, the supergene alteration produced a gossan zone with goethite, malachite, azurite and cuprian crandallite. The gossan evolves at 3 m in depth to a supergenic enrichment zone with Cu-rich sulphides as chalcocite that replaces the primary chalcopyrite (Rafel *et al.* in press). Recent archaeological excavation at Turquesa mine revealed nearly 75 mining stone tools, mainly picks and hammers. Typical round hollows were found close to the cupper-vein pointing to the extraction of ore by "firesetting" during mining activities in Pre-historic times. Current research questions concern the mining technologies applied and when they have occurred. Thus, the main goals of this work are to confirm the evidences of firesetting as the characteristic technique employed in prehistoric ore extraction, and to develop appropriate protocols to absolute dating by using luminescence techniques.

A total of seven rock fragments from two round hollows (MT1 and MT2) and one soil sample inside MT 2 were collected. In addition two samples from the hosted rock and one sample from the unexplored copper vein were collected. In situ gamma spectrometry was measured close to each of the collected samples. TL protocol (Castaing et al, 2005) and a semi-quantitative protocol (Rodrigues et al, 2013) were applied to all the studied samples, enabling to study the TL, OSL, and IRSL signals in enriched quartz coarse grains and polimineralic coarse grains. Samples with heating features were detailed studied using SAR-OSL and single grain protocols, in order to evaluate the possibility of absolute dating the firesetting events with luminescence techniques.

Results were very promising on the use of luminescence techniques to attain the main goals. In two samples from the round hollow MT1, low TL-OSL natural signals were found, pointing to firesetting techniques of ore extraction. So far, SAR-OSL seems to be the most appropriate technique to data those events, even dispersed values were found for De. This is most probably due to the inherent heterogeneous range of temperatures obtained during firesetting events.

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# OSL Ages from Salt Marshes; Potential Application in Sea-Level Studies

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The ability of salt marsh stratigraphies to act as high resolution "tide gauges" of Holocene sea-level change is now well established (Barlow et al., 2013; Edwards and Horton, 2000; Gehrels, 2000). It is vital for sea-level reconstructions from salt marshes to have well-defined and robust chronologies in order to produce robust age depth models for the entire core. Typically AMS radiocarbon ages, from either plant material or bulk samples where sufficient plant remains are lacking, remain the predominant source of age data in salt marshes. Whilst a suitable and widely used method for dating sediments of ages spanning the entire Holocene, radiocarbon techniques have significant issues in their application to sea-level reconstructions for the last 500 y (Reimer et al., 2009). This is a function of substantial fluctuations in global atmospheric $^{14}C$ over this period (Barlow et al. 2014). This results in a great deal of so called "wiggle" in the radiocarbon calibration curve for the last 500 y. As a result, several calibration solutions may be possible for a single date (Barlow et al. 2013). Further complications can arise from contamination of bulk samples from either sources of old carbon (e.g. coal) or modern carbon (e.g. contemporary root networks).

Despite its own potential limitations in intertidal settings (high grain size variability, incomplete bleaching, bioturbation and vertical sediment mixing) (Madsen et al., 2011), OSL may represent an alternative age constraint to radiocarbon in marshes with discrete sandy deposits (e.g. storm deposits). This study presents the results of attempts to date sandy deposits in an Anglesey (North Wales) salt marsh with the goal of demonstrating its potential use in overcoming the limitations of radiocarbon in sea-level studies. This forms part of a wider study attempting to reconstruct Late Holocene sea-level using salt marsh foraminifera.

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# Assessing residual dose of post-IR IRSL of K-feldspar in modern and Holocene beach–shoreface sands, Pacific coast of eastern Japan

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Infrared stimulated luminescence (IRSL) and post-IR IRSL (pIRIR) of K-feldspar are harder to bleach than quartz optically-stimulated luminescence (OSL), and likely lead to overestimate of sediment date. However, residual doses of modern sediments have not been determined systematically, hindering their strict estimate and thus reliable application of K-feldspar IRSL and pIRIR dating to various environments. This is especially critical for Japan's active tectonic margin as quartz grains from young orogens are dim and there is extensive distribution of coastal and shallow-marine sediments since the middle Pleistocene to date for characterizing palaeo-environmental changes. We assessed the magnitude of residual dose of K-feldspar coarse grains (180–250 μm in diameter) extracted from modern and Holocene beach–shoreface sands along the Pacific coast at Kujukuri, eastern Japan. In $IRSL_{50}$, modern foreshore and shoreface sands, obtained from the subaerial beach to lower shoreface 34 m deep, show residual doses < 0.2 Gy, which correspond to age overestimate of only several decades assuming the average annual dose in the area (2.5 Gy/ka). $pIRIR_{50/150}$ is characterized by residual doses of 1–3 Gy, equivalent to 400 to 1300 years overestimate. Residual doses of $pIRIR_{50/290}$ are up to 30 Gy, suggesting possible overestimate by >10000 years. For each signal, shoreface sands show no correlation of residual dose with the water depth. In contrast, one sample from foreshore shows lower residual doses of $pIRIR_{50/150}$ and $pIRIR_{50/290}$ than shoreface sands, suggesting that sustained subaerial sunlight bleaching appears to diminish the difficult-to-bleach component of these signals. A shoaling-upward beach-shoreface succession recognized in a sediment core in the Kujukuri strand plain reveals concordant results with modern sands. The succession is dated younger than 2400 years by radiocarbon dating. Fading-corrected $IR_{50}$ ages agree well with or even slightly younger than expected ages, indicating that the residual dose is ignorable. In contrast, corrected $pIRIR_{50/150}$ and $pIRIR_{50/290}$ ages show overestimates of 700–1300 years and 9000–12000 years, respectively, as also expected from modern sands. These results show $IR_{50}$ is generally well-bleached even in the underwater environment up to 34 m deep off the Pacific coast at Kujukuri or sand grains are extensively circulated between the nearshore and deeper water so that residual $IR_{50}$ is not accumulated much before the deposition. So far, $IR_{50}$ appears to be the best signal for dating Holocene sand in this area and $pIRIR_{50/290}$ is likely to retain a residual dose that is critical even for distinguishing sub-stages in the Last interglacial period (Marine Isotope Stages 5a, 5c, and 5e). $pIRIR_{50/150}$ may have an advantage in strictly dating the late Pleistocene coastal deposits if associated with a sufficiently low fading rate.

# Chronology for mountainous river terraces: OSL/IRSL and rock dating techniques applied to carbonate-rich terraces in the Atlas Mountains

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Improvements in numerical dating methods continues to open new possibilities for understanding sedimentary archives and thus unravelling Earth surface processes (e.g. Rixhon et al, 2017). In general, the Optically Stimulated Luminescence (OSL) dating is successful for deposits spanning last 100 ka, while Infra-Red Luminescence (IRSL) dating of feldspar can be applied on longer timescales (Buylaert et al, 2012). The Atlas Mountains in Morocco contain an abundance of carbonate-rich river terraces recording glacial-interglacial river evolution (Stokes et al., 2017) and are an ideal place to apply OSL techniques on mountainous river sediments deposited at distinct time scales.
River strath terraces are formed by transition between valley widening and downcutting of terraces in response to local divergence of sediment-transport capacity (Hancock; and Anderson, 2002). The formation of terraces in response to a change in climate can be distinguished from a response to a change in local uplift rates (Hancock; and Anderson, 2002). While separating climatic from tectonic signals in the geomorphic record remains a challenges, it is possible using the records of erosional surfaces and sediments of river terraces. Where river strath terraces and their sediments are preserved in mountainous settings they form the ideal opportunity to test the timescales and responses of surface process to climate and tectonic histories. This requires high resolution dating of river terraces and their coarse-grained sediments. IRSL dating has the potential to provide insight into glacial-interglacial erosional and depositional processes over the last few cycles. An experimental method of bedrock exposure (Sohbati et al, 2012) has the potential to unlock insight into erosional processes on the timescale of river terrace formation.

Analysis of sediments, bedrock and pebbles was undertaken in the summer of 2018 after a terrace mapping and sampling campaign in the Atlas. OSL and IRSL analysis of the material resulted in age estimates and has established the sensitivities of various rock material to Luminescence signals. Further work will include extensive sampling and dating of terrace conglomerates, as well as targeted sampling for rock exposure dating.

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