Controls on the Distribution of Volcanism and Intra-Basaltic Sediments in the Cambo-Rosebank Region, West of Shetland

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Abstract: The magma-rich North Atlantic Margin is one of the last frontier areas of hydrocarbon exploration within the United Kingdom Continental Shelf. In 2004, a major oil and gas discovery (Rosebank) was made within Palaeocene to Eocene age lavas in the Faroe-Shetland Basin. The Rosebank field consists of intra-basaltic terrestrial to marginal marine reservoir sequences, separated by basaltic lava flows and volcaniclastics. Despite the identification of a major intra-lava incised drainage system running parallel to the SW-NE trending Rosebank Field, the controls on the distribution of both the volcanics and intra-volcanic sediments was previously unclear, in part due to the difficulties that volcanic sequences pose to seismic acquisition, processing and interpretation. This has led to uncertainty in defining the wider intra-basaltic play. However, the examination of the recently acquired FSB2011/12 MultiClient GeoStreamer® Survey has facilitated increased definition of the geological units within and below the volcanic succession, and a reinterpretation of the Late Palaeocene to Early Eocene stratigraphy. Through integration of 3D seismic data and well analysis we present a regional overview of the volcanics and intra-basaltic sediments in the Rosebank region of the Faroe-Shetland Basin. We find that the structural setting of the Rosebank Field, in addition to lava flow morphology, strongly influences the distribution of the intra-basaltic play-fairway within the Palaeocene-Eocene Flett Formation. Restriction of fluvial siliciclastic sediments adjacent to the Corona Ridge extends the theorised Rosebank play fairway to the area southwest of the Rosebank Field. Our analysis indicates that understanding basin structure is integral to the success of intra-basaltic plays.

Hydrocarbon exploration in the Faroe-Shetland Basin (FSB), located on the Atlantic Margin of the United Kingdom Continental Shelf (UKCS), has been ongoing for the last 40 years.

Initially, during the early exploration history of the basin it was hoped that the FSB would mimic the prospectivity of the neighbouring North Sea. However, it has not met with the same success, being both technically and geologically challenging in terms of hydrocarbon exploration and production, in part due to the presence of igneous rocks throughout much of the basin (Varming *et al.,* 2012).

Throughout much of the Late Palaeocene and Early Eocene, the Faroe-Shetland Basin was subject to the eruption of up to 6.6 km of flood basalts, which form part of the Palaeogene North Atlantic Igneous Province and cover over 50% of the north-western side of the basin (White *et al.,* 2003; Schofield & Jolley, 2013) (Fig. 1). Despite heightened drilling activity in the early 2000's, the area of the basin covered by volcanics remains relatively underexplored and a frontier area for exploration (Varming *et al.,* 2012). The discovery of the Rosebank Field in 2004, situated on the feather edge of the flood basalts, opened up a new play type within the basin with ~56.1 to 55.2 Ma siliciclastic dominated reservoir successions that developed within the volcanic succession during periods of volcanic quiescence (Duncan *et al.,* 2009; Poppitt *et al.,* 2016). Whilst fluvial channels have been identified within the Rosebank reservoir equivalent successions (Schofield & Jolley, 2013) the detailed stratigraphy and the controls on the emplacement of volcanics and intra-volcanic sedimentary rocks remains poorly understood both locally and regionally. In particular, the origin and wider distribution of the 'clean' sand units that form the Rosebank and intra-basaltic play fairway remain enigmatic (Schofield & Jolley, 2013).

The PGS and TGS Geostreamer® broadband seismic data, acquired in 2011/2012, spans the featheredge of the basalt cover imaging the transition from the Upper Palaeocene to Lower Eocene volcanics and similar age sediments in the Faroe-Shetland Basin (Fig. 2). Additionally, it provides a hitherto unprecedented view of basement structure and sill geometries in an area where intra and sub-basalt seismic imaging has been particularly

challenging (Spitzer *et al.,* 2008). The aim of this paper is to detail the stratigraphy of the Late Palaeocene/Early Eocene volcanic succession in the Faroe-Shetland Basin and investigate the controls on the distribution of volcanic and intra-basaltic sediments, by providing insights into the underlying basement structure. We also highlight the potential areas for further exploration within the volcanic successions of the Faroe-Shetland Basin.

Geological History

Regional Structure

The Faroe-Shetland Basin consists of a series of SW-NE trending rift basins and structural highs that formed during episodic Mesozoic rifting (Fig. 1) (Duindam & Hoorn, 1987). The basin is bounded to the north and south by the Erlend Platform and the Wyville Thomson Ridge, respectively (Dore *et al.*, 1999). The Faroe-Shetland Basin can be divided into several sub-basins, of which the Judd, Foinaven, Flett and Corona are referred to in this study (Fig. 1). The most widely used stratigraphical scheme in the Faroe-Shetland Basin is the T-sequence scheme and although this was defined within the Judd and Foinaven basins in the SW of the basin (Ebdon *et al.,* 1995) (Fig. 3), it is used here for consistency with previous studies (Schofield & Jolley, 2013; Schofield *et al.,* 2015). Additionally, the standard UK Offshore Operators Association (UKOAA) lithostratigraphic nomenclature is used to refer to formations or key horizons (Fig. 3).

The tectonic evolution of the Faroe-Shetland Basin encompasses a number of rifting and compressional events that span a time period of ~400 Ma, from the Devonian to the Cenozoic (Dean *et al.,* 1999; Dore *et al.,* 1999). Onshore, the Caledonian orogeny formed a NE-SW trending basement grain throughout Scotland (Dean *et al.,* 1999). This structural grain

is thought to extend offshore into the NE Atlantic Margin, influencing subsequent tectonic events within the Faroe-Shetland Basin (Kimbell *et al.,* 2005). The basement grain is thought to have a long-lasting effect on the structural fabric of the Faroe-Shetland Basin, through nucleation of possible transfer zones (deep-seated shear zones) (Ellis et al., 2009) and localisation of faults along pre-existing structural weaknesses (Moy *et al.,* 2009; Dore *et al.,* 1997b).

Importantly, much of the Cenozoic basin structure within the Faroe-Shetland Basin was initiated during the Cretaceous. For a period of ~70 Myrs from the early Cretaceous, the Faroe-Shetland Basin underwent repeated rifting events and, in the Flett sub-basin, a 1000-3000 m thick, post-rift Cretaceous succession was deposited (Dean 1999).

Palaeocene depositional environment within the FSB

In the FSB, the early Palaeocene is represented by deep marine conditions with a series of basin floor fans that transported sands towards the basin centre from the basin margins such as the Judd High (Lamers & Carmichael, 1999). These basin floor fans were followed by deposition of the Lamba Formation (sequence T36 - T38, ~58.4– 56.1 Ma), which represents a major northerly progradational event within the Judd and Foinaven Sub-basins, recording a change from basal slope conditions to a deltaic succession composed of mudstones and subordinate sandstones (Shaw-Champion *et al.*, 2008). During this time, the shelf edge was positioned along the northern edge of the Westray High (marked by the northern extent of the Lamba Fm. clinoforms in Fig. 4). The upper Lamba Formation, (sequence T38), contains a number of north to north-westerly prograding clinoforms ~500 m high (Shaw-Champion et al., 2008), which likely formed at or close to sea level as the delta front prograded into deeper water (Smallwood, 2002).

During the Late Palaeocene (sequence T38/T40 boundary), the FSB was uplifted and an erosional surface developed truncating the Lamba and underlying formations in the Judd and Foinaven Sub-Basins. (Morse, 2013; Champion, 2008). Coincident with uplift, eruption of the Faroe Island Basalt Group (FIBG) commenced at the onset of sequence T40 (56.1 Ma) with a series of flood basalts emplaced within the basin up to sequence T45 (~55.2 Ma; Schofield & Jolley, 2013). Siliciclastic sediments deposited within the volcanic succession ('intra-basaltic sediments') during this time period are collectively grouped within sequences T40 to T45 and referred to as the 'Colsay Member' of the Flett Formation (Duncan & Hansen, 2009).

The supra-volcanic succession, sequence T45, termed the Hildasay Sandstone Member (Knox *et al.,* 1997), is more widely distributed in comparison to sequence T40, in places covering the T38/T40 unconformity, although it pinches out towards the basin bounding highs such as the Rona Ridge and the Solan Bank High (Ebdon *et al.,* 1995). Sequence T45 lowstand tracts are restricted to the centre of the Corona and Flett sub-basins area and deposited in a bathyal setting with highstand and transgressive tracts on the shelf deposited in a shallow to marginal marine setting (Ebdon *et al.,* 1995).

By the deposition of the Balder Formation (sequence T50), emplacement of lavas in the Faroe-Shetland region had ceased. The Balder Tuff member, contained within the lower part of the formation has typically been used as an historical seismic marker within the North Sea and the Faroe-Shetland Basin. This widespread tuff horizon has been linked to the incipient Greenland-Faroes rift and the initiation of seafloor spreading in the North Atlantic (Jolley & Bell, 2002; Jolley & Widdowson, 2005; Watson *et al.*, 2017).

Overview of the Cambo-Rosebank Region

The area surrounding the Cambo High, North of the Westray Ridge within the Faroe-Shetland Basin, presents an opportunity to gain a better understanding of the interplay between volcanics and intra-volcanic sediments (Figure 4). At the centre of the study area are two major structural highs; the Westray and Cambo Highs. The Cambo High (which covers an area of ~60 km^2), drilled during evaluation of the Cambo prospect in 2002 (204/10- 1), is granodioritc in composition. Similarly, the Westray High (which covers an area of ~70 km^2), although smaller in size, is granitic in composition (well 205/15-2). Both highs are thought to be Caledonian age igneous plutons as demonstrated by onlapping Cretaceous claystones (e.g. at the base of well 204/14-2) (Watson et al. 2017).

Two ridges extend to the north and south of the Cambo and Westray High. The northern Corona Ridge strikes ~150 km across the Faroe-Shetland Basin in a SW-NE direction. In the south, the top of the ridge is capped by the Jurassic Kimmeridge Clay Formation overlying Upper Jurassic Rona Formation sandstones and Carboniferous Clair Group sandstones (wells 213/27-1 and 213/27-2). Further to the north, the ridge is capped by Triassic sandstones situated above Carboniferous to Devonian age sediments (213/23-1). The ridge is onlapped by Cretaceous to Palaeocene age sediments along its extent and is consequently interpreted as a Mesozoic age tilted fault block that developed during Cretaceous aged rifting.

Of key stratigraphic and exploration importance in this study, is the Rosebank Field, located towards the southern extent of the Corona Ridge ~ 30 km north east of the Cambo High. Exploration wells targeting the Rosebank Field drilled three anticlinal closures within Rosebank and Rosebank North (Poppitt *et al*, 2016). The southern ridge, deemed the Westray, strikes ~30 km NNE-SSW and is generally capped by Jurassic sediments suggesting a similar origin to that of the Corona Ridge (204/15-2).

Data and Methods

The main dataset used in this study is the FSB2011/12 MultiClient GeoStreamer® survey. Covering an area of 2662 km^2, the survey was acquired over the northern Westray Ridge, the Cambo High and the southwestern Corona Ridge, spanning the transition between a siliciclastic dominated terrain to the South to a volcanic terrain in the North (Fig. 3 & Fig. 4). Typically, conventional streamers suffer from near surface noise created by ocean waves. These creates ghosts that interfere at particular frequencies, dependent on streamer depth, attenuating certain parts of the frequency range (Fig. 5B). The Geostreamer® is a dual sensor marine streamer comprising of co-located hydrophones and vertical particle motion sensors that record both the upcoming and downgoing wavefield information (Fig. 5A). As the ghosts will be recorded with opposite polarity by the hydrophone and normal polarity by the particle motion sensors (Fig. 5B), the notches created by interference can be infilled by the complimentary spectra to create a deghosted frequency spectrum that records the full frequency bandwith of the seismic data. Increased high frequencies reduce the dominant wavelength recorded within the seismic data and thus lead to finer vertical resolution of the seismic. Increased low frequencies help to reduce the side lobes contained within the data. Furthermore, the data used within this study had been processed a number of times by PGS prior to it being provided for interpretation. A dual sensor wave field separation was undergone to reduce the impact of mechanical noise on the particle motion sensor (Day *et al.*, 2013). A 3D surface-relation multiple elimination was used to suppress multiples within the data (e.g. Dandem & Verschuur, 1998). To further reduce the impact of multiples and noise on the seismic data, a high-resolution Radon demultiple was used (e.g. Hargreaves *et al.*, 2001). Finally, an anisotropic Kirchhoff prestack time migration was used to improve imaging,

in particular for steeper events (Kirstiansen *et al.*, 2003). The interpretation conducted within this study was undertaken using the Final Kirchhoff PSTM Stack that has been waveshaped to zero phase. The data was not converted from time to depth.

The data is displayed with a reverse polarity, whereby a downward increase in acoustic impedance corresponds to a negative amplitude (red) reflection and a downward decrease in acoustic impedance is represented by a positive amplitude (blue) reflection. Basalt within the Rosebank Field has an interval velocity of ~3800 ms^{-1} (taken from ~2987 m measured depth in well 213/27- 2) with a dominant frequency of ~25 Hz (taken from the Geostreamer® FSB 2011/12 survey). These values were used to calculate a vertical resolution of ~38 m for the extrusive volcanics in the Rosebank Field. Similarly, the intra-basaltic Colsay 3 of well 213/27-2 had an internal velocity of ~3000 m (taken from ~2950 m) with a dominant frequency of ~23 Hz had a vertical resolution of ~32.5 m.

Due to the preservation of both low and high frequencies in dual sensor streamers, the survey aides with better identification of geological units within and below the volcanic succession, especially at the lower frequencies required to image structures sub-basalt (Ziolkowski *et al.,* 2003). The broad nature of the frequency spectrum in broadband surveys is particularly useful for spectral decomposition, as more variation is observed in colour blends, aiding interpretation of horizons produced during seismic analysis (Szafian & Gómez-Martínez, 2015).

Within the confines of the FSB2011/2012 Geostreamer Survey, seventeen wells were used to aid analysis, ten of which drilled extrusive volcanics: Svinoy (6004/12 – 1); six wells from the Rosebank Field (205/01-1, 213/26-1, 213/27-1, 213/27-2, 213/27-3, 213/27-4) (Figs. 5 & 6) and four wells from the Cambo Field, a nearby four-way closure consisting of Lower Eocene deltaic to shoreface sands (Fielding et al., 2014) (204/10-1, 204/10-2, 204/10a-3, 204/10a-4) (Fig. 5). A 1D synthetic seismic was generated from the southern Rosebank wells

209 within the Geostreamer® survey (205/01- 1 and 213/26- 1), using the sonic and density
210 wireline data throughout the post-volcanic and volcanic succession (Fig. 6). Velocity data for
211 all wells within the survey was of high quality (i.e. well headers matched with the seismic well
212 tie) and the well tie facilitated correlation of the Rosebank wells with the Cambo wells (Fig.
213 7).

214 **Distribution and Stratigraphy of Volcanics and Intra-volcanic Sediments**

215

216 Where penetrated by wells in the study area, the volcanic succession reaches thicknesses of
217 up to ~ 120 m, thickening into the Flett and Corona Basins and thinning towards the Westray
218 High in the south. The intra-basaltic units in the study area have been deemed the Colsay
219 Member of the Flett Formation (Duncan & Hansen, 2009). The Colsay Member was further
220 divided into numbered units based on their stratigraphic level in the sequence (Fig. 8). The
221 first intra-volcanic sequence penetrated was deemed Colsay 1, the second Colsay 2 and so
222 on. The volcanics in the region were not numbered, but given a broader name of Upper,
223 Middle or Lower dependent on their relative level in the sequence (Fig. 8). Here, we provide
224 a detailed description and interpretation of the different units within the volcanics succession,
225 based on the seismic and well analysis conducted within this study. In order to capture the
226 evolution of the study area, we start at the base of the succession (Colsay 4) and work up
227 from there. A detailed description and interpretation of the different units within the volcanic
228 succession is presented below.

229

230 ***Colsay 4***

231

232 The base of the volcanic succession is marked by a regionally extensive seismic 'soft kick' that
233 ties back to the Colsay 4 unit and similar-aged volcaniclastic sediments in the available wells

(Fig. 7). Deposition of Colsay 4 sediments precedes the eruption of the Rosebank Lower Volcanics and this stratigraphic marker onlaps the Cambo and Westray Highs. Typically volcanicastic in lithology, Colsay 4 overlies marine shales at the base of the volcanic succession with the transition marked by a ~ 5 m thick coarsening upwards siltstone package overlying a thick, Lower Palaeocene claystone succession. In the south of the Rosebank Field, volcaniclastic sediments typically consist of interbedded claystones and siltstones and to the north they grade into alternating siltstone and volcanicastic sandstone beds. Notably, in wells drilled off crest of the Corona ridge (213/26-1, 213/27-2), thin (~10 m) packages of siliciclastic sandstones were encountered at the very top of the Colsay 4 succession (Fig. 8).

Interpretation

Colsay 4 is a regressive package that developed prior to the eruption of volcanics in the study area. The absence of volcanics and the presence of volcaniclastic sediments in the Rosebank and Cambo Wells suggests that early T40 age eruptions were not drilled by available wells, but were being actively eroded. This conforms to palynological work that also suggests Cycle I and basal Cycle II volcanics present on the Faroe Islands are not present in the Rosebank region (Jolley *et al.* 2012).

Colsay 4 siliciclastic sediments were encountered at the very top of the sequence by wells drilled off-structure (213/26-1, 213/27-2), but were absent in wells drilled on top of the Corona ridge (e.g. 213/27- 1) (Fig. 8), This suggests that, prior to eruption of the Rosebank Lower Volcancs, the sides of structural highs, such as the Corona and Westray Ridges, were a focal point for transportation of siliciclastic sediments.

Rosebank Lower Volcanics (RLV)

Rosebank Lower Volcanics (RLV) cover much of the study area and are encountered by all Rosebank wells. Volcanics of this age are also encountered on the Cambo Structure. The Rosebank Lower Volcanics form a seismic 'hard-kick' that brightens north of the Corona Ridge, thinning onto palaeohighs and towards the south of the study area (6004/12-1z). The RLV can be confidently tied back to the 213/26-1 well where the contact between Colsay 3 sediments and the Rosebank Lower Volcanics is clearly imaged (Fig. 6). Basal sequence T40 flows are thin (~7 m) and characteristically tabular classic lava flows with thin basal crusts and thick upper crusts (Nelson *et al.*, 2009a; Millett *et al.,* 2016) (Fig. 8). These basal flows are most common on the northern side of the Corona ridge (213/26-1). The top of the RLV succession in the south of the Rosebank Field is typically marked by a ~40 to 50 m thick flow. The petrophysical characteristics of the Rosebank Lower Volcanics flows resemble those of compound lava flows, possessing a consistently high density (~2.55–2.7 g/cm^3), and a consistently high sonic velocity (~45–80 μs/ft) (Fig. 9) (Millett *et al.*, 2016). The whole succession thins considerably toward Rosebank North (213/27- 3) where only a couple of small lava flows are observed (~3 – 7 m). In the South of the study area, Svinoy (6004/12-1) penetrated a thin (5 m) T40 volcanic package, highlighting the widespread nature of T40 aged volcanics.

Interpretation

Located at the base of the volcanic succession, the sequence T40 volcanics are of equivalent age to the Upper Beinisvørð Formation of the FIBG (Cycle 2 of Jolley *et al.* 2012). Well and seismic data suggest that, initially, classic tabular lava flows were emplaced over a regionally

283 extensive area. Subsequent sequence T40 volcanism is recorded by more localised compound
284 lava flows (213/26-1).
285
286 ***Colsay 3***
287
288 North of the Corona Ridge, the Colsay 3 seismic horizon is a high amplitude, laterally
289 continuous positive seismic reflection (Fig. 7). Within the south of the Rosebank Field, the
290 Colsay 3 package is relatively thin (~10 m thick) consisting mainly of floodplain (213/26-1) and
291 fluvial (205/01-1) sedimentary packages (Fig. 10). The sequence thickens considerably into the
292 central Rosebank wells, where thick (~50 m) successions of alternating sandstones, claystones
293 and siltstones indicative of an estuarine environment are recorded (Schofield & Jolley, 2013).
294 These successions were cored during the drilling of the 213/27-2 well where the sandstone
295 composition is dominantly quartzose and feldspathic (Fig. 10). In Rosebank North, the
296 sequence continues to thicken (~120 m), and is dominated by siltstone with a few influxes of
297 volcaniclastic sandstone.
298 The Colsay 3 reflector was also mapped to the south of the Corona Ridge where it
299 dims to the north of the T38/T40 unconformity. In RMS amplitude extraction and spectral
300 decomposition of this horizon, a linear feature, with an axis orientated SW-NE, can be
301 observed between the Cambo High and the southern extent of the Rosebank Field (Fig. 11).
302 The Cambo High is a palaeohigh in the Cambo-Rosebank area that has a provenance of 400-
303 500 m relative to the Corona Ridge. On the Cambo High, the linear feature is a ~5 km wide
304 topographical low that thins towards the south of the Rosebank Field where it is intersected
305 by the 205/01-1 well. A similar topographic low is observed to the north of the Corona
306 Ridge, coinciding with the proposed intra-basaltic drainage system imaged by Schofield & Jolley
307 (2013).

Interpretation

The Colsay 3 unit marks a hiatus in volcanism in the Faroe-Shetland Basin significant enough to allow a dominantly siliciclastic sedimentary environment to re-establish itself in the greater Rosebank and Cambo area. The fluvial to estuarine, non-volcaniclastic facies observed here, alongside the orientation of the SW-NE trending intra-basaltic fluvial system described by Schofield & Jolley (2013), suggest that Colsay 3 is largely sourced from the area south of the flood basalts, where sources of clean sediment exist. However, through core analysis and seismic geomorphology of the Colsay 3 reflector, we also recognise local contributors to intra-volcanic sedimentation. Due to its seismic character and the dominance of fluvial sedimentary facies in well 205/01-1 (Poppitt *et al.*, 2016), the linear feature running between the Cambo and Rosebank Field, is interpreted as a topographic low exploited by a fluvial system. Due to the concurrent deposition of coarse grains of quartz and feldspar within Colsay 3 (e.g. 213/27-2 Colsay 3 cored sequence, Fig. 10) and what appears to be subaerial exposure of parts of the granodioritc Cambo High during deposition of Colsay 3 (Fig. 11), we suggest that parts of the Colsay 3 succession in Rosebank are sourced relatively locally from the Cambo High (20 km away).

Colsay 2

The Colsay 2 volcanic and intra-volcanic unit is a laterally extensive negative seismic reflection that brightens significantly on the northern edge of the Corona Ridge (Fig. 6 & 7). Similarly, it is penetrated by all Rosebank wells in the study area (Fig. 8). Where penetrated, top Colsay 2 is marked by a basalt flow that thins (from ~20 m to 0 m) towards Rosebank North where

it grades to volcaniclastic sandstones. In the centre of the Rosebank Field (wells 213/27-1, 2 and 4) there is a thin (~10 m) siliciclastic Colsay 2 intra-basaltic package that thickens towards Rosebank North (~ 40 m) (Fig. 8). To the south (as cored by 205/01-1), the top of the Colsay 2 intra-basaltic package is marked by volcaniclastic siltstones, siltstones and lignitic material. Whilst north of the Corona Ridge the Colsay 2 reflector is a laterally extensive negative seismic reflection, progressively south of the Corona Ridge, the reflection appears less bright, thinner, and more fragmented (Fig. 7). It is seen to onlap the T38/T40 unconformity on the northern side of the Westray High. In well 205/01-1, relative to well 213/26-1, the intersection of the linear feature between Cambo and Rosebank (imaged in the Colsay 3 spectral decomposition) corresponds with an increase in the proportion of volcaniclastic sandstones (Fig. 7).

Interpretation

The Colsay 2 member records a period of lower volcanic activity in the Rosebank-Cambo region, during which siliclastic sedimentary systems compete with the volcanics for accommodation space. Many of the features identified in Colsay 3, such as the potential drainage systems parallel to the Corona Ridge, remain established during this period of time. As siliciclastic systems remain active alongside the volcanics during Colsay 2, it is likely that any drainage systems contain a large proportion of volcaniclastic and siliciclastic material relative to the surrounding area (e.g. well 205/01-1 and the topographic lows in Figure 9). The basalt flows intersected by well 213/26-1, are potentially a source for volcaniclastic sandstones in the Rosebank Field.

Colsay 1

Within the FSB 2011/2012 Survey, the Colsay 1 reflector is the most laterally extensive, prominent positive seismic reflection within the volcanic succession (Fig. 6 & Fig. 7). North of the Cambo High, the reflector is continuous, brightening north of the Corona Ridge. The bright area abuts the Corona Ridge and this increase in brightness is marked by a shift to higher frequencies observed through use of spectral decomposition (Fig. 11). South of the Cambo High, the reflector becomes much less continuous and less bright until it onlaps the T38/T40 unconformity in the region of the Westray High (~ 5 km north of well 204/14-2, Fig. 4).

The Colsay 1 member can be confidently tied back to all available Rosebank Wells (Fig. 6, 7 & 8) although it is not intersected by any of the Cambo wells available. Notably, the base of the unit is marked by a ~5 m fining upwards package and an influx of siltstone. The Colsay 1 reflector nearly drapes the Cambo High, suggesting that it was nearly buried during Colsay 1 times (Fig. 7).Notably, the linear feature running between Cambo and the Corona Ridge, visible within the Colsay 2 and 3 units is fainter when imaged on the Colsay 1 reflection (Fig. 11).

Interpretation

The Colsay 1 intra-volcanic member records a significant hiatus in volcanic activity, several marine transgressions and the boundary between T40 and T45 in the study area. In the central Rosebank wells, the basal section of Colsay 1 is sequence T40. Sediments of this age are typically fluvial sandstones, similar in composition to Colsay 3. Sequence T40 Colsay sediments are capped by a major transgression marked by an influx of shales and siltstones, and the overlying Colsay 1 package is sequence T45 in age and fully marine. An increase in the

brightness of the Colsay 1 reflector to the north of the Corona Ridge (observable in Fig. 7A) is marked by an increase in the abundance of siltstones and claystones relative to sandstones in Colsay 1, from 47% of the succession (205/01-1) to 62% (213/26-1). This change in seismic and sedimentary facies just north of the Corona Ridge, is taken to be an approximate position of the coastline during Colsay 1.

The lack of a feature corresponding to the proposed drainage system imaged between Cambo and Rosebank in Colsay 3 suggests that, by the end of Colsay 1, the drainage system had become infilled by a combination of late stage T40 volcanics and the Colsay 2 and 3 successions in the area.

Rosebank Upper Volcanics

The Rosebank Upper Volcanics, situated towards the top of the volcanic succession, are some of the most clearly imaged lava flows observed within the seismic data (Fig. 13). Seismically, the Upper Volcanics form a negative seismic reflection representative of the transition between the overlying volcaniclastics and the lava flows themselves. The lava flows have a particularly discontinuous seismic response and individual flow lobes can be identified (Fig. 13B). Their petrophysical character differs from the lower volcanics in displaying a saw tooth texture density and sonic, typical of compound lava flows (Millett *et al.,* 2016) (see Fig. 9). In RMS amplitude extractions of the horizons, the lava flows form relative bright spots.

Unlike the underlying successions, the lateral extent of the Rosebank Upper Volcanics is constrained to the area surrounding the Corona Ridge, with the full extent of the horizon mapped shown by Figure 13. A major vent structure (1 x 1.5 km) situated ~1 km south of the 205/01-1 well was clearly imaged with separate lava flows flowing either north into troughs in

the Corona Ridge, or South into the Flett Basin (Schofield *et al.*, 2015). The vent structure is situated directly above the minimum depth reached by an underlying sill and disruption in the seismic beneath the vent structure may represent the plumbing system of this vent (Fig. 13). A similar feature is noted north of the Corona Ridge, where the presence of a smaller lava flow is coincident with a vent positioned above the flow lobe of a sill (Fig. 13).

Interpretation

The Rosebank Upper Volcanics are a series of lava flows representing the subaerial eruption of basalt following deposition of Colsay 1. Compound lava flows of this age are stratigraphically equivalent to the Malinstindur Formation in the Faroe Islands Basalt Group (Passey & Jolley, 2008). Despite this, the range of thicknesses observed in the available wells and the variability in the areal extent of the lava flows observed in the study area highlights that basinal eruptions were separate volcanic events from those on the Faroe Islands. The coincidence of the Faroe-Shetland Sill Complex with eruptive centres highlights the importance of sills in facilitating magma transport within the Faroe-Shetland Basin (Schofield *et al.*, 2015).

Rosebank Upper Volcaniclastics

The Rosebank Upper Volcaniclastics represent the uppermost section of the volcanic succession in the wider Rosebank and Cambo area. They are identified as a bright negative seismic reflection that is identifiable over the entire FSB2011/2012 survey (Fig. 7). In Rosebank, the Rosebank Upper Volcaniclastics are typically volcaniclastic (predominantly volcaniclastic sandstone) sedimentary rocks of sequence T45 in age. The unit differs in the Cambo region where the first volcanic units encountered are basalts interbedded with predominantly

volcaniclastic claystones (Fig. 8). Wells 213/27-2 and 213/27-4 of Rosebank are devoid of volcaniclastic sandstone and are wholly made up of volcaniclastic claystones and siltstones (Fig. 14).

Interpretation

Rosebank Upper Volcaniclastics appear to be the weathering products of underlying and nearby lava flows. As coarser grained epiclastic volcaniclastics are generally deposited more proximal to eroded parent bodies (Fisher, 1961), coarse-grained volcaniclastics in the south of the Rosebank Field are correlated with the sequence T45 eruptive centre proximal to the south of the Rosebank Field (Fig. 13). Lava flows on the Cambo High remained exposed throughout much of the deposition of the Upper Volcaniclastics and were potentially a source for volcaniclastics seen in well 204/10a-3 (Cambo) and 205/01-1.

Upper Sequence T45 Lava Flows (Enni Equivalent)

The upper lava flows are represented by a bright hard kick restricted to the north of the Cambo High and Corona Ridge. Although not penetrated by any wells, the horizon mapped extends towards the 213/26-1 and 205/01-1 wells in the south of the Rosebank Field where the sequence is dominated by volcaniclastic sandstones representing the erosive products of nearby basalt flows. Spectral decomposition was undertaken on the horizon mapped with lava flows appearing as a zone of high relative amplitude within the data (Fig. 15). The brightness of the upper lava flows attenuates and scatters the seismic signal, leading to ghosting in the underlying Rosebank Upper Volcaniclastics.

458 ***Interpretation***

459

460 Onshore the Faroe Islands, the sequence T45 Enni Formation represents the youngest
461 sequences in the FIBG. They are typically extensive compound lava flows with a MORB-like
462 composition (Rasmussen & Noe-Nygaard 1970; Waagstein *et al.* 2002). The very uppermost
463 flows identified in the study area are stratigraphically equivalent to the Enni Formation due to
464 their stratigraphical position at the very top of the volcanic sequence (Schofield & Jolley, 2013).

465

466 **Isochron Thickness of the Colsay Sequences**

467

468 Isochron thickness maps were created for the most regionally extensive volcanic
469 horizons and used as a proxy for the thickness of volcanics and intra-volcanic sediments.
470 Figure 16 shows an isochron thickness map between base Colsay 1 and top Upper
471 Volcaniclastics, encompassing Colsay 1 sediments, the Rosebank Upper Volcanics and the
472 Rosebank Upper Volcaniclastics. Notably, two areas of thickening exist either side of the
473 Corona Ridge. The northern area coincides with the proposed fluvial system identified by
474 Schofield & Jolley (2013), whilst the southern area coincides with the Colsay 3 and Colsay 2
475 proposed drainage system. As such, thickness maps provide evidence that areas either side
476 of the Corona Ridge were prone to repeated exploitation by fluvial sedimentation. However,
477 the Rosebank Upper Volcanics lava flows are also observed infilling the lows either side and
478 within the Corona Ridge (Fig. 13A and D). Therefore, areas of thickened siliciclastic
479 successions may also coincide with areas of thickened volcanics.

480

481 **Discussion**

482

Palaeogeographic Evolution of the Cambo-Rosebank Region

The interpretation of several seismic datasets combined with the petrophysical analysis and correlation of available wells allows the stratigraphic evolution of the Late Palaeocene to Early Eocene volcanic succession to be determined. Initial interpretations of the Rosebank Field envisaged the Corona Ridge as a palaeohigh that acted as a focal point for the interfingering of volcanics and siliciclastic sediments prograding from the North West and South East, respectively (Helland-Hansen 2009). However, on the basis of new data, the following palaeogeographic settings have been reconstructed for the Upper Palaeocene and Lower Eocene (Fig. 17). Notably, during periods of volcanic quiescence (Fig. 17A), siliciclastic sedimentary systems are able to build out into the centre of the Faroe-Shetland Basin towards highs such as the Corona Ridge. During periods of volcanic activity, these sedimentary systems are diverted away from areas of active eruption (Fig. 17B). The controls on the location of sedimentary systems and areas of active eruption are discussed.

Controls on the Distribution of Colsay Member Sequences

During the eruption and emplacement of continental flood basalts, pre-existing fluvial systems may be overwhelmed or diverted. During periods of volcanic quiescence, fluvial systems may become re-established if their catchments are located in areas that are not influenced by volcanism (Ebinghaus et al. 2014). The distribution and development of intra-basaltic drainage systems during periods of quiescence are strongly influenced by the topography created by preceding lava flows (Reidel *et al.,* 2013) in addition to the pre-existing topographic lows that were not filled by lavas (Schofield & Jolley, 2013; Ebinghaus *et al.,* 2014).

507 The predictable evolution of continental flood basalts has been recognised within Large
508 Igneous Provinces (Jerram & Widdowson 2005). During the inception of a Large Igneous
509 Province, low volumes of lava erupt directly onto pre-existing bedrock. During this stage, the
510 pre-eruption topography exerts a control on distribution of eruptive products (Beeson *et al.*,
511 1989). The main phase of a flood basalt province is marked by repeated eruption of a number
512 of high volume lava flows that cover large areas (e.g. 6340 km^2 for the Springbok-PAV unit B
513 in the Parana-Etendeka province; Jerram & Widdowson 2005) , originating from a number of
514 spatially restricted eruption sites and fissures. Whilst the location of the eruption sites and
515 fissures is largely controlled by lithospheric and crustal weaknesses, the distribution of lava
516 flows is also controlled by lava sheet topography and infilling of topography by other flows or
517 intra-volcanic sediments. The overall duration of this main stage is typically in the order of
518 500 kyr (Baksi, 1988; Jerram & Widdowson, 2005). During the final stage of volcanism, the
519 eruption volumes decrease and eruption centres become more widely distributed.
520
521 Additionally, small scale changes in individual lava flows and sedimentary systems are imposed
522 on the large scale changes described above.

523 • Channelized or intra-canyon lava flows are generated by flow into a pre-existing
524 topographic low primarily controlled by tectonic activity and pre-existing erosional
525 surface topography (Beeson *et al.*, 1989).
526 • Sheet like lava flows indicate low, relatively flat topographic relief. Drainage systems
527 with source areas outside the lava field are likely to dam and buttress against the lava
528 field, or flow around it (Beeson *et al.*, 1989).
529 • Deep and wide topographic lows such as river valleys are often preserved during lava
530 flow-emplacement, promoting re-establishment of drainage systems along their
531 pathway (Schofield and Jolley, 2013).

The Faroe-Shetland Basin is divided into a series of NE-SW trending sub-basins that have acted as depocentres from the Cretaceous to the present-day (Ritchie *et al.,* 2011). In the study area, basement highs such as Cambo and Westray are granodioritic to granitic in composition and thus more resistive to faulting and erosion (Watson et al. 2017). The basement ridges adjacent to the Cambo and Westray Highs (the Westray and Corona ridges) typically consist of Jurassic and older sediments that were downthrown deeper into the basin during Cretaceous rifting. In the Faroe-Shetland Basin, this structural heterogeneity strongly controls the distribution of Colsay Member sequences within the Rosebank Field. Parallel to the sides of the Corona Ridge, palaeolows were repeatedly exploited by volcanics and intra-basaltic sediments, illustrated by the isochron thickness map (Fig. 16) and fluvial sediments in 205/01-1. The continual expression of these topographical lows throughout the emplacement of the volcanic succession suggests that topography generated prior to eruption of the T40 lava flows was not infilled and bypassed by later volcanic or sedimentary events. Instead, longstanding topographical lows either side of the Corona Ridge were exploited repeatedly by volcanism and intra-basaltic units. It has been suggested that the lack of faulting throughout the Palaeocene of the Faroe-Shetland Basin is due to accommodation of extension in upper Cretaceous shales (Dean 1999). Notably, the greatest thicknesses of the tertiary sediment typically overly the thickest Cretaceous successions. Therefore, we might expect that the thickest Cretaceous successions, found within the lows of the Corona Ridge, differentially compact during deposition of the volcanic sequences generating the topographical lows observed here.

Controls on the Distribution of Volcanics

In addition to lava flows and intra-basaltic sediments infilling ridge-adjacent topographical lows, the flow directions of intrusions within the Faroe-Shetland Sill Complex are also strongly controlled by the basement structure; in particular where basement bounding faults act as input points for intrusions into the Faroe-Shetland Basin (Schofield et al 2015). A close spatial relationship between several sills in the study area and the location of lava flows has been presented (e.g. Fig. 13) and it is proposed that the Faroe-Shetland Sill Complex sourced large parts of the volcanism described in this study. Because magma transport within basins tends to favour faults (Thomson and Schofield, 2008; Magee *et al.* 2013; Schofield *et al.* 2015), large parts of the Faroe-Shetland Basin volcanic succession were erupted on major highs like the Corona Ridge, raising the possibility that this area has substantial unimaged intrusions (e.g. Schofield *et al.* 2015). Due to the difficulty posed by intra and sub-basalt imaging, we cannot preclude that other sections of the Rosebank Field reservoirs are intruded, in particular by difficult to image sub-vertical dykes (Helland-Hansen, 2009, Schofield *et al.,* 2015).

The Intra-Basaltic Play; a Restricted Play West of Shetland?

Whilst the volcanic succession on the Corona Ridge has been shown to contain significant accumulations of petroliferous siliciclastic intra-basaltic sediments (Duncan *et al. 2009*), other intra-basaltic and supra-basaltic prospects drilled throughout the Faroe-Shetland Basin have so far proven to be less successful, leading to questions about the viability of the wider intra-basaltic play within the Faroe-Shetland Basin. A key uncertainty associated with the intra-basaltic play is understanding how siliciclastic sediments are transported into and dispersed throughout the volcanic succession.

The Súla intra-basaltic prospect, drilled by Statoil in 2014, is situated ~20 km north west of the Rosebank Field, in the Corona Basin. Although intra-basaltic sediments were

582 encountered they were not of prospective reservoir quality (P1847 Relinquishment Report).
583 The 213/27-3 Rosebank North well faced a similar issue, situated ~6 km north of the
584 Rosebank Main Field, with only poor quality sandstones encountered. In line with the
585 palaeogeographic reconstructions presented in this paper (Fig. 17), areas north of the
586 Rosebank Field are likely situated in a predominantly shelfal setting, outside of the play fairway
587 that makes Rosebank viable.

588 A similar reduction in the quality and quantity of Colsay siliciclastic sands in noted to
589 the south east of the Rosebank Field. The Aberlour prospect (214/28-1) tested the south-
590 eastern extent of the Colsay sequence on the Corona Ridge. Although six Colsay sandstone
591 intervals were encountered, they were thin and discrete, interbedded with volcanics and
592 claystone sequences. Sandstone composition was typically quartzose, like Rosebank, however
593 more fine grained. Further down dip, into the Flett Basin, intra-basaltic sediments are
594 indicative of a deeper shelfal environment and are of poor reservoir quality (e.g. Tomintoul
595 205/9-2). Consequently, given the reconstructed palaeoenviroment (Fig. 17), it is unlikely that
596 significant quantities of clean sand were sourced from either the south east or the north of
597 the basin. It is therefore necessary to invoke transport of sediment from the south west of
598 the Rosebank Field. Here, the major T38/T40 erosional surface provides a record of a large
599 sediment transfer event with palaeovalleys funnelling sediment into the Foinaven Sub-Basin,
600 west of the Cambo High (Smallwood and Gill, 2002, Champion, M.E. *et al.,* 2008). Whilst fluvial
601 sequences may be expected in this area (e.g. the sequence T40 204/18-1 fluvial sequence), the
602 Anne-Marie prospect, drilled in 2010 ~15 km west of the Cambo High, encountered over 1
603 km of volcanics before drilling was halted. This area of thickened volcanics would have acted
604 as a barrier to intra-basaltic siliciclastic sediments. However, during periods of volcanic
605 quiescence, diversion of fluvial sediments through the narrow corridor between Anne-Marie
606 and the Cambo High could have provided a source of 'clean' sands in Rosebank. It should be

noted that the quality of sediment contained within these fluvial systems is questionable due to the deltaic to marginal marine facies they erode into (e.g. Longan 6005/15-1 as detailed by Morse, 2011).

Our findings suggest that the intra-basaltic play fairway within the Faroe-Shetland Basin is fairly narrow. A 30 × 30 km focal point for 'clean' intra-basaltic sands, comprising of the drainage system identified by Schofield & Jolley (2013) and another drainage system extending from Cambo to Rosebank, appear to represent the thickest accumulations of 'clean' intra-basaltic sands (Fig. 16). In terms of future potential exploration areas within the greater Cambo-Rosebank area, the identified drainage system located between Rosebank and Cambo potentially offers the best chance of success, in terms of reservoir risk, as this appears to be the system which supplied Rosebank with siliciclastic sand.

Towards the North of the Cambo structure, the same drainage system appears to onlap against the Cambo high (Fig. 16). Well 204/10a-5, was drilled in 2013 by Hess to appraise the down dip extent of the Colsay Member off the Cambo High (Fig. 16). The well intersected an 18 metre thick Colsay sequence, consisting of mudstone and a thin (~3 m) sand unit. However, inspecting the well location (Fig. 16), it appears the well was drilled on the very feather edge of the drainage system that extends between Cambo and Rosebank. Therefore, 204/10a-5 was potentially not drilled in an optimum location to intersect a thick Colsay reservoir sequence. Colsay 1 and 3 sequences, which represent the main reservoir units in Rosebank, can be seen to thin and pinch against the Cambo high (Fig. 16C), forming the potential for a stratigraphic trap and separate hydrocarbon accumulation against the Cambo High. This pinch out is located ~500 m northwards of well 204/10a-5.

Conclusions

High quality seismic data sets have been integrated with well data to detail the controls on the distribution of volcanics and intra-basaltic sedimentation in the Cambo-Rosebank region of the Faroe-Shetland Basin. The structural setting of the Cambo-Rosebank region strongly controls both volcanism and sedimentation in the area. 'Clean' sands within the Rosebank Field are largely sourced from the southwest with the play fairway of the Rosebank Field restricted to the area surrounding the Corona Ridge. The volcanic sequences in Rosebank were erupted centrally within the basin, typically adjacent to, or on, structural weaknesses. Although the Rosebank play fairway seems to be spatially restricted, the Cambo-Rosebank region has significant exploration potential, particularly in zones of thickening adjacent to the southern Corona Ridge.

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Figure Captions

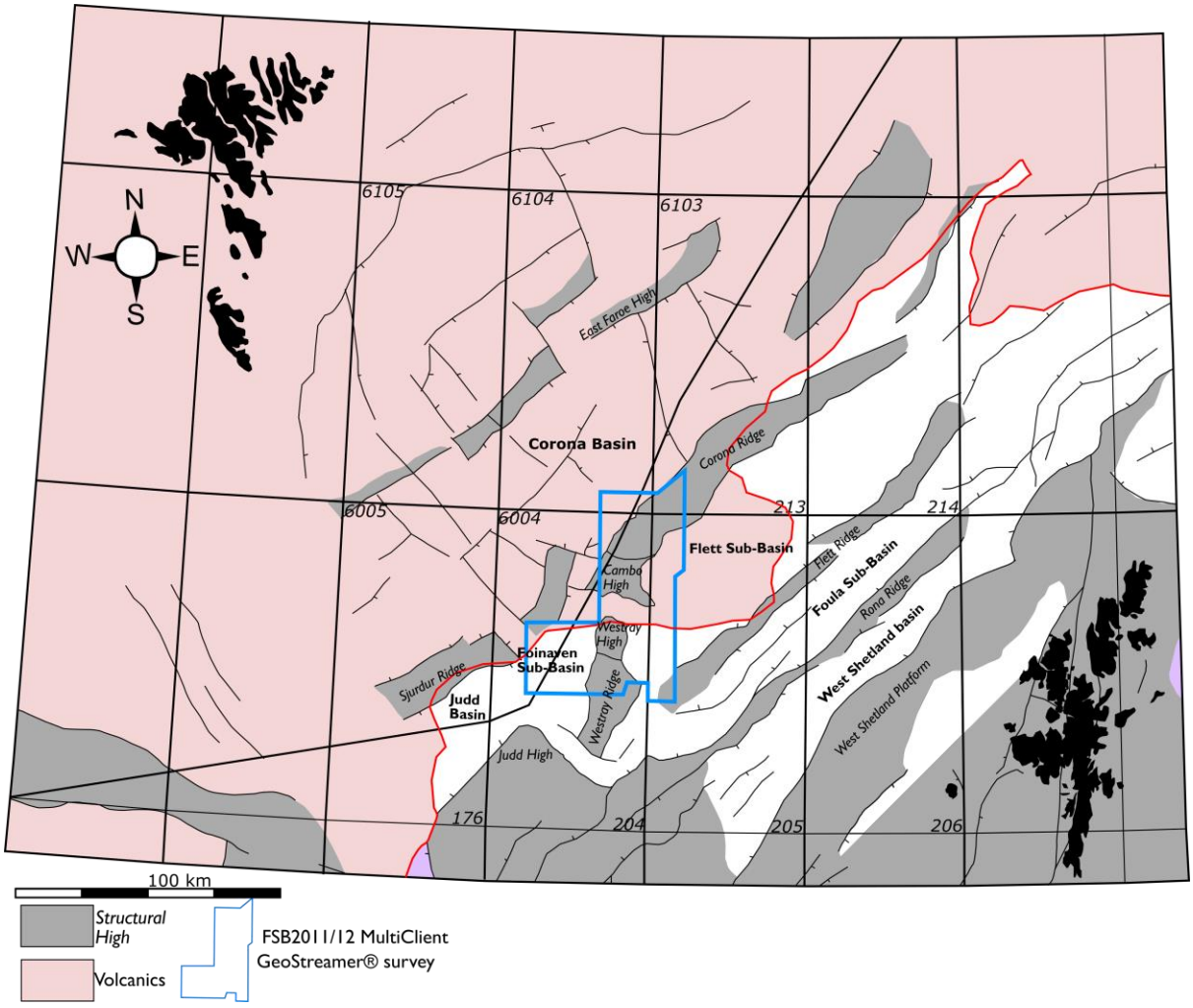
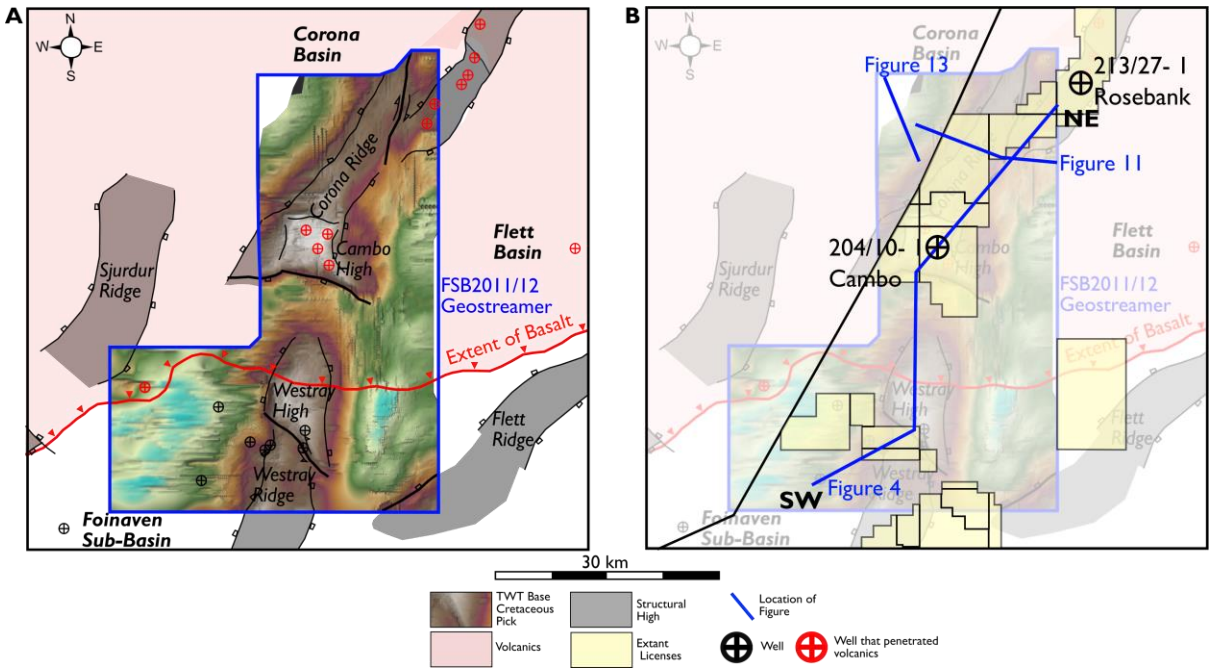


Fig 1. Map of the Faroe-Shetland Basin highlighting main structural highs and the areal extent of Upper Palaeocene/Lower Eocene volcanics. Modified from Moy (2009). Outline of the FSB2011/12 Multiclient Geostreamer® survey included.



857

858 **Fig 2.** (a) Plan view of the FSB2011/12 Multiclient Geostreamer® survey including TWT
859 map of the base Cretaceous. Main structural elements of the study area are shown as well
860 as the extent of the basalt cover. Outline of seismic coverage and wells used within the
861 study shown. (b) Outline of currently extent licenses within the study area. Location of later
862 figures highlighted.

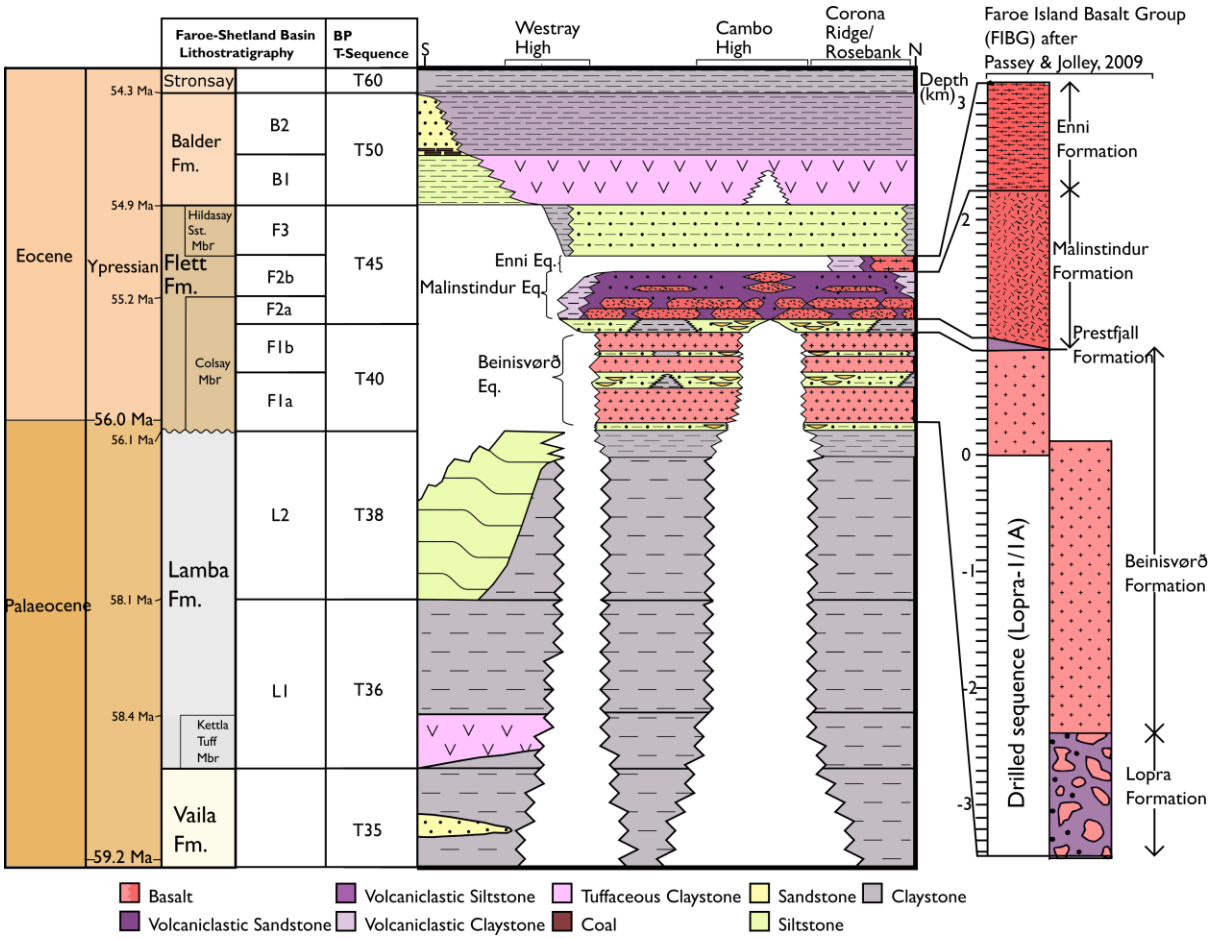
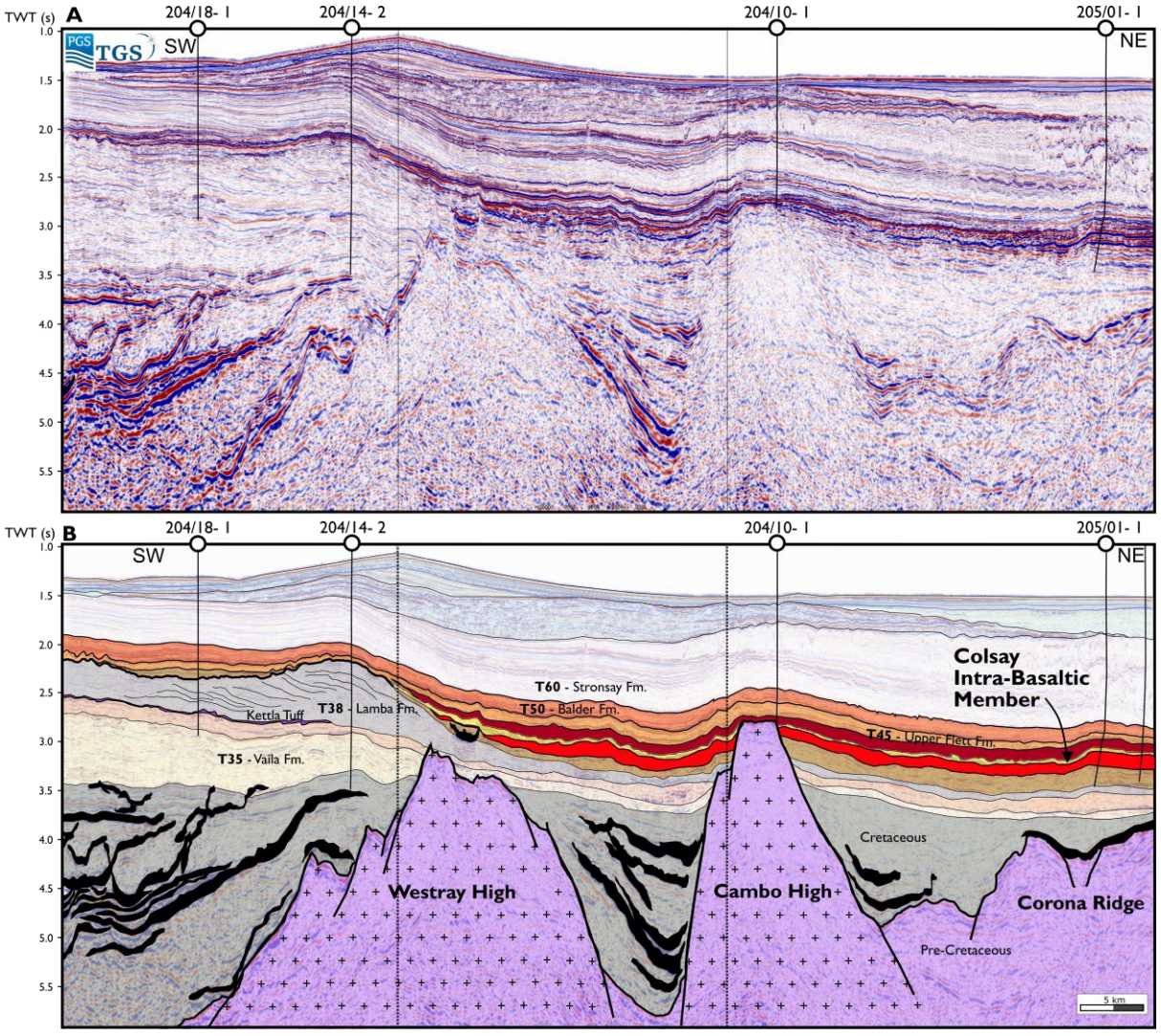
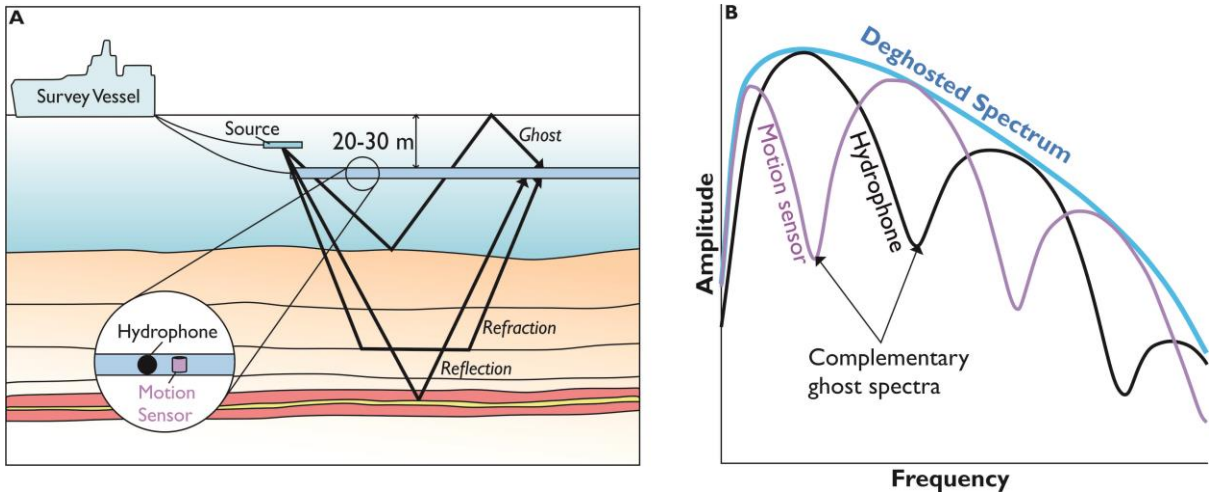


Fig 3. Chronostratigraphic chart of the Upper Palaeocene and Lower Eocene of the study area incorporating BP's T-sequence scheme (Ebdon *et al.,* 1995) with the lithostratigraphy of Ritchie (2011). The relative stratigraphical position of the Faroe Islands Basalt Group is shown after Passel & Jolley, 2009.



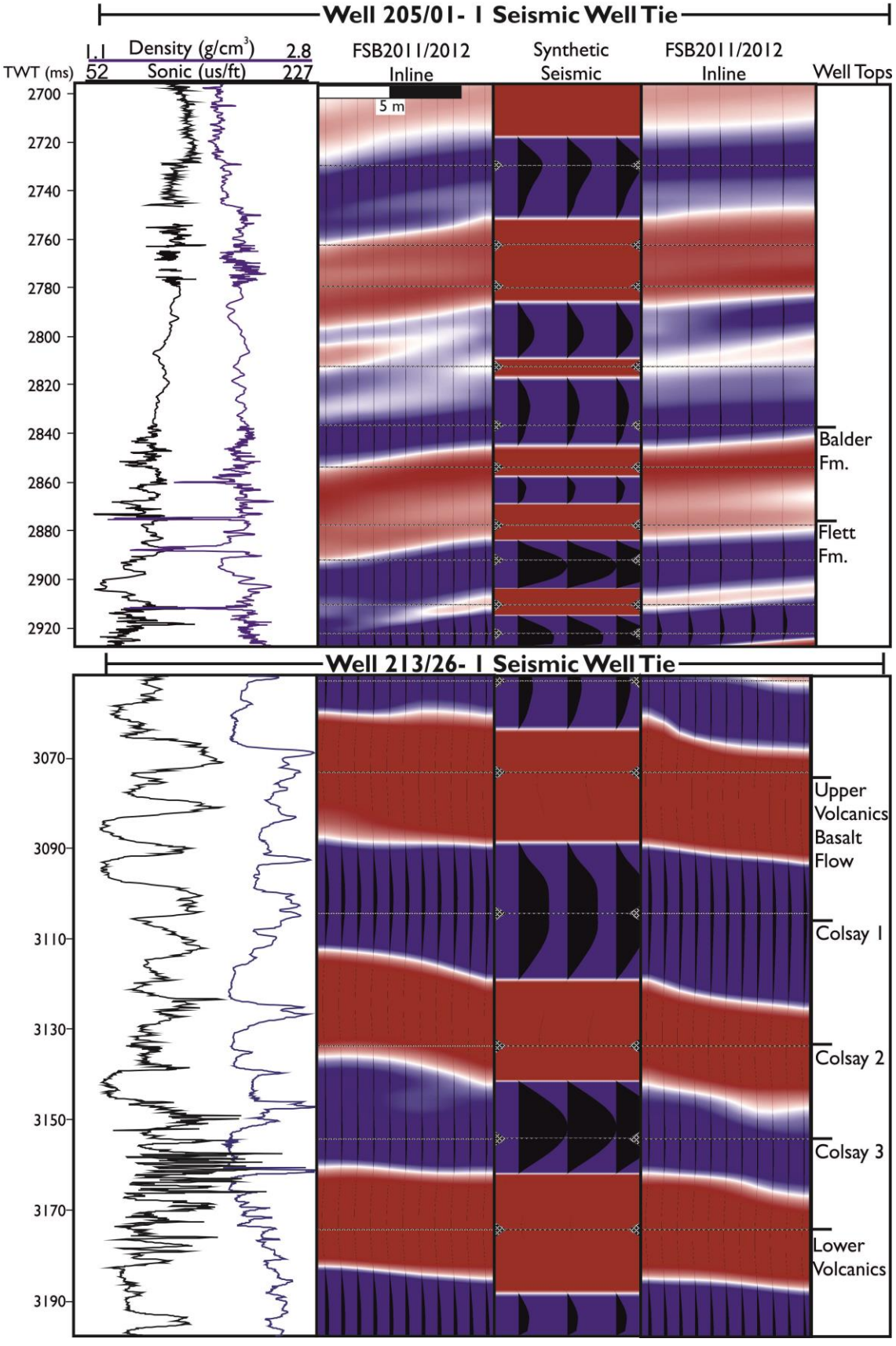
868

869 **Fig 4.** (a) Uninterpreted regional seismic line of the study area. Data courtesy of PGS (the
870 FSB2011/12 MultiClient GeoStreamer® survey) (b) Interpreted regional seismic line of the
871 study area highlighting the Upper Palaeocene/ Lower Eocene succession. Key geological
872 features referred to in the text highlighted in bold.



873

Fig. 5 Outline of the Geostreamer® technology used during the acquisition of the FSB2011/2012 Survey. **A** Graphic detailing the depth at which the streamer is towed, the dual sensors used during acquisition of the data, and the principle behind the ghost reflection within seismic data. **B** Graph used to indicate the principle behind the deghosting of the Geostreamer data. The hydrophone and motion sensor record complementary ghost spectra that, when summed, eliminate gaps within the frequency gaps within the seismic data.


Well 205/01- 1 Seismic Well Tie
1.1
Density (g/cm3)
2.8
TWT (ms)
52
Sonic (us/ft)
227
FSB2011/2012 Inline
Synthetic Seismic
FSB2011/2012 Inline
Well Tops
5 m
2700
2720
2740
2760
2780
2800
2820
2840
2860
2880
2900
2920
Balder Fm.
Flett Fm.
Well 213/26- 1 Seismic Well Tie
3070
3090
3110
3130
3150
3170
3190
Upper Volcanics Basalt Flow
Colsay 1
Colsay 2
Colsay 3
Lower Volcanics

881

Fig. 6 Seismic well tie for the Rosebank wells within the Geostreamer. The 205/01- 1 well is used to demonstrate the fit between the well logs and FSB 2011/2012 survey in the post-volcanic succession. The 213/26- 1 well is used to demonstrate the close fit between the well data throughout the volcanic succession. Synthetic seismic was generated in Petrel using a combination of sonic and density wireline data. A volcanic succession well tie for the 205/01- 1 well is not shown due to the lack of density data throughout the Rosebank Upper Volcaniclastics.

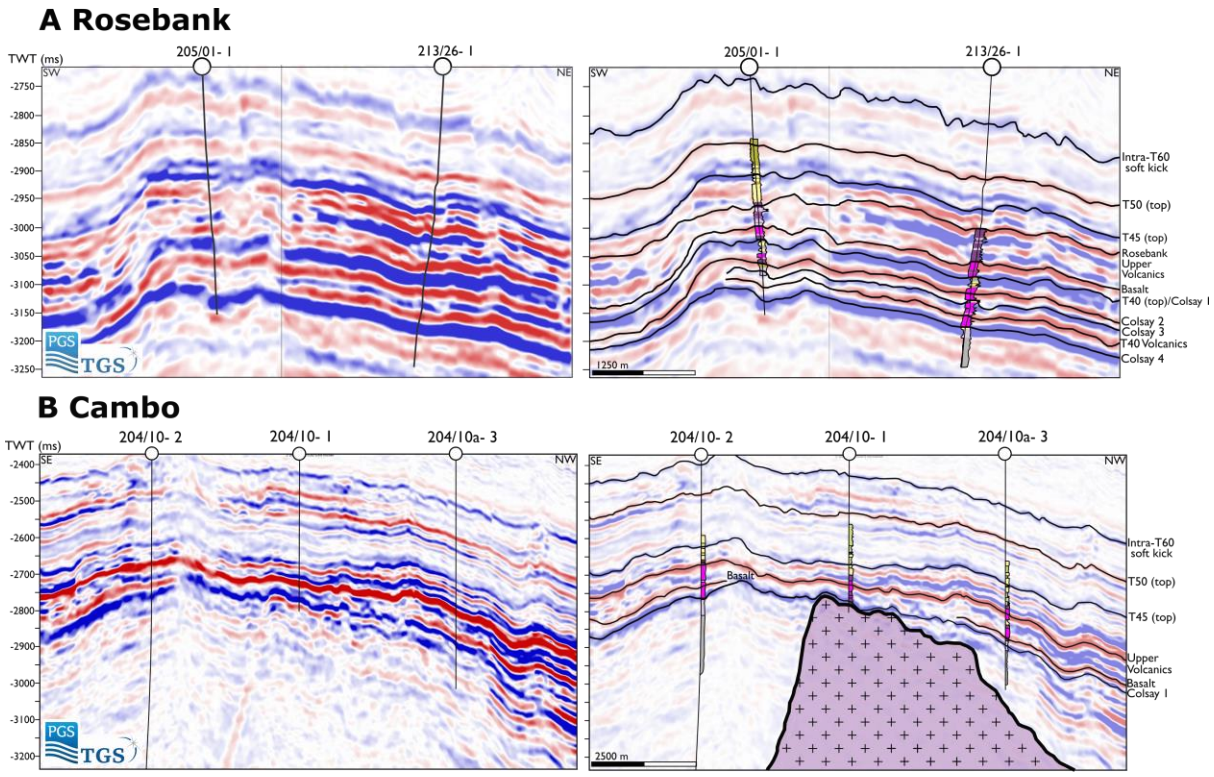
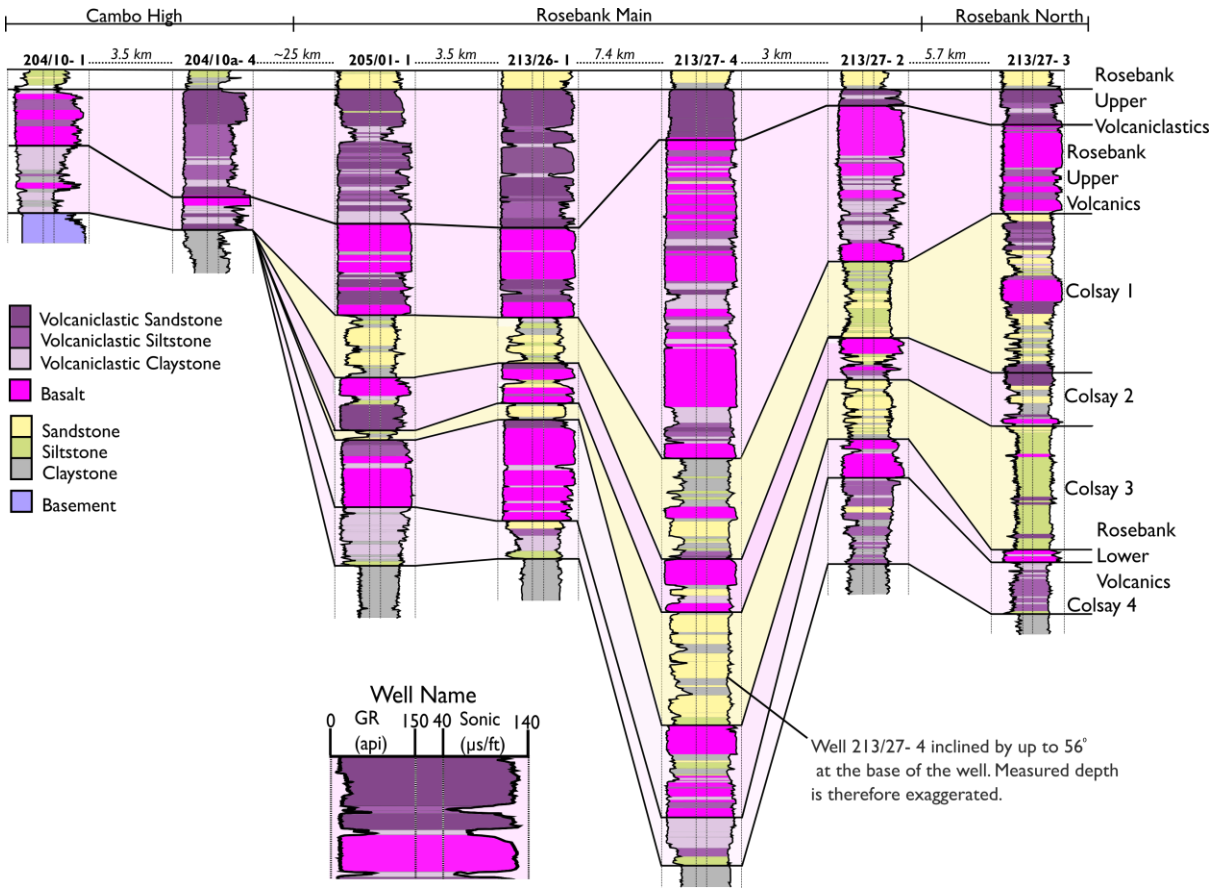
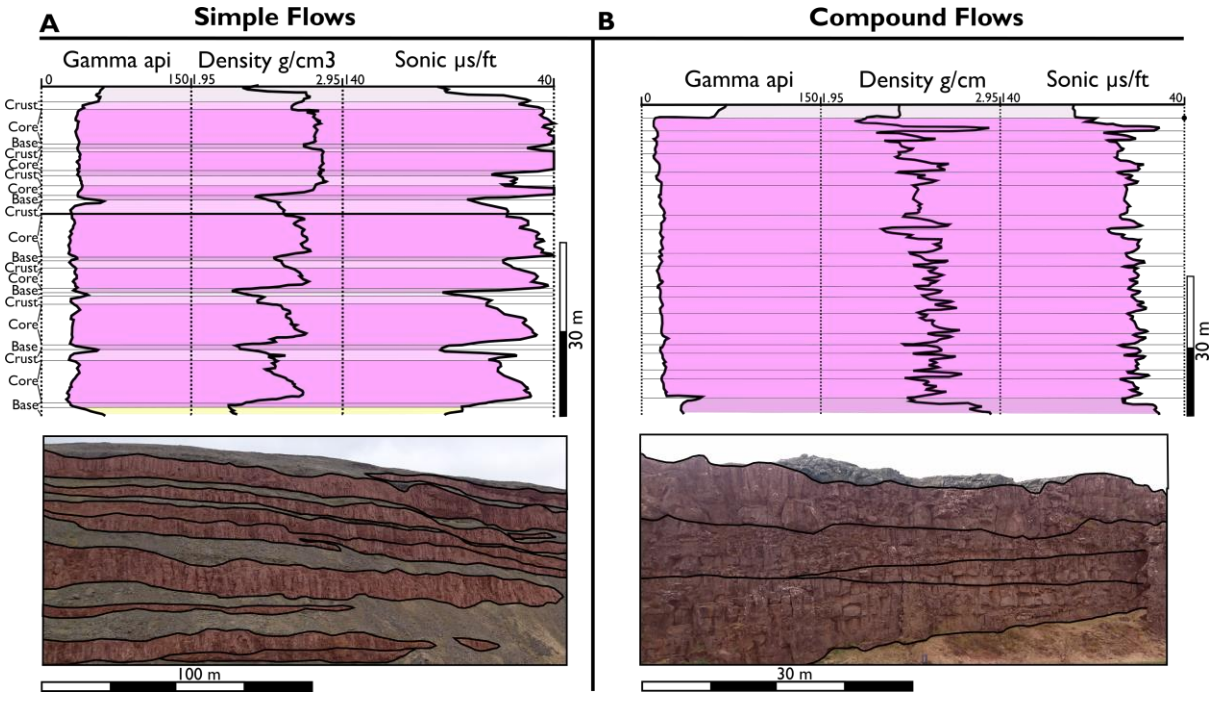


Fig 7. Interpreted and uninterpreted seismic lines of the **A** Cambo High and **B** southern Rosebank wells highlighting key geological horizons within and above the volcanic succession. Data courtesy of PGS (the FSB2011/12 MultiClient GeoStreamer® survey)



893

894 **Fig. 8** Well correlation of the entire volcanic succession throughout the Rosebank field,
895 joined to wells from the Cambo field, 25 km to the southwest. Well 213/27- 4 is highly
896 deviated resulting in an exaggerated measured depth.



897

Fig 9. Petrophysical, seismic and outcrop expression of **A** simple and **B** compound lava flows. Petrophysical logs taken from the 213/26- 1 Rosebank Well. Photos taken on Iceland.

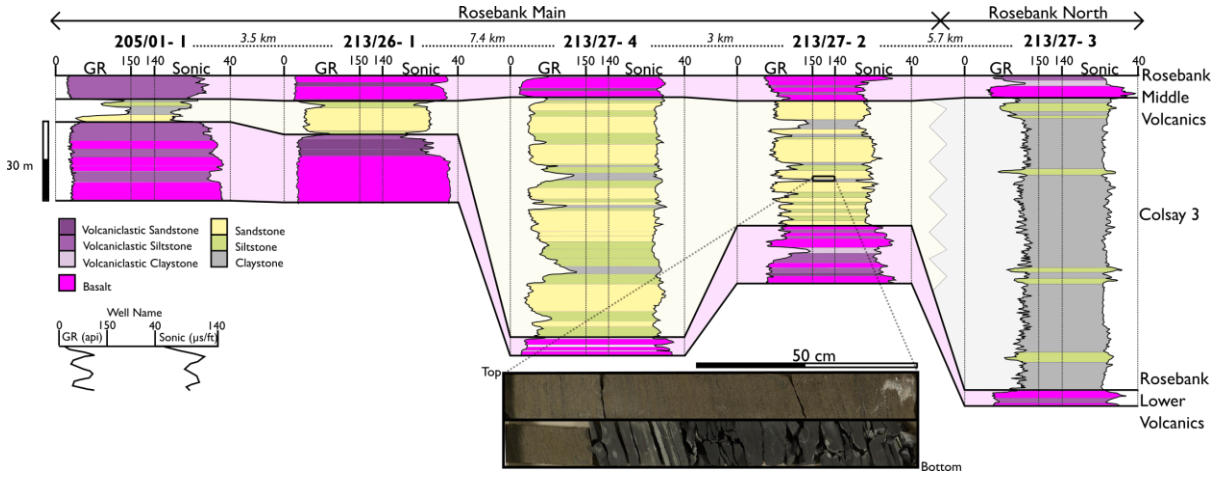


Fig 10. Well correlation of the Colsay 3 package through 5 of the Rosebank Wells, SW to NE along the Corona Ridge. Conventional core and its location within the 213/27- 2 well is shown. Detailed description of Colsay 3 is provided within the text.

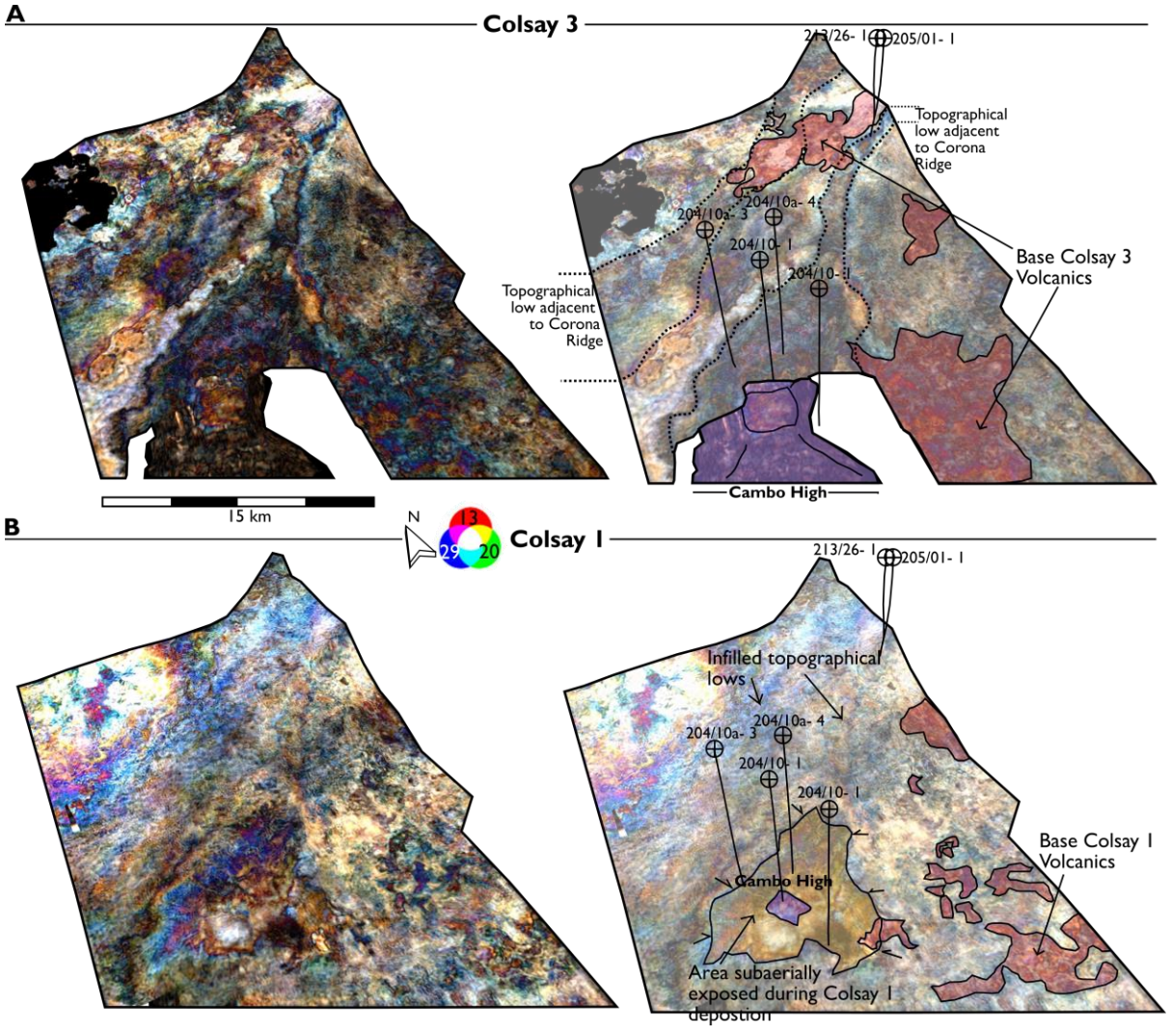


Fig 11. RGB frequency spectral decompositions carried out on Colsay 1 and Colsay 3 horizons mapped within the Faroe-Shetland Basin 2011/12 Geostreamer© Survey Spectral decompositions of **A** Colsay 3 and **B** Colsay 1 seismic horizons. Spectral decompositions were carried out within GeoTeric. Interpreted horizons highlight key features described in the text.

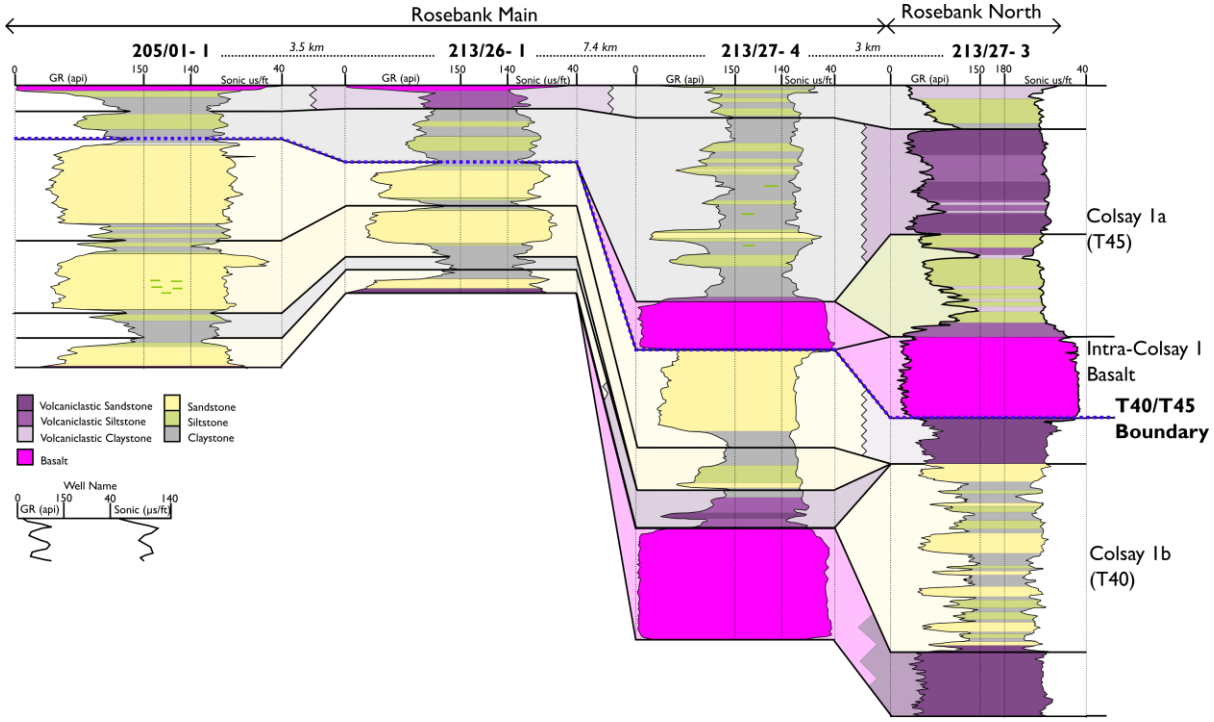
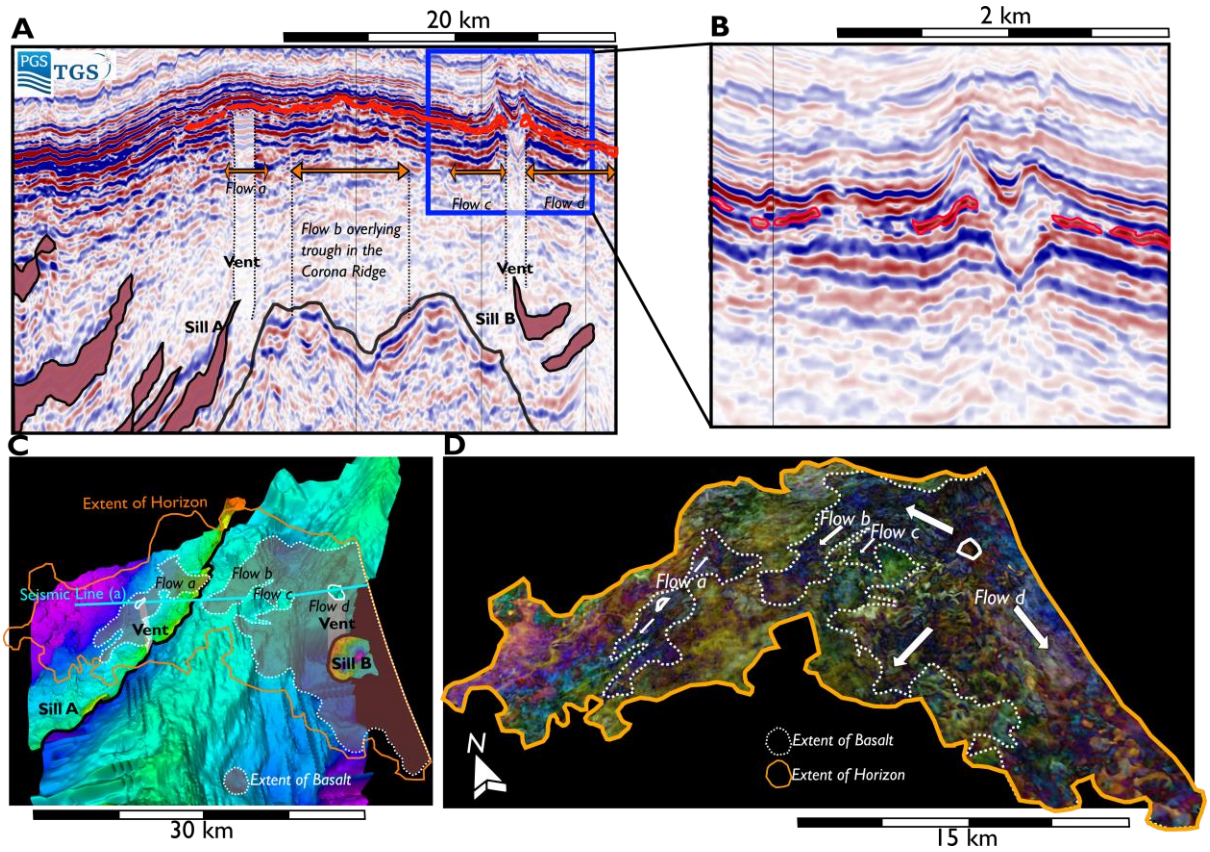


Fig 12. Well correlation of the Colsay 1 package through 4 of the Rosebank Wells, SW to NE along the Corona Ridge. Detailed description of Colsay 1 is provided within the text.



913

914 **Fig 13. A** Interpreted seismic line across the Corona Ridge highlighting the Rosebank
915 Upper Volcanics seismic horizon, the Corona Ridge and the location of igneous intrusions.
916 **B** Inset of a highlighting major vent structure and the seismic character of the Rosebank
917 Upper Volcanics. **C** Location of major features overlying a TWT map of the base
918 Cretaceous. **D** Spectral decomposition of the Rosebank Upper Volcanics seismic horizon
919 showing the outline and flow direction of lava flows.

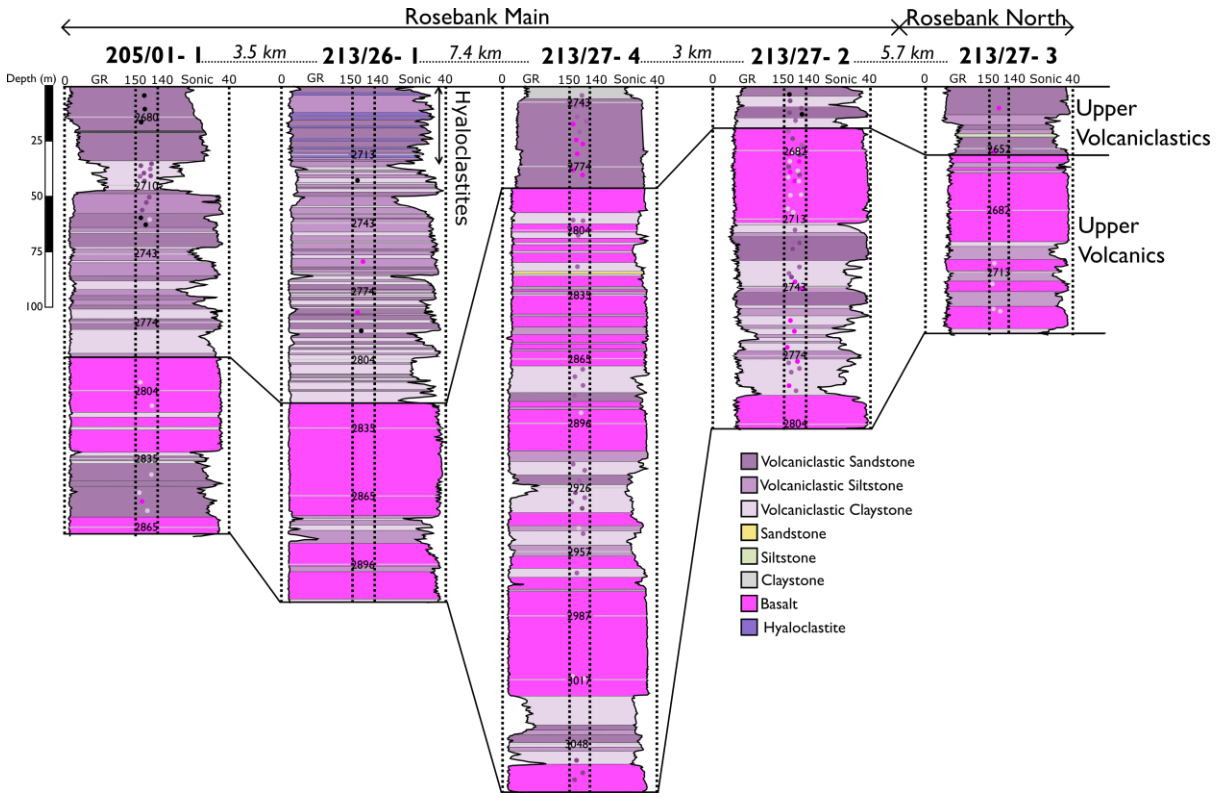


Fig 14. Well Correlation of the Rosebank Upper Volcanics package and the Rosebank Upper Volcaniclastics package through 5 of the Rosebank Wells, SW to NE along the Corona Ridge. Both units are described in detail within the text.

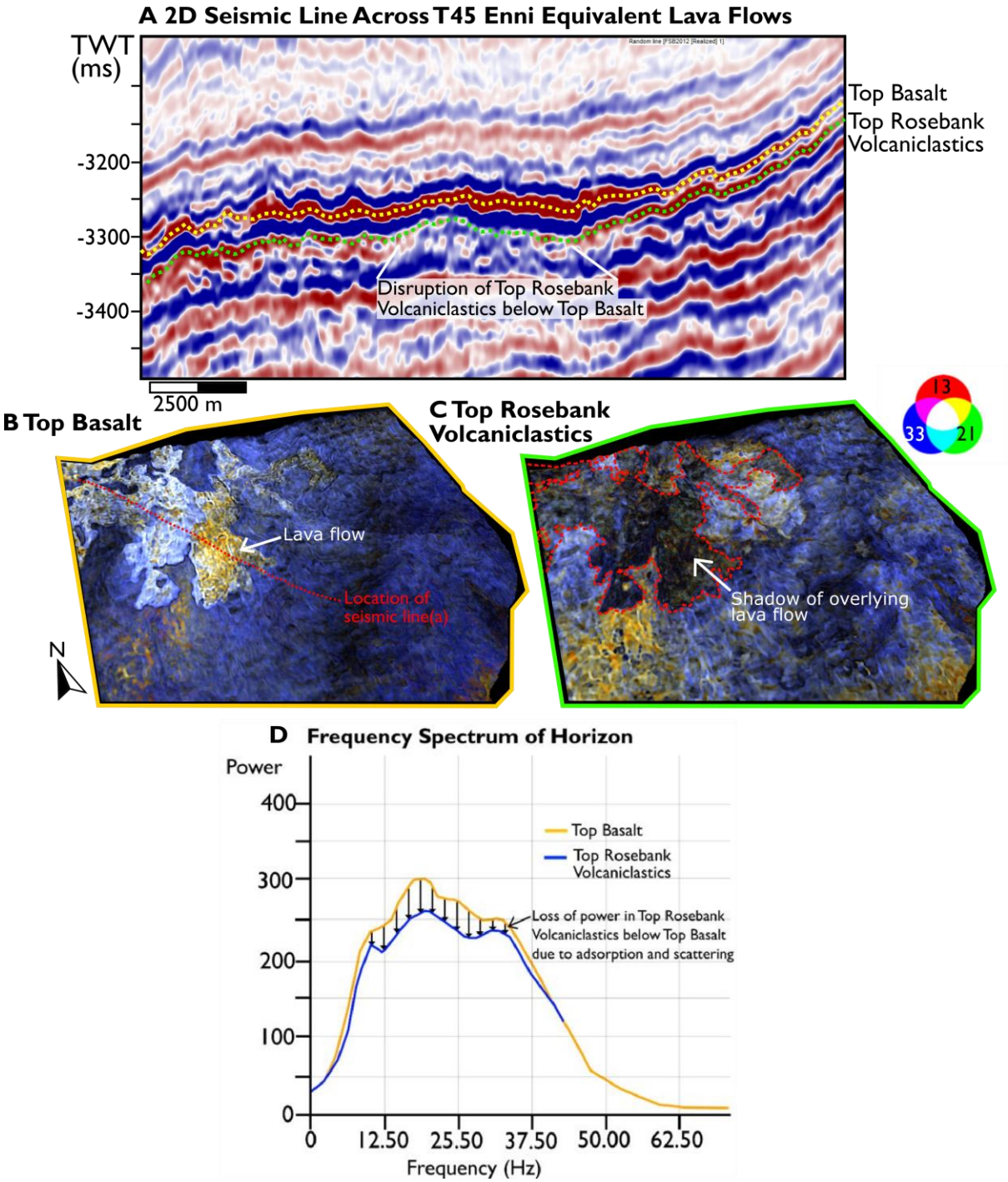


Fig 15. Sequence T45 Enni equivalent lava flows. **A** Seismic line across Enni equivalent lava flows. Location shown in Fig 2. **B** RGB Spectral decomposition of Top Basalt horizon. **C** Spectral decomposition of Top Rosebank Volcaniclastics horizon, underlying the Top Basalt horizon. Ghosting of the overlying lava flow is highlighted in red. **D** Frequency spectrum of horizons **B** and **C**. Note the loss in power of the frequency spectrum below the Top basalt horizon due to attenuation and scattering of seismic waves in the volcanics.

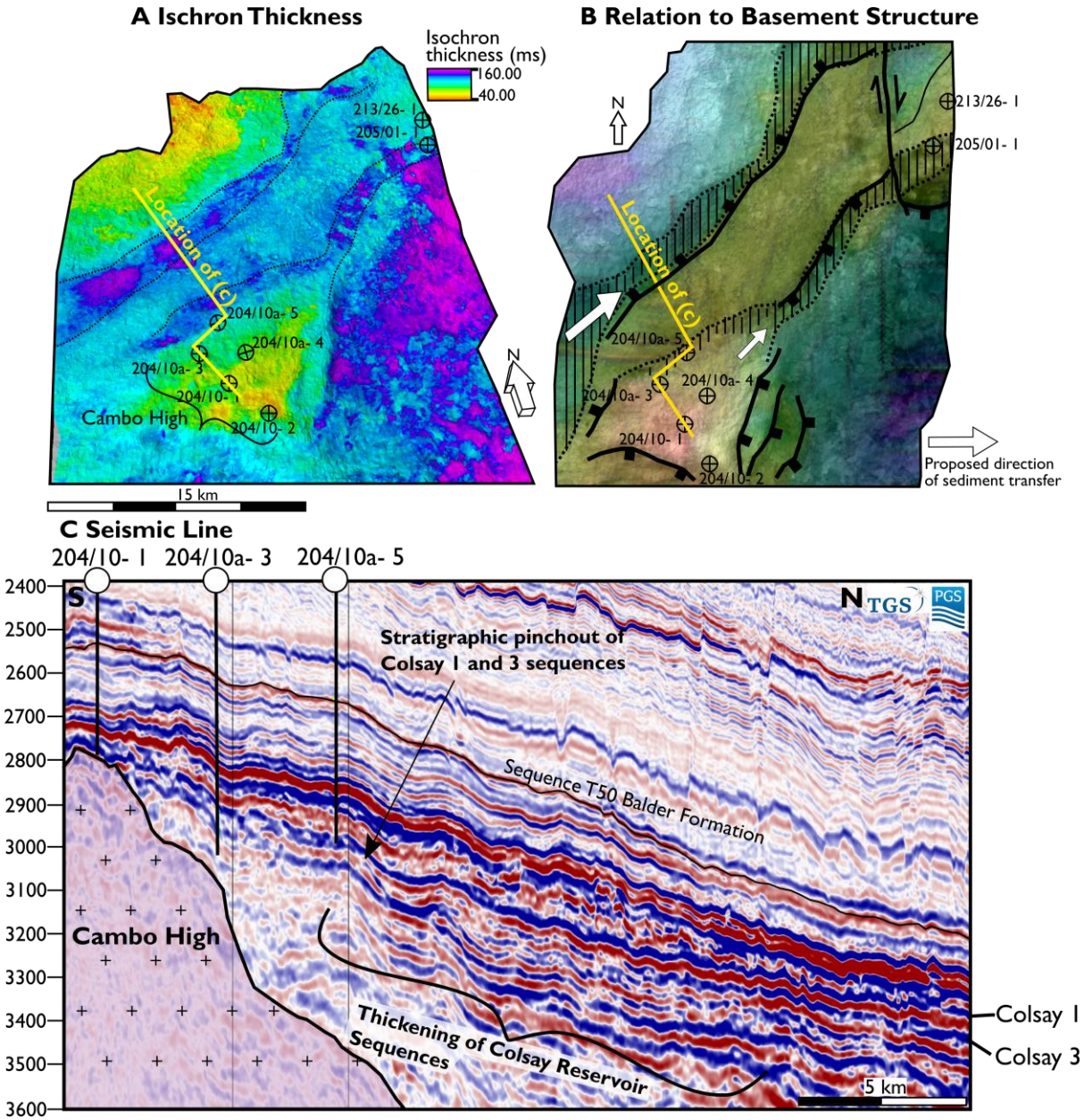


Fig 16. A Isochron thickness of the succession between base Colsay 1 and top Rosebank Volcanics. **B** Isochron thickness displayed as a transparent black-white surface overlain on top of a TWT map of the base Cretaceous. This highlights that the two zones of thickening occur either side of the Corona Ridge. **C** Seismic line taken from the Cambo High and towards the north, demonstrating pronounced thickening of the Colsay sequences just north of 204/10a- 5 Cambo well.

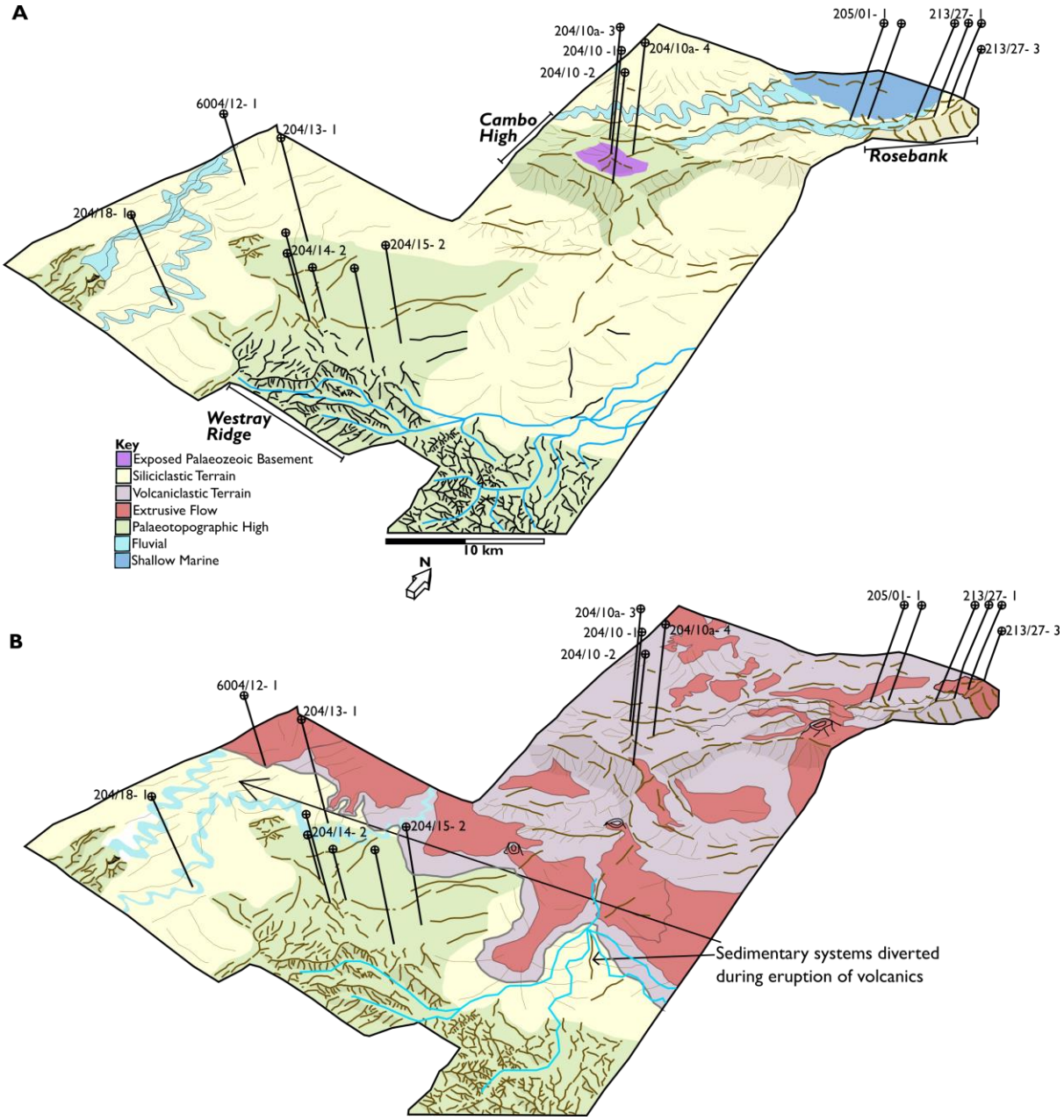


Fig 17. Palaeogeographic reconstructions of the Upper Palaeocene and Lower Eocene of the FSB2011/12 MultiClient GeoStreamer® survey. **A** Entirely siliciclastic palaeoenvironment inidicative of Colsay 1 age sediments. **B** Entirely volcanic palaeoenvironment inidicative of the Rosebank Upper Volcaniclastics.