Enhancing the prospectivity of the Wyville Thomson Ridge

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Føroya Kolvetni (Faroe Petroleum) was awarded Licence 012, covering part of the Wyville Thomson Ridge, in the second Faroese Licensing Round and this paper summarises some initial results from their work programme. Interest in the prospectivity of the Wyville Thomson Ridge was stimulated in the 1990s by a proposal that it forms a compressional anticline with a thin carapace of Paleogene lavas, overlying an inverted sedimentary basin. Gravity interpretation confirms that the ridge can be modelled as an inverted basin, although uncertainties inherent in the method limit the accuracy of the thickness estimates. Seismic reflection data shot in 2005 provide improved resolution of the pre-lava succession, with some reflector packages resembling seismic facies from the prospective Paleocene succession in the Faroe-Shetland Basin. The *Rannvá* exploration lead consists of an extremely large four-way dip closure beneath thin lavas at the crest of the Wyville Thomson Ridge. Source rock presence and maturity, hydrocarbon migration, and reservoir development in the Licence 012 area are discussed on the basis of regional observations.

This prospectivity assessment of licensed acreage in the Faroese sector of the north-east Atlantic margin focuses upon the Wyville Thomson Ridge, a linear bathymetric high mantled by volcanic rocks, which forms a physical barrier between the Rockall Trough and the Faroe-Shetland Channel (Morton *et al.* 1988b; Stoker *et al.* 1988; Earle *et al*.1989) (Fig.1). In the vicinity of the median line, a buried transfer zone probably underlies the whole structure (Rumph *et al.* 1993; Stoker *et al*. 1993; Tate *et al.* 1999; Waddams and Cordingley 1999). Further to the east, the same transfer zone may control the boundary between the Stack Skerry and West Shetland basins (Duindam and Van Hoorn 1987), or form a part of a broader complex of geophysically defined lineaments, which act together to control the polarity of basins on the Hebridean Platform **(**Kimbell *et al.* 2005). In either case, it is likely that reactivation of a pre-existing basement structure underlying the Wyville Thomson Ridge accommodated the displacement of the main axis of Cretaceous extension between the Faroe-Shetland and Rockall basins. The Rona Ridge marks the boundary of the Faroe-Shetland Basin in the north, while the West Lewis Ridge and the Rockall Basin, which form the equivalent structures in the south, are offset westwards across the Wyville Thomson Ridge. An early interpretation of the Wyville Thomson Ridge as a 12 km thick pile of basalt overlying Cretaceous oceanic crust was based on gravity modelling together with flexural considerations (Roberts *et al.* 1983). Subsequently, Boldreel and Andersen (1993; 1994; 1995; 1998) made the alternative proposal, partly based on seismic data, that the bathymetric high originated as an inverted sedimentary basin, capped by volcanic rocks. Others have used gravity and magnetic data in conjunction to support an inverted basin model (Tate *et al.* 1999; Waddams and Cordingley 1999). However, the actual thickness of the concealed sedimentary succession in these interpretations remains poorly constrained. Waddams and Cordingley (1999) show a pre-Cretaceous sedimentary succession more than 8 km thick, with the top of the metamorphic basement lying at a depth of more than 10 km beneath the centre of the ridge. In contrast, the model of Tate *et al.* (1999) for a similar profile shows basement no deeper than 4 - 6.5 km, rising northwards towards the Munkagrunnur Ridge.

The presence of widespread energy-absorbent volcanic sequences largely accounts for the poor response of the seismic reflection method to the deeper structure of the Faroes continental shelf (White *et al.* 2003), but recently acquired wide-angle seismic data have helped to establish that some pre-volcanic sediments are preserved locally (Richardson *et al.* 1999; Raum *et al*. 2005; Spitzer *et al*. 2005).

Well data

The well database used in the regional prospectivity assessment consisted mainly of selected hydrocarbon exploration wells from the UK sector, including 154/3-1, 163/6-1A, 164/7-1, 164/25-1Z and 164/25-2. These were supplemented with geological data obtained from relevant shallow boreholes drilled in the West of Shetland area by the British Geological Survey.

The UK well 164/7-1 (Fig. 1), which was drilled in the NE Rockall Basin in 1997 by Conoco, tested a large, apparently domal closure that was interpreted by the operators as an anticlinal feature with potential reservoirs and source rocks in the Mesozoic section (Archer *et al.* 2005). However, after penetrating 1166 m of Paleogene volcanic rocks, the well was terminated within a predominantly argillaceous, basinal Cretaceous sequence, without establishing the presence of potential reservoirs or source rocks in the pre-volcanic interval. In the well, Maastrichtian and Campanian rocks are absent and the Paleogene lavas are proven to rest unconformably on a deeply eroded Cretaceous section possibly of Coniacian to Albian age. In the absence of reservoirs and hydrocarbon shows, the well was not tested. Subsequent analysis revealed that the formation of the structural dome was associated with the intrusion of more than 40 basic igneous sills within the Cretaceous section. Interpretation of 3D seismic data across the structure showed that the sills are disposed concentrically around a central uplifted area and have radial outward dips. Potential field data suggest that this whole structure is probably of igneous origin and may be compared with the classic laccolithic intrusions of the Henry Mountains, USA (Jackson and Pollard 1990). The presence in this area of a large volume, deep-seated igneous body associated with sill intrusion is partly confirmed by the locally enhanced levels of thermal maturity within the Cretaceous succession, as indicated by extremely high values of vitrinite reflectance. Radiometric age dates obtained by the $^{40}Ar/^{39}Ar$ method from the sills have given early Paleocene ages of 63-64 ± 0.5 Ma. These observations combine to suggest that basic sill intrusion in this area was accompanied by local uplift and erosion of the Cretaceous succession, preceding the growth of the lava shield (Archer *et al.* 2005).

The nearby well 163/6-1A, which was drilled in the Rockall Trough as a stratigraphic test, also proved a thick succession of Paleocene basic extrusive rocks, before terminating in a volcanic interval of dacitic composition (Morton *et al.* 1988a) (Fig. 1). The interpretation of seismic and potential field data indicates that these rocks form part of the Darwin volcanic centre (Abrahams and Ritchie 1991). The presence of a Mesozoic section around Darwin remains unproven, but discontinuous high amplitude reflectors observed on seismic data are interpreted as an indication of pervasive sill intrusion at depth (Tate *et al.* 1999).

Most of the exploration effort in the adjoining part of the UK sector has focused upon the eastern flank of the NE Rockall Basin, where several wells have tested potential structures. Well 165/25-2 on the crest of the West Lewis Ridge, and nearby well 154/3-1, both penetrated Paleocene volcanic successions before terminating in metamorphic basement. In 164/25-2, a partly arenaceous clastic interval of Thanetian age separates a thinly bedded upper series of volcanic rocks from a lower volcanic succession that rests directly upon Lewisian basement. In 154/3-1, thin sediments of Campanian age, underlain by thick undated conglomerates, separate an undivided Paleocene volcanic succession from Lewisian basement at terminal depth. With their lack of source rocks and poor development of potential reservoirs, these wells have downgraded hydrocarbon prospectivity in the area of the West Lewis Ridge.

Immediately to the east of the West Lewis Ridge, well 164/25-1Z drilled an anticlinal closure formed by the structural inversion of the West Lewis Basin during the Cenozoic. In this well, the volcanic interval is thin and occurs near the top of a thickly developed Paleocene clastic succession, which includes abundant sandstones. The succession is predominantly of Thanetian age, but a thinly bedded basal interval of Danian sandstones is also present. The Danian rocks overlie Cretaceous mudstones, which rest unconformably on the varied succession of Triassic sediments in which the well terminated. Basic igneous sills, up to 185 m thick, intrude much of the Cretaceous and some of the Paleocene interval in the well. Although the 164/25-1Z well shows that Jurassic rocks are absent locally, shallow boreholes drilled by the British Geological Survey have established the presence of potential hydrocarbon source rocks of Jurassic age elsewhere in the West Lewis Basin (Isaksen *et al.* 2000).

Seismic interpretation

The initial appraisal of the proposed licence area was supported by a detailed interpretation of the seismic profile YMR97-206 (Shot points 101-2500) (Fig. 2). Beginning in the UK sector, this line trends SW-NE across the Wyville Thomson Ridge to provide a complete geological section through the licence blocks 6007/17, 21 and 22 (Fig. 3). Seismic interpretation was aided by reference to regional profiles from adjoining blocks (Boldreel and Andersen 1993; 1994; 1998; Tate *et al.* 1999; Waddams and Cordingley 1999; Sorensen 2003; Archer *et al.* 2005; Keser Neish and Ziska 2005; Johnson *et al.* 2005). In addition, published structural contour maps of the top Paleogene lava surface (Tate *et al.* 1999; Keser Neish and Ziska 2005) were used to relate the interpreted seismic profile to the regional structure. Eight picked horizons (sea bed; near base Pliocene; top Paleogene; near top Eocene; near top Lower Eocene (Ypresian); top Paleogene lavas; base Paleogene lavas and intra-Paleocene) were provisionally correlated with the regional event stratigraphy of Johnson *et al.* (2005). Identification and dating of events below the top of the lavas remains speculative.

Following the award of the blocks, Føroya Kolvetni purchased additional selected profiles from a non-exclusive seismic survey acquired across the ridge by Fugro-Geoteam in 1997 (Fig. 3). A single regional line (SW84-091) was used to tie this seismic grid to well 164/7-1 (Fig. 3). A provisional structural contour map showed where the top lava reflector was truncated at the sea bed on the flanks of the high. Since the identification of the true base of the volcanic succession often remains uncertain on seismic data from the Atlantic margin, it is clearly beneficial that the thickness of the lava pile has been reduced by post-volcanic erosion above a potential sub-volcanic target at the crest of the Wyville Thomson Ridge. Extending the interpretation of the presumed base of the volcanic succession throughout the seismic grid defined two separate structural culminations along the ridge axis. The western culmination, which lies entirely within the Faroese sector, forms the basis of the *Rannvá* exploration lead.

Re-examination of the original line YMR97-206 (Fig. 2), in the light of the additional profiles led to the recognition of a discontinuous low amplitude reflector beneath the inferred base of the volcanic succession. This reflector is parallel to the lavas and appears to define the base of a mounded seismically transparent interval below the centre of the ridge. Horizon-flattening software was used to restore a reconstructed top lava event to its approximate pre-inversion position to reveal the original depositional geometry of the deeper, possibly pre-volcanic, reflectors. The wedging packages of high amplitude events previously identified on the flanks of the structure appeared on this display to onlap an axial mound-like feature.

In 2005, Føroya Kolvetni shot a set of seismic profiles infilling the original grid (Fig. 3) (for details of acquisition and processing parameters, see Holden *et al*. *this volume*). These lines included one profile (FP2005-002) that was planned specifically to transect the top of the previously identified *Rannvá* structural closure. This line established that the base of the lavas was even shallower than predicted, while the improved acquisition parameters and processing sequence revealed a deeper set of reflectors below the centre of the ridge (Fig. 4). Most of these are short high amplitude events probably related to basic intrusions and possibly affected by faults striking parallel to the ridge and throwing down towards the ridge axis. In the Faroe-Shetland and Rockall basins, reflections related to basic sills occur predominantly within the Cretaceous succession. To assess the tectonic implications of these observations, a palaeogeographic map of structural elements in the vicinity of the UK-Faroes median line was modified to include a Mesozoic basin at the site of the Wyville Thomson Ridge (Fig. 5).

Improved imaging of the Wyville Thomson Ridge allows the seismic facies directly below the volcanic layer to be compared with Paleogene reflectivity in the Faroe-Shetland Basin. Comparison with published seismic profiles (for example, Smallwood and Gill 2002, their Fig. 2; Smallwood *et al*. 2004, their Fig. 13) reveals a particular correspondence between the seismic character of the interval that pinches out beneath the flanks of the ridge and that of the Upper Flett and Balder formations (Fig. 4). It follows that the mounded seismically transparent interval onlapped by these reflectors, which occurs beneath the axis of the ridge, may be equivalent to the prograding wedge of Lamba Formation sediments in the UK sector (Figs. 2, 4). If this is the case, then the reflector previously recognised at the base of the transparent interval probably corresponds to the Kettla Tuff Member, which is already known to be a regionally extensive seismic marker (Figs. 2, 4). Elsewhere along the Atlantic margin, a thin shale interval underlying the Kettla Tuff acts as a local seal to the thick turbidite sequences of the Vaila Formation, which form the main Paleocene reservoir in the UK sector. Based on this analogy, a seismic interval corresponding to potential Vaila Formation turbidites beneath the Wyville Thomson Ridge is indicated on Figure 4. The absence of equivalent sediments from the nearby well 164/7-1 can be attributed to non-deposition or erosion at the pre-lava unconformity surface above a structural high (Archer *et al*. 2005).

Biostratigraphic ages obtained from side-wall cores in well 164/7-1 show that the local volcanic succession must have been extruded rapidly, possibly from the Faroe Bank Channel Knoll volcanic centre, during the latest Paleocene and earliest Eocene (Archer *et al*. 2005). The lavas, which may be penecontemporaneous with the Balder Formation, buried the inferred Paleocene sedimentary succession at the Wyville Thomson Ridge as they thinned southwards towards the Rockall Basin. After the formation of the lava shield, local erosion during the earliest Eocene was followed by marine transgression across the Faroes Shelf (Waagstein and Heilmann-Clausen 1995). Subsequent Middle Eocene deposition in the Faroe-Shetland Basin shows thinning towards the rising axes of basin inversion anticlines (Smallwood 2004). Seismic evidence of Middle and Upper Eocene chaotic facies from adjoining basins suggests that the Wyville Thomson Ridge was also affected by basin inversion at this time, with folding and uplifting of lavas at the ridge, while a new depocentre developed above the former structural high on its southern flank. The margins of the Drekaeyga intrusive centre (Keser Neish and Ziska 2005) were deformed and the Ymir Ridge evolved as a series of transpressional anticlines, possibly buttressed against the Darwin-Geikie Ridge and its associated igneous intrusions (Boldreel and Andersen 1993; 1994; 1998; Tate *et al.* 1999). A similar pattern of footwall deformation has been observed in sandbox experiments of inverted half graben (Panien *et al.* 2005). If the tectonic model developed by Imber *et al*. (2005) for the Vøring Basin can be applied to this part of the Atlantic Margin, it is possible that an episode of localised basin inversion was initiated by the effect of sinistral transpression on a restraining right-stepping offset of basement blocks across the Wyville Thomson transfer zone (Fig. 5).

Uplift of the Wyville Thomson Ridge contributed to a change in oceanic circulation in the evolving Atlantic Ocean. The development of a major submarine unconformity surface near the end of the late Eocene (= C30 event of Stoker 1999) is commonly taken to mark the onset of bottom water circulation in the Atlantic. The late Eocene unconformity was onlapped, as the Rockall Basin continued to deepen during the Oligocene. Then a further episode of uplift and erosion generated another regionally significant unconformity, marking the top of the Paleogene (this was formerly described as the latest Oligocene/early Miocene unconformity (LOEMU) or C20 event by Stoker *et al* (2002) and is equivalent to the TPU event of

Smallwood (2004) in the Faroe-Shetland Basin). The interval between these late Eocene and top Paleogene unconformities is characterised by a set of small-displacement, compaction-related normal faults that developed in semi-consolidated sediments of predominantly Oligocene age, on the flanks of rising anticlines, including the Wyville Thomson Ridge (Johnson *et al*. 2005). The next regionally significant unconformity is interpreted as the base of the Pliocene-Pleistocene succession on the Atlantic margin and probably corresponds to the C10 reflector of Stoker *et al.* (2002, 2005).

Seismic interpretation concluded with the preparation of revised structural contour maps incorporating the new seismic data. Maps of top Paleogene lava, base Paleogene lava and possible top Paleocene reservoir horizons improved the structural resolution of the *Rannvá* lead and helped to define the depth to a potential target (Fig. 6).

Potential field interpretation

Despite the improved resolution of the recent seismic reflection data, there is still little firm evidence for the early geological history and thickness of any precursor basin beneath the Wyville Thomson Ridge. Potential field data provide an independent means of assessing the deep structure of the area.

The large differences between previous gravity interpretations (Roberts *et al*. 1983; Tate *et al*. 1999; Waddams and Cordingley 1999) illustrate the non-uniqueness inherent in gravity modelling where independent constraints are limited. Comparison with magnetic data does help to reduce the uncertainty. Borehole sampling (Archer *et al*. 2005) and the characteristics of the observed magnetic anomalies indicate that the lavas are reversely magnetised. On the basis of rock property measurements (e.g. Shoenharting and Abrahamsen, 1984; Abrahamsen *et al.*, 1984; Sharma, 1994) they are estimated to have a net intensity of magnetisation of 3 - 4 A/m in a direction approximately opposite to the Earth's present field. When magnetisations of this order are adopted in the alternative models for the Wyville Thomson Ridge, the results prove diagnostic. The thick lava pile modelled by Roberts *et al.* (1983) generates a much larger magnetic anomaly than is observed, whereas the thin, folded lava layer in the interpretations of Tate *et al*. (1999), Waddams and Cordingley (1999) and the present study produce a response of appropriate amplitude.

New gravity modelling was undertaken using the results of the seismic interpretation described above. The aim was to remove the gravity effect of the seismically resolved sedimentary and volcanic rocks and interpret the residual anomalies in terms of underlying structure. The modelling focused on seismic lines YMR97-206 and YMR97-208 (Figs. 3, 7). Positive features over the Wyville Thomson and Ymir ridges dominate the free-air gravity anomaly pattern (Fig. 7), and another positive anomaly is associated with the Faroe Bank Channel Knoll volcanic centre (Roberts *et al*., 1983; Boldreel and Andersen, 1999; Keser Neish and Ziska, 2005). The Drekaeyga volcanic centre (Fig. 7), which has been identified on seismic and magnetic data between the Wyville Thomson and Ymir ridges does not generate a strong free-air gravity feature (Keser Neish, 2004; Keser Neish and Ziska, 2005). Densities of 2.00 Mg/m^3 and 2.55 Mg/m^3 were assumed for post lava sediments and lavas respectively. The relatively low density assumed for the latter reflects the very heterogeneous nature of the volcanic sequence, as revealed by well 164/7-1. Although high densities (2.55-2.85 Mg/m^3) do occur in the interiors of individual flows, values decrease to 2.15-2.55 Mg/m^3 at flow margins (Archer *et al*. 2005). Initial whole-crustal 2D models were constructed assuming that crustal thickness varied such that the bathymetric and cover sequence features identified by seismic surveys (down to the base of the lavas) were in isostatic equilibrium. A two-layer crust was assumed to underlie the lavas, with densities in its upper and lower parts of 2.75 Mg/m^3 and 2.95 Mg/m^3 respectively, and the mantle density was 3.3 Mg/m^3.

The gravity responses predicted by these initial models differed significantly from the observed field, and the next stage was to investigate the extent to which the sub-lava sedimentary rocks could contribute to these differences. Such rocks have been proved at well 164/7-1, about 14 km SSW of the southern end of line 208 (Fig. 6), where a 1.3 km section comprising Paleogene lavas and tuffs underlain by heavily intruded Cretaceous claystones was intersected (Archer *et al*. 2005). The geoseismic interpretation of Archer *et al*. (2005, their Fig. 19) suggests that the top of the acoustic basement lies less than 1 km below the bottom of 164/7-1, but at considerably greater depths away from the dome that was drilled by this well. On the basis of the limited available evidence it has been assumed that about 3 km of pre-Cretaceous sedimentary rocks underlie the southern end of line 208. This was used as reference against which pre-lava sedimentary thicknesses variations elsewhere were modelled, as it is not possible to predict absolute thicknesses from the available data in this modelling context. The gravity model presented by Archer *et al*. (2005; their Fig. 16) assumed a high density (2.79 Mg/m^3) for the intruded Cretaceous section. While this might be appropriate for the inferred laccolith drilled by 164/7-1, densities are almost certainly significantly lower away from this local intrusive feature. In the present modelling, the pre-lava unit has been divided into upper and lower parts and these assigned average densities (2.50 Mg/m^3 and 2.62 Mg/m^3 respectively) that are closer to those predicted from consideration of the effect of compaction on normal mudrocks. The use of the same density for the uppermost part of the pre-lava sequence, regardless of its depth of burial, is compatible with an interpretation in which these rocks originally lay at similar depths but were subsequently affected by different degrees of structural inversion. The effects of inversion were not extended to deeper density structure, and the interface between the 2.50 Mg/m^3 and 2.62 Mg/m^3 components in the pre-lava sedimentary sequence is a modelling approximation with no structural or stratigraphic significance.

Starting at the nominal reference point at the southern end of line 208, the model for this line does not require large changes in the thickness of the pre-lava sedimentary rocks on the southern side of the Wyville Thomson Ridge (Fig. 8). A reduction in pre-lava sediment thickness to the north of the ridge is, however, suggested by the modelling. Offline effects from the Faroe Channel Knoll volcanic centre affect this part of the section, and are only crudely simulated in the model. Changes in basement density across the Wyville Thomson Ridge may also have an influence (assuming that it overlies a reactivated basement structure), but have not been incorporated into the current models.

It was necessary to introduce the Faroe Bank Channel Knoll and Drekaeyga volcanic centres into the model for line 206 to produce a satisfactory match between observed and calculated gravity fields. There is latitude in the way the gravity response is partitioned between the volcanic centres and the sediment thickness variations, but it does appear likely that there is a relatively thick pre-lava sedimentary section beneath the Wyville Thomson Ridge on this line (Fig. 8).

Comparison of these models with the (subsequently published) results of a wide-angle seismic profile across the Wyville Thomson Ridge in the UK sector (Klingelhöfer *et al*. 2005) reveals significant similarities in the thicknesses and depths obtained by these different methods (Fig. 8). In each case, the greatest pre-lava sedimentary thickness occurs beneath the axis of the ridge. However, the apparent indication from the three profiles that this sequence thickens north-westwards towards the Faroese sector should be treated with caution, given the limitations and assumptions of the gravity interpretations. Significant uncertainties remain with regard to control points for the pre-lava sequence and the influence of variations in the thickness and properties of the underlying basement. For example, the gravity modelling adopted an initial assumption of isostatic equilibrium, but the seismic model for profile D does not indicate such equilibrium (implying that the ridge topography is supported by lithospheric strength). The consequences of this were tested by flattening the Moho beneath the ridge in the gravity models and investigating the influence on modelled upper crustal structure. The broad geometries were similar, but an increase in sedimentary thickness beneath the ridge of up to 2 km was required. The conclusion is that the gravity modelling supports the presence of a thick sedimentary sequence beneath the Wyville Thomson Ridge but that the details of its geometry are currently not accurately quantified.

Rannvá lead

The major lead in the licence application area is named *Rannvá* and consists of an anticlinal, four-way dip closure formed during the Cenozoic by the compressional inversion of a sedimentary basin inferred to underlie the Wyville Thomson Ridge (Fig. 6). The geological history of this basin remains largely unknown and, at present, its hydrocarbon potential can only be assessed on the basis of regional observations.

Source rocks

To the south of the Wyville Thomson Ridge, well 164/7-1 did not penetrate any hydrocarbon source rocks (Archer *et al.* 2005). The Cretaceous succession in which the well terminated was shown to be thermally metamorphosed, over-mature and incapable of generating hydrocarbons. This metamorphism is not regional in extent, but was caused by the location of the well above a major plutonic intrusion and its associated shallower complex of basic sills. Potential source rocks are more likely to be developed within deeper Jurassic sequences, but sediments of this age remain unproven, not only beneath the Wyville Thomson Ridge, but also in the NE Rockall Basin. However, some core material recovered from BGS shallow boreholes at the margin of the nearby West Lewis Basin does consist of potential source rocks, including oil-prone Middle Jurassic (Bathonian) sediments and Kimmeridge Clay Formation mudstones of Lower Cretaceous (Ryazanian) age (Isaksen *et al.* 2000). These rocks reflect the varied nature of the hydrocarbon sources that have contributed to the Foinaven and Schiehallion oilfields in the adjoining Faroe-Shetland Basin (Bailey *et al*. 1987; Spencer *et al.* 1999). They also provide an indication that similar source material may be more extensively preserved elsewhere in the separate marginal basins of the Rockall Basin area. Previous interpretations of the Rockall Basin, which implied that it was largely of early Cretaceous origin and possibly lacked Jurassic source rocks, did much to downgrade the prospectivity of the area (Musgrove and Mitchener 1996). Although the early structural and stratigraphic evolution of the basin remains poorly understood, the recent Doolish discovery by Irish well 12/2-1 casts significant doubt on this pessimistic view of the region and increases the likelihood that an effective petroleum system will also be developed in the area between the Faroe-Shetland and Rockall basins. Similarly, the presence of Devono-Carboniferous strata close to the median line in UK well 213/23-1 means that older Palaeozoic sources may also be capable of generating hydrocarbons in parts of the Atlantic margin, even if Mesozoic source rocks are absent.

Reservoirs

The 164/25-1Z exploration well in the West Lewis Basin previously established that potential Paleocene reservoirs are preserved locally beneath volcanic rocks. However, the expectation that a similar succession may be developed in a comparable basinal setting in the NE Rockall Basin was not confirmed by the 164/7-1 well, which proved a kilometre-thick pile of thinly bedded lavas and pyroclastic rocks completely devoid of potential reservoirs (Archer *et al.*

2005). This well showed that, even in a predominantly basinal area, Paleocene reservoir distribution depends partly on the pattern of pre-volcanic uplift. The lack of a reservoir interval in the 164/7-1 well is attributed to development of a local structural high during the episode of basic sill intrusion that preceded the growth of the lava shield. Better Paleocene reservoirs are likely to be found away from areas of pre-volcanic uplift. Similarities between seismic facies from the pre-volcanic interval beneath the Wyville Thomson Ridge and late Paleocene-early Eocene reflectivity patterns in the Faroe-Shetland Basin increase the possibility that late Paleocene turbidite reservoirs might be preserved in a contemporaneous basin currently concealed by the lava shield. These potential reservoirs could be distal equivalents of the pre-Kettla Tuff Vaila Sandstones of the Foinaven-Schiehallion area (Lamers and Carmichael 1999), or earlier Paleocene sandstones like those of the Marjun discovery in the Faroese sector (Smallwood *et al.* 2002). Such sandstones need not be derived from the eastern margin of the basin; an origin on the Faroes Shelf, or more local provenance from the block underlying the Faroe Bank Channel Knoll volcanic centre, cannot be ruled out. Regional considerations suggest that older potential reservoirs may exist at Turonian and Cenomanian level, but reservoir sandstones of this age were not present in the nearby 164/7-1 well. Currently, the deeper stratigraphy of the basin underlying the Wyville Thomson Ridge remains unknown, but basins of similar scale on adjoining parts of the margin commonly originated as sandstone-dominated Permo-Triassic half graben.

Seals

In the Faroe-Shetland Basin, Vaila Formation mudstones underlying the Kettla Tuff provide a widespread seal for reservoirs consisting of overlapping basin floor turbidites. The sealing horizon in the Wyville Thomson Ridge area may consist of fine-grained volcaniclastic sediments at the base of a kilometre-thick pile of interbedded basic lavas and tuffs. Intra-formational seals may also be present in the pre-volcanic succession.

Trap

An analysis of the exploration history of the West of Shetland area has shown that most failed wells were explained by the invalidity of the trap (Loizou 2005). The unexpected failure of drilling targets defined by amplitude analysis has helped to restore interest in simpler structural plays in this area. The *Rannvá* lead is based on a robust four-way dip closure (Fig. 6). This anticlinal trap formed by basin inversion and is closed along strike by variation in the preserved thickness of the partially eroded volcanic shield that caps the structure. Thinning of the volcanic carapace at the culmination of the trap increases the risk of breaching, and means that the deleterious effects of flushing and biodegradation present additional risks.

Migration

The complex structural history of the Wyville Thomson Ridge area, combined with the uncertainty about the present depth of burial and maturity of potential source rocks makes it difficult to reconstruct regional hydrocarbon migration paths. However the juxtaposition of a structural high and an inverted basin means that the remigration ('motel') model of Doré and Lundin (1996) could be applied to this area. This model suggests that early-formed hydrocarbons can be stored temporarily in traps formed by horsts or tilted blocks, before remigrating into a different structure as new traps are created by basin inversion. By this means, previously mobilised oil may still be available to fill late developing structures by remigration, even as the original source rocks themselves become over-mature. Recent reappraisals of the thermal history of the basin have suggested that such models may no longer be required to maintain prospectivity of the area, with source rock maturity being inhibited instead by the development of overpressure in basinal successions. This process might sufficiently postpone oil generation to allow late forming structures to be filled, without the need for remigration (Carr and Scotchman 2003).

Conclusions

Føroya Kolvetni have carried out an initial assessment of the hydrocarbon prospectivity of Licence 012 acreage in the Faroese sector of the Atlantic margin. Their *Rannvá* exploration lead consists of a major sub-volcanic anticlinal closure beneath the crest of the Wyville Thomson Ridge. Comparison of Paleocene seismic facies with those of the productive Faroe-Shetland Basin suggests that a correlative of the Kettla Tuff Member may be present beneath the ridge axis, and turbidite sandstone reservoirs are possibly developed immediately below this level. The presence of source rocks and the deeper structure of the area remain uncertain, but evidence obtained from regional geological analogues, sandbox experiments into basin inversion, and modelling of potential field data, is consistent with the development of an inverted Mesozoic half graben at depth.

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Figures

1: Structural setting of the Wyville Thomson Ridge (modified from Johnson *et al.* 2005), with the area of Faroese Licence 012 in yellow. The dashed line marks the location of part of a regional wide-angle seismic profile (Line D from Klingelhöfer *et al*. 2005) (see Fig. 8).

2: a: Interpretation of part of seismic line YMR97-206 across the Wyville Thomson Ridge: The dashed reflector was used to in the process of horizon flattening and represents the conjectural restored top of the Paleogene volcanic succession before erosion (for location, see Figure 3).
b: A play concept diagram for the Wyville Thomson Ridge based on seismic line YMR97-206, showing a speculative schematic reconstruction of an underlying Mesozoic-Paleocene basin.

3: Wyville Thomson Ridge area: Location map of interpreted seismic reflection profiles, with the boundary of the Licence 012 area outlined in yellow.

4: a: Wyville Thomson Ridge: Interpreted seismic line FP05-6007-02 (for location, see Figure 3).
b: Seismic line FP05-6007-02, flattened at top lava level, including the dashed segment of reflector, which represents the conjectural restored top of the volcanic succession before erosion at the crest of the ridge. Coloured seismic facies below the inferred base of the volcanic succession are interpreted by comparison with seismic data from the SW Faroe-Shetland Basin (Smallwood and Gill 2002; Smallwood *et al*. 2004).

5: Simplified map showing structural elements of the Atlantic margin in the vicinity of the UK-Faroes median line: Tonal variation is used diagrammatically to indicate the comparative structural relief of the Cretaceous-Paleocene basins (green) and highs (pink) before Eocene-Recent uplift and inversion. The axis of inversion to the north of the Judd High is taken from Smallwood and Gill (2004).

6: *Rannvá* exploration lead summary map: *Rannvá* lead consists of a pre-volcanic four-way dip closure beneath the axis of the Wyville Thomson Ridge. Provisional structural contours within the closure, colour shaded at intervals of 100 metres, are based on a seismic reflector possibly corresponding to the Kettla Tuff (Smallwood and Gill 2002; Smallwood *et al*. 2004).

7: Colour shaded-relief image of the free-air gravity anomalies from the YMR97 survey. Illumination is from the north. Heavy lines indicate the location of the model profiles.

8: Gravity models for lines YMR97-206 and YMR97-208 incorporating a pre-lava sedimentary layer and the influence of volcanic centres. Note that the Faroe Bank Channel Knoll volcanic centre lies between the two lines (closer to 206), so its effect is only crudely simulated. Volcanic centres have a half-strike length of 10 km; other bodies are 2D. Numbers on the models indicate densities in Mg/m^3. Line D, for comparison, is based on a segment of a wide-angle seismic reflection profile that crosses the Wyville Thomson Ridge along strike within the UK sector (Klingelhöfer *et al*. 2005) (for location, see Fig. 1).

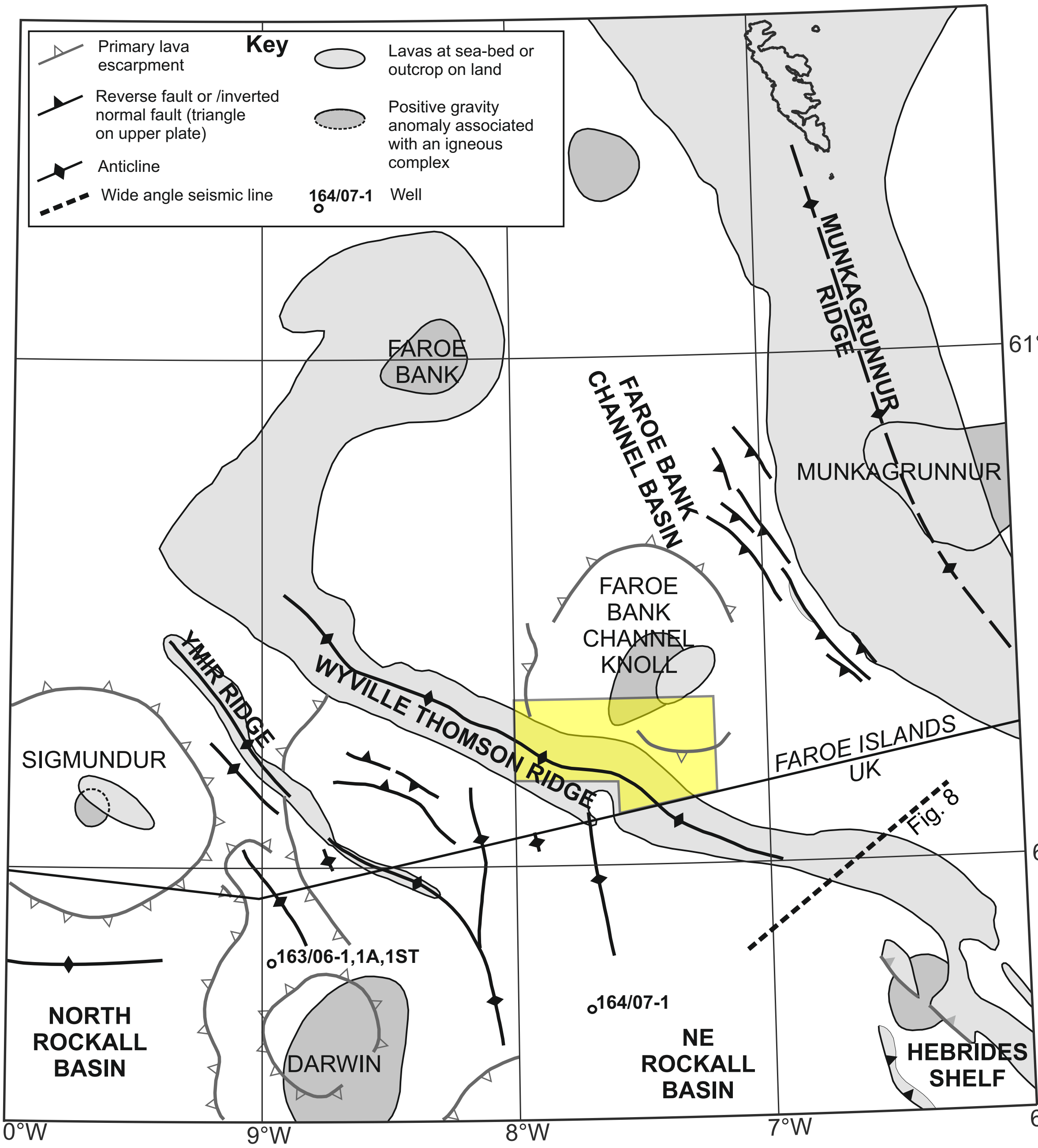


Figure 1. (K Smith *et al.*)

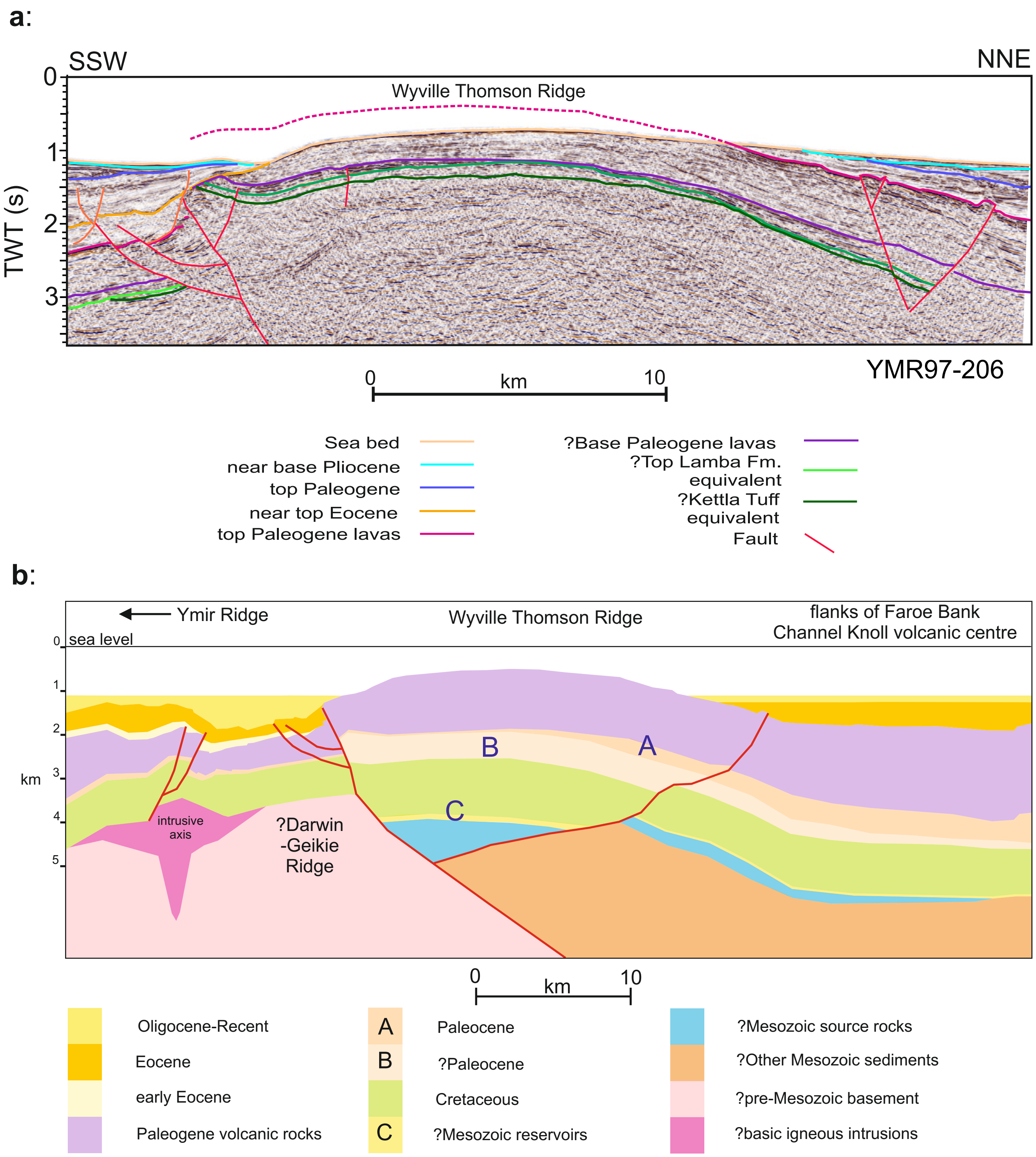


Figure 2. (K Smith *et al.*)

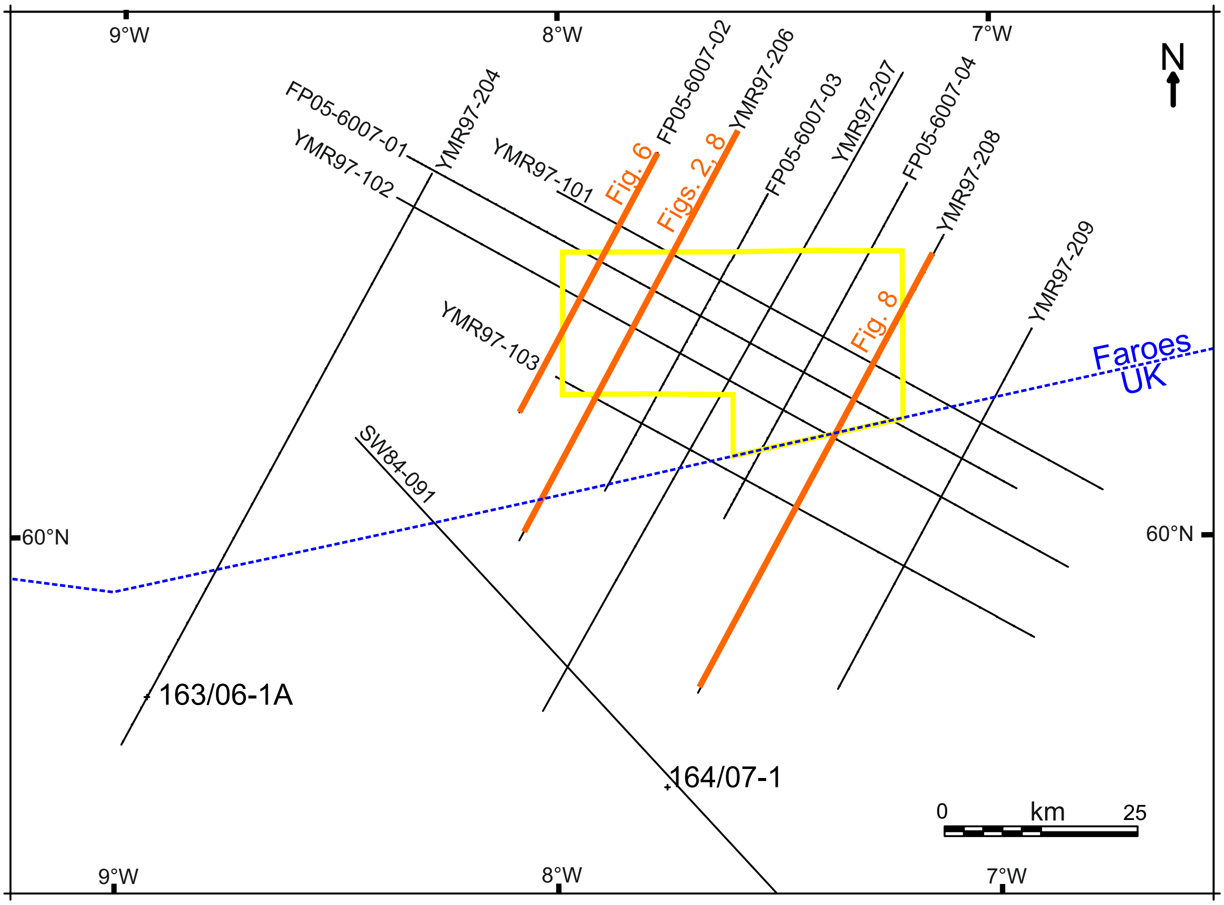
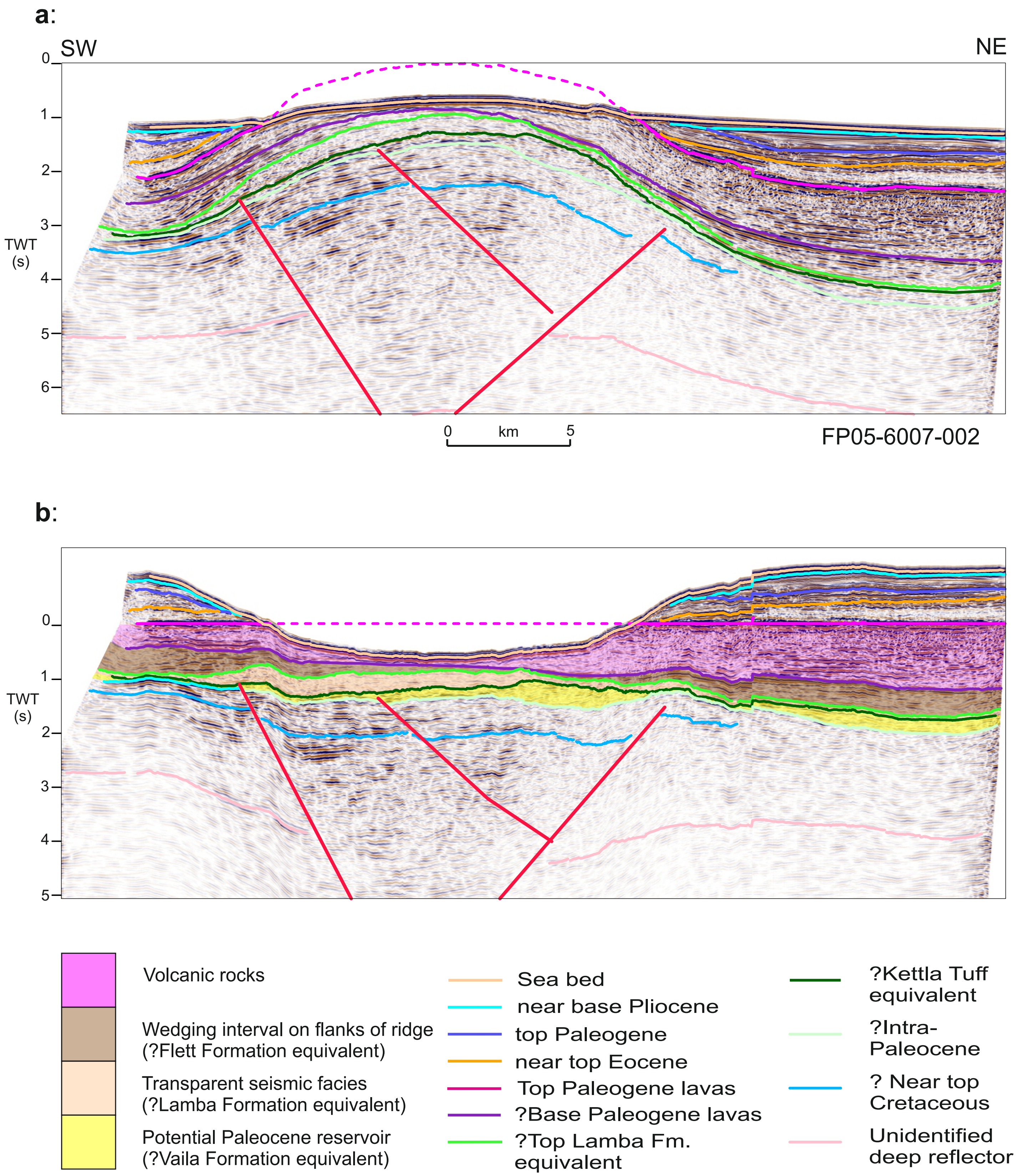


Figure 3. (K Smith *et al.*)



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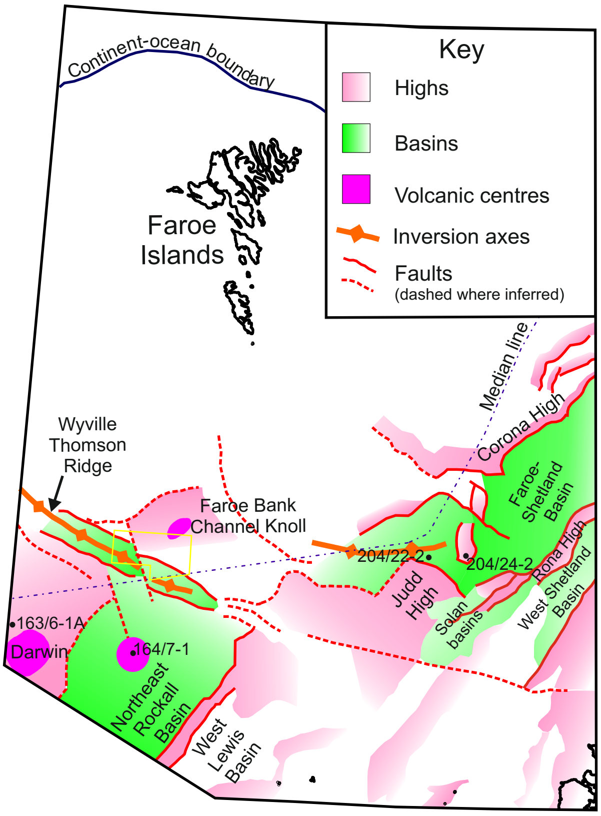

Figure 5. (K Smith *et al.*)

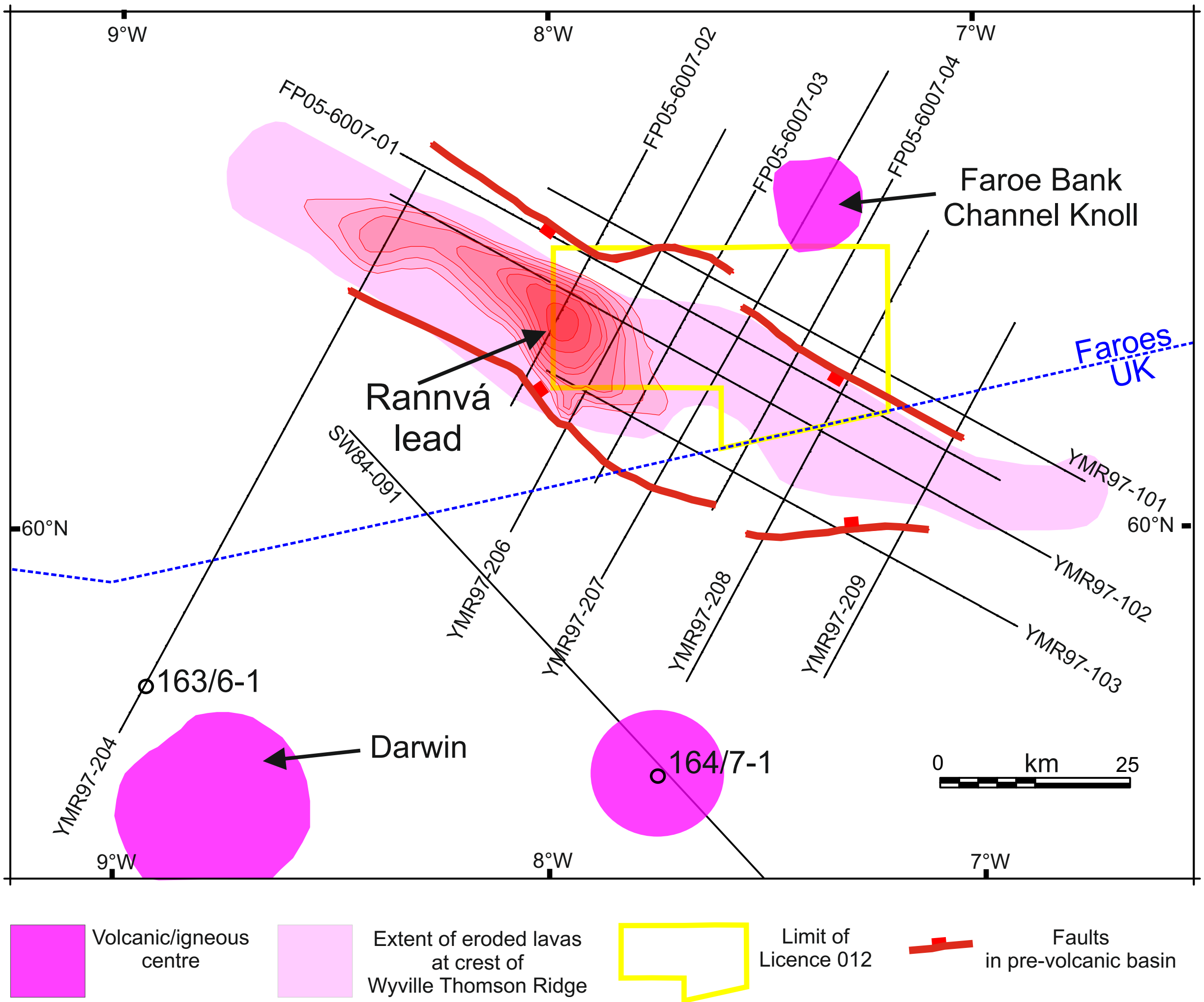

Figure 6. (K Smith *et al.*)

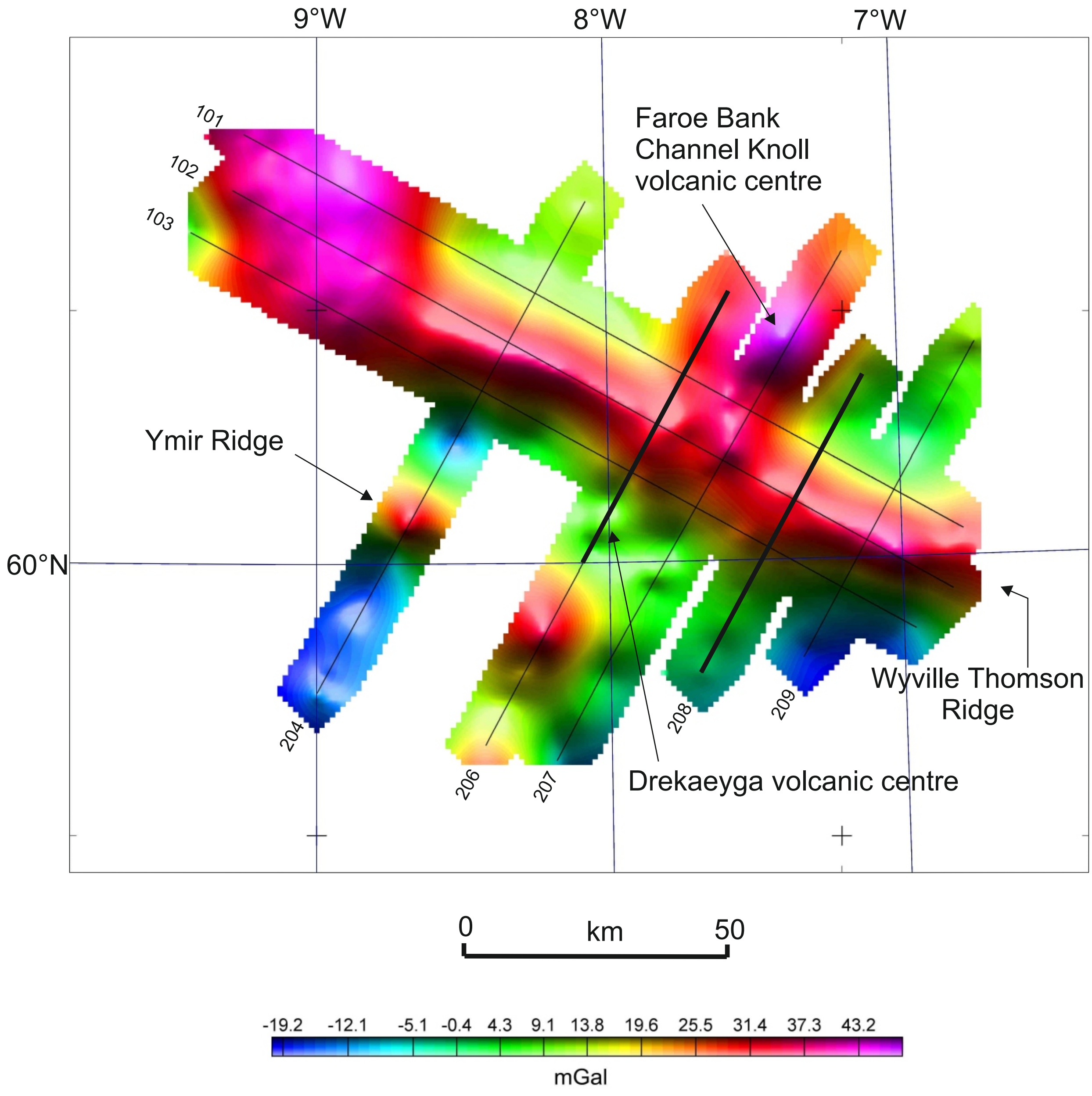

Figure 7. (K Smith *et al.*)

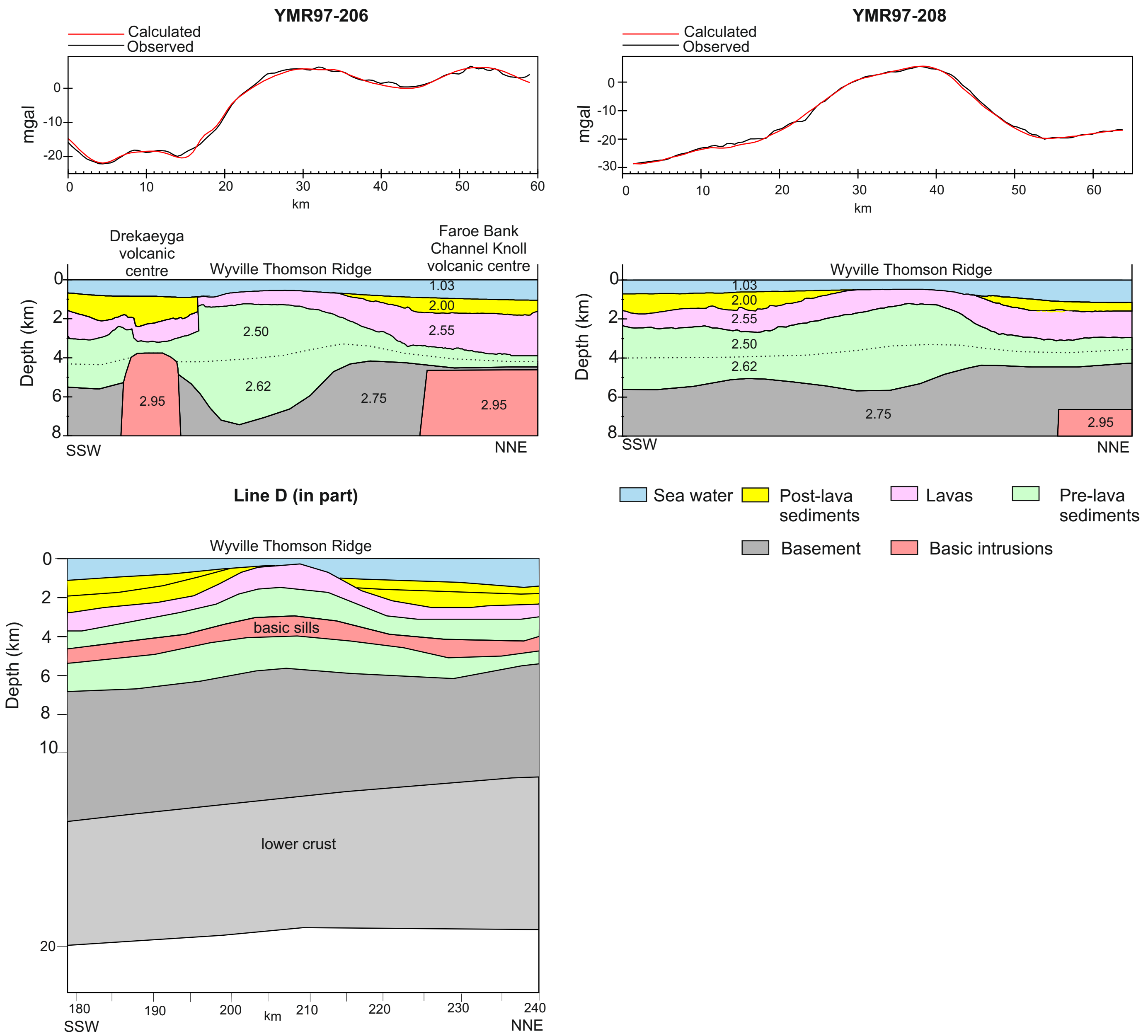

Figure 8. (K Smith *et al.*)