PS Evidence for Along Strike Variation in Structural Style, Geometry and Its Possible Causes: A Case Study Along the UK Flank of the Faeroe-Shetland Basin (North Atlantic Margin)*

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Search and Discovery Article #30178 (2011)
Posted August 31, 2011

*Adapted from poster presentation at AAPG Annual Convention and Exhibition, Houston, Texas, USA, April 10-13, 2011

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Abstract

Newly reprocessed seismic data across the Faeroe-Shetland Basin has given improved data quality and enabled the identification of a combination of extension and inversion systems resulting in different geometries observed along the UK flank of the basin. The stratigraphic succession is simply comprised of sand and shale alternations with limestone bands from Devonian to Late Cretaceous, and sand, shale, tuff, and lava flow with associated dykes and sills dominating Palelocene to Recent.

In the southern part the structural style is characterized by extension with intense dyke and sill emplacement. The resulting geometry is roll-over anticline, inflation anticline and fault types are polygonal faults and listric extensional faults. In the central part of the Muckle Basin the early extensional regime was overprinted with mild contraction during the Late Cretaceous. This contraction resulted in localized uplift and buckling which caused erosion of Jurassic/Early Cretaceous sediment and deposition of mass transport deposits down slope. Polygonal faults are formed in the deeper sequence of the basin during the Cenozoic. In the northern part, the structural style shows intense contraction that resulted in more significant inversion with pronounced harpoon structures dominant in the Cretaceous sections, dykes and sill emplacement and imbricate faults with the mass transport deposits during the Cenozoic.

This complexity is interpreted to be caused by a combination of: (i) Segmentation of the basins due to its evolution (from intra-cratonic pull-apart basin), (ii) NW Europe regional plate movement, associated with the opening of the Atlantic, (iii) Emplacement of intrusive and extrusive volcanism, dykes and sills in the Paleogene, (iv) Boundary fault movement, oblique extension and a possible transfer fault movement causing transtensional contraction and buckling especially in the Muckle sub basin, and (v) Sudden

subsidence, dewatering and gravitation loading/sliding resulting in sediment progradation and polygonal faulting in deeper parts of the basin.

The varying influence of these factors may account for the distribution, complexity and distinct structural style and geometries along the UK flank of the Faeroe-Shetland Basin. An understanding of these factors is critical for exploration success with the Faeroe-Shetland Basin.

Evidence for Along Strike Variation in Structural Styles, Geometries & its Possible Causes: UK Flank, Faeroe-Shetland Basin, North Atlantic Margin

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1 Introduction

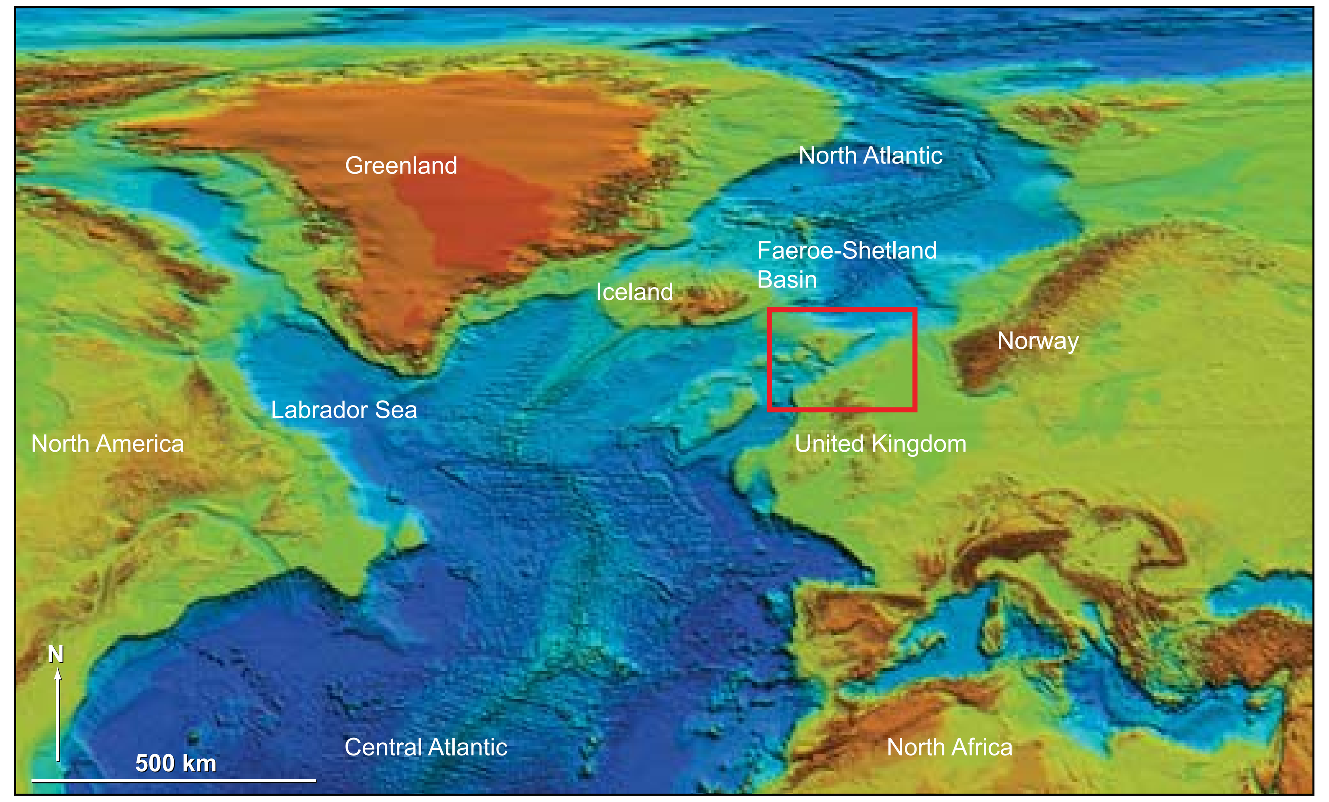

Figure 1. SRTM30 Digital Elevation Model of the North Atlantic Margin. The research area is highlighted.

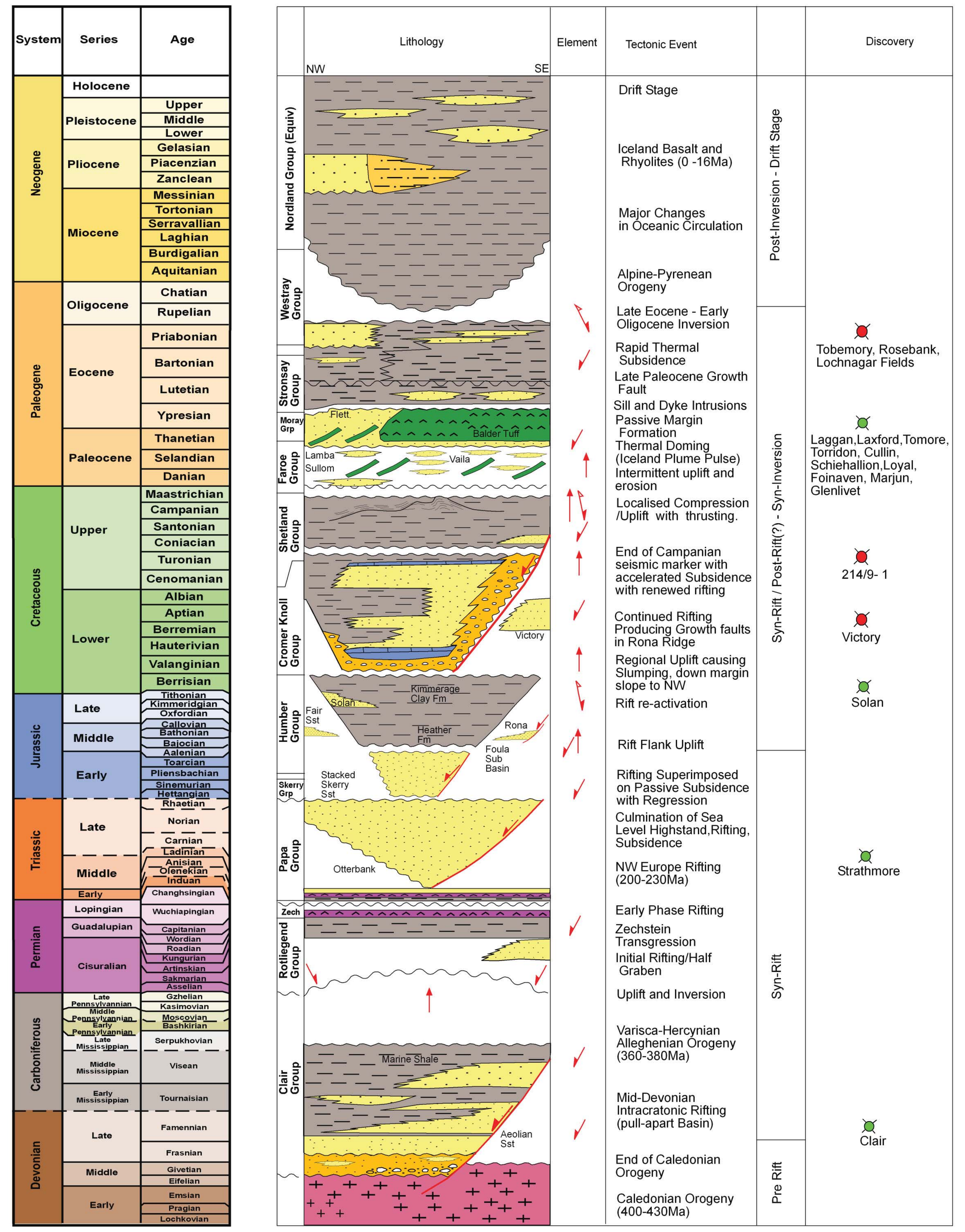
Figure 2. Tectonostratigraphy of Faeroe-Shetland Basin. Modified from Grant et al. 1999

Introduction

The study area is within 61° N-62° N and 2° W- 1° W ,Faeroe-Shetland Basin and is located on the North Atlantic Volcanic Passive margin to the NW of the British Isles (Figure 1). Passive Margins have been identified to be important hydrocarbon province around the world with huge discoveries. They are Formed from Separation of Continents and consist of Offshore Continental Platform and Oceanic Continental Shelf and constitute 61% of HC resources with 31% (~592 giant field) from mature passive margins and 30% from continental rift basins evolving into passive margins e.g. Gulf of Mexico, Gulf of Guinea, NW Atlantics (North sea) etc. Mann et al 2001. The Faeroe-Shetland basin has an estimated Undiscovered mean recoverable reserves ~159 (million tonnes) of oil and more than 121 billion cubic feet of gas. (Decc Resource Estimate 2010). Exploration began in the 1970's based on poorly imaged data which yielded little success due to poor understanding of its tectonostratigraphic evulotion and also its volcanic nature. In recent years, an improvement in technology has enhanced data quality and imaging, this has lead to an increase in the understaning of the basin evolution. This research shows break through observation of the structural style due to an improved reprocessing technology applied by TGS which drastically enhanced seismic quality of the regional 2D lines within the sill complex and below the basalt across the basin (Figure 6)

Geology of NW Europe (Focused on Faeroe-Shetland)

The evolution of the Faeroe-Shetland basin is strongly related to the Plate movement in the North Atlantic province. Plate movement and re-organisation provides a valuable insight into the formation, interaction and relationship of the Faeroe-Shetland basin.The structural and stratigraphic record of the North Atlantic Province within which the Faeroe-Shetland belongs, reflects the complex geological evolution during which orogenic events, associated with the accretion of continental fragments and the collision of major continents, alternated with periods of wrench faulting and crustal extension forming several basins in the North Atlantic Province (Ziegler, 1993). The geological evolution of different parts of the North Atlantic Province reflects through time frequent changes in their tectonic setting and changes in the geodynamic processes that governed the subsidence and/or destruction of sedimentary basins. Thus, basins of different geotectonic origin developed, some stacked on top of one another while others were partly destroyed as the province evolved. (Ziegler, 1993).

In the North Atlantics, five main phases of plate boundary reorganization that accompanied the late Paleozoic assembly of Pangea and its subsequent disintegration, a hypothesis described by Ziegler 1993, are: Caledonian Cycles (Ordovician-Devonian), Hercynian Megacycle (Carboniferous-Early Permian), Late Permian - Mid-Jurassic Plate Reorganization, Late Mesozoic Break-up Phase (Mid-Jurassic-Early Cretaceous) and Passive Margin Development (Late Cretaceous-Cenozoic).

Tectonostratigraphy of Faeroe-Shetland Basin

The Faeroe-Sheland basin evolved from a pull-apart basin (Pre-rift) into a rift basin from Carboniferous to Early/Mid Jurassic (syn-rift/Post-rift?). This continued into the Cretaceous with intensity of rifting more in the Jurassic and Mid Cretaceous times. Better seismic imaging has revealed that there was uplift/tranpressional compression in the Late Jurassic and continued in certain sub-basins (Syn-inversion). This continued with extension and inversion dorminating in many sub-basin during the Palaeocene. There are 3 important regional events in the Faeroe-Shetland basin (Ziegler,1999): Caledonian orogeny (Silurian), Mesozoic-Early Cenozoic rift phase with deposition of thick Mesozoic sediments (Mid Jurassic - Latest Cretaceous) and North Atlantic spreading accompanied by basalt, lava eruption, renewed subsidence and flank uplift causing mass sedimentary deposition in the Eocene to recent. (Figure 2). The value to knowledge as a result of data enhancement is the contraction and buckling during Jurassic (?) to Cretaceous.

2 Regional Geology

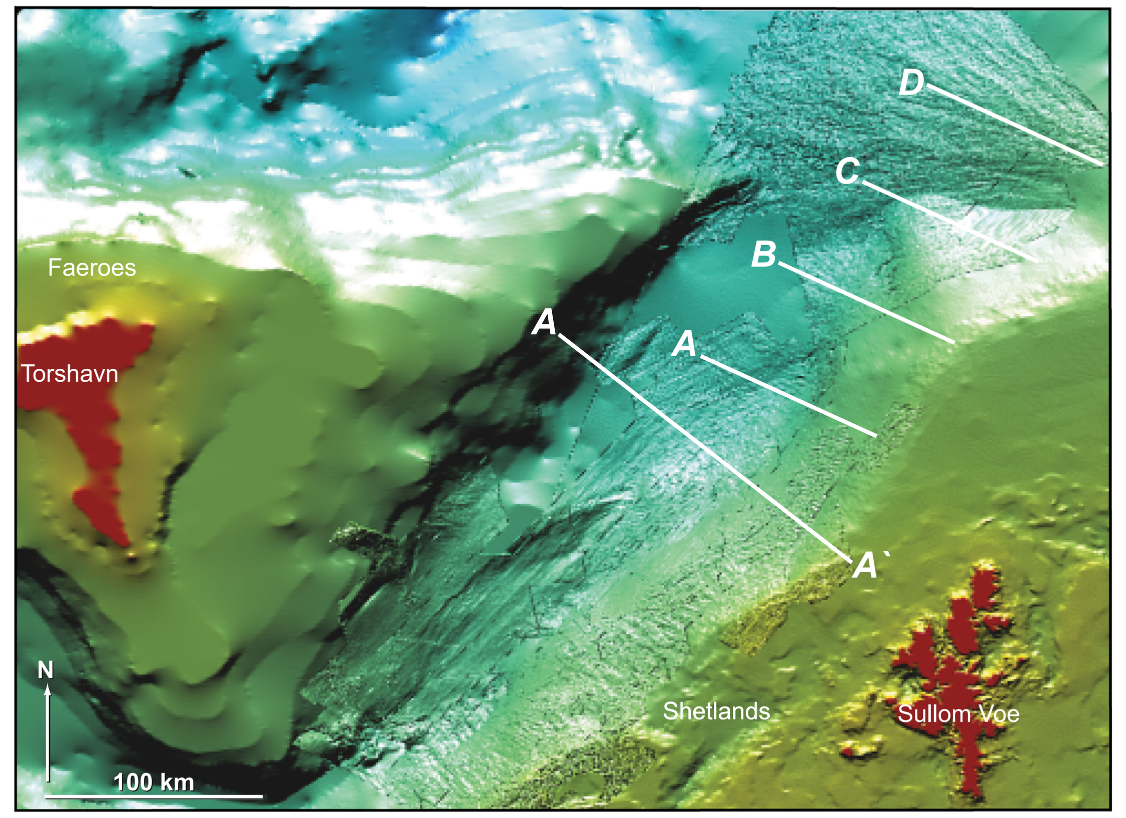

Figure 4. Sea bed Geomorphological data of the Faeroe-Shetland Basin. Data provided by British Geological Survey

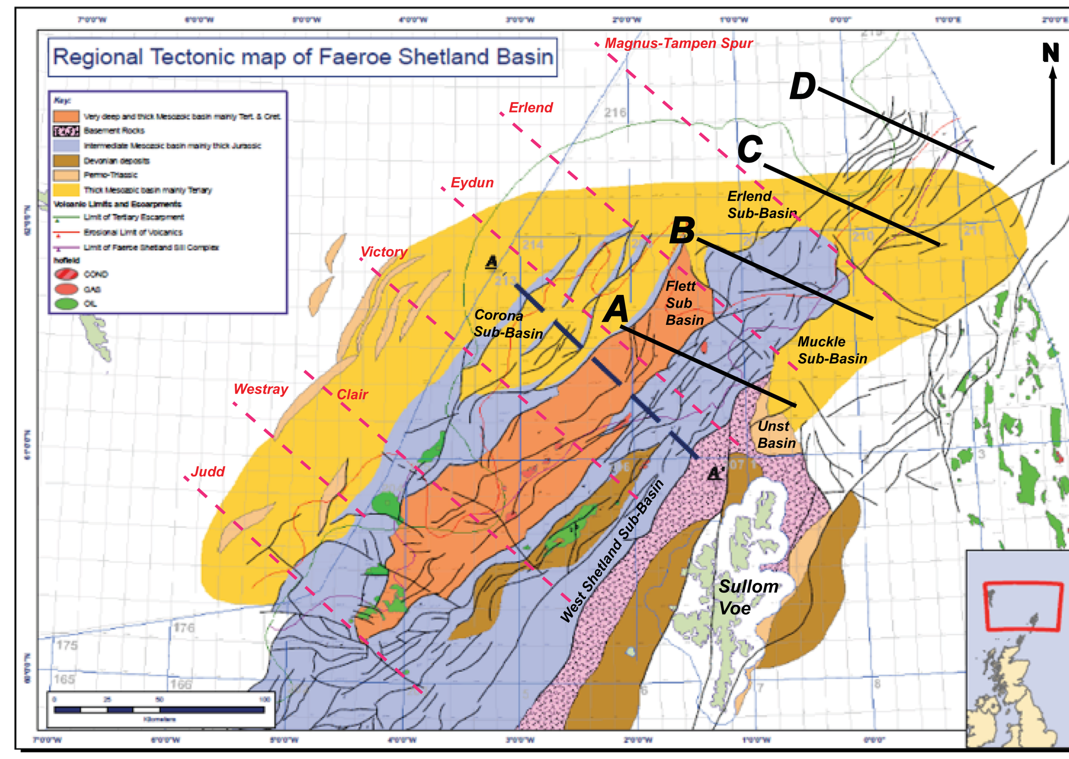

Figure 5. Regional Tectonic Map of the Faeroe-Shetland Basin. Modified from Larsen et al 2010

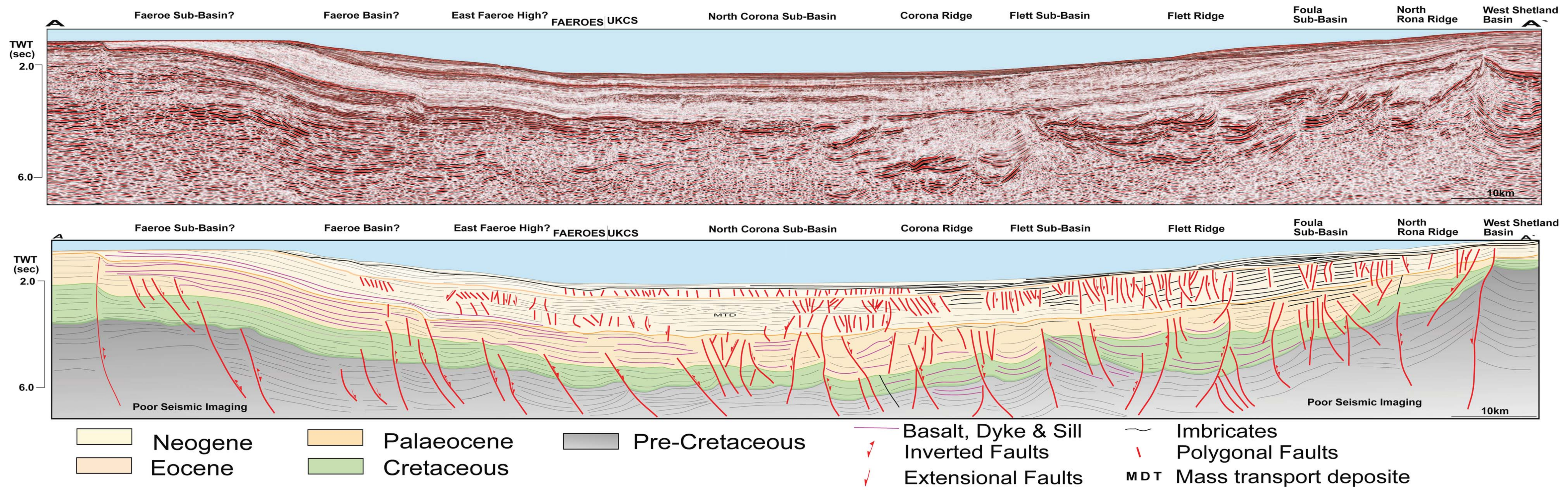

Figure 6. Regional Cross Section A-A` though the Faeroe-Shetland Basin showing general structural style of the Area .Three generation of faults is shown in the across basin. Data Provided by TGS

Geologic Setting

The Faeroe-Shetland basin is located in the Northern part of the North Atlantic Margin. It is bounded by the Wyville-Thompson transfer zone in the Southwest to the Nordland-Silje transfer zone to the Northeast close to the United Kingdom border and is delineated by the MØre basin in the Northeast. In the Northeast it is bounded by Faeroe platform and on the Southeast by Shetland platform with Igneous intrusives and extrusive in the North and West. (Figure 4).

The Faeroe-Shetland basin was fromed as a result of a failed rift from Rockall. It evolved from a Pull-apart basin into a developed rift basin and is believed to be in a passive margin stage. The basin faults show a NE-SW orientation which is orthogonal to the streching direction. The basin is segmented during the early stages of its formation and transfer fault lineaments observed to offset other faults with some en-echelon pattern and slightly oblique to the transfer fault movement.

The pronounced NE-SW fault orientation (Figure 5) was formed by multiple phase of Mesozoic extension from Mid-Jurassic to Cretaceous, leading ultimately to continental break-up in the Late Paleocene-Early Eocene. Subsequently, the area underwent several phase of tertiary compression (Boldreel and Andersen, 1993; Dore and Lundin, 1996) and uplift (White and Lovell, 1997) which can readily be observed in some stratigraphic interval. Varying degrees of uplifts within the basin had a strong effect on hydrocarbon migration, trapping and remigration into Cenozoic reservoirs (Herries et al., 1999). Margin uplift bordering the main bounding faults is an important facet of the evolution and sedimentation pattern. Its effect in the Paleocene and Neogene has a strong control on the present day architecture of the basin (Jasper and Chalmers, 2000).

Tectonically, the area of study has been divided into: Older Cretaceous sequence (Pre-rift - Syn-rift/Post-rift?), Early Cretaceous- Late Palaeocene sequence (Syn-rift/Post-rift? – Syn-Inversion) and Eocene – Holocene (Post-Inversion – Drift Stage).

A cross section through the basin from East to West shows 5 generation of faults are dorminant in the basin (Figure 6). They are: (i) Planar/Domino faults which are basement controlled fault is suggested to control the geometry of the basin. They are aligned in the NE-SW direction and orthogonal to the spreading direction. (ii)The Listric extensional fault which produce classic roll-over structure (figure 9). They have very shallow dip angle and the faults is interpreted to slide on a detachment layer which is highly organic shale as seen from many examples from basins with high organic shales like the Niger Delta. (iii)Polygonal faults which is seen in the Eocene to Recent across the basin in the Southern part. (iv) imbricate faults which is seen in the Eocene to Recent across the basin in the North part (v) Transform faults observed to be active until early Palaeocene. The Western part of the basin is dorminated by basalts (Figure 6) with seaward dipping reflectors from the Faeroes with the limit of basalt escapement in Figure 5. Away from the Western part, towards the Eastern part is the limit of dyke and sill complex within which there are swarms of sills and dykes with wings . Volcanics in the basin hinders proper seismic imaging below basalt and within the sill and dyke complex.

3 Regional Stratigraphy & Seismostratigraphy

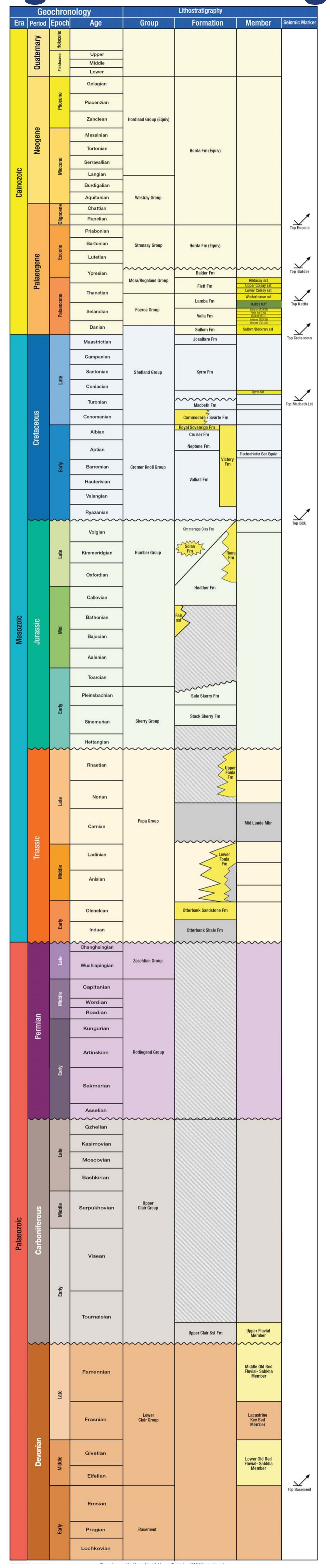
Figure 7. Generalised Stratigraphy of the Faeroe-Shetland Basin from Devonian to Neogene. Seven seismic markers can be identified regionally is highligted. Devonian Stratigraphy & Mesozoic Stratigraphy is modified from Allen & Mange Rajetsky 1952 & Grant et al 1999

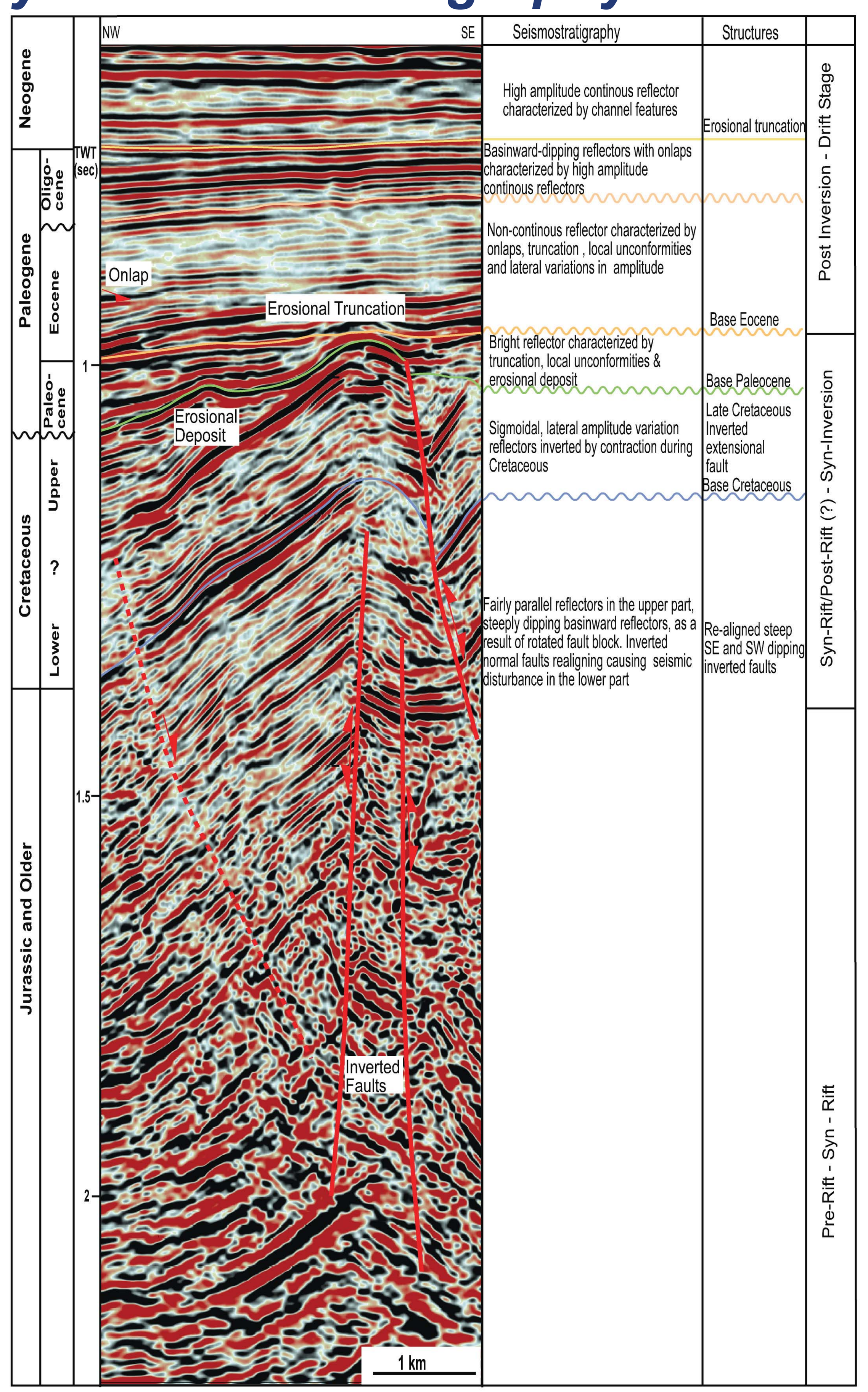

Figure 8. Seismostratigraphy of the Muckle Sub-basin. Showing four main unconformity prominent in the basin with associated truncations

Regional Stratigraphy & Seismostratigraphy

The stratigraphy of the basin starts from Devonian with the deposition of fluvial continental sandstone and musstone. This is followed by a period of non-deposition until the Triassic with sparse deposition of Triassic sediment in certain parts of the basin. Rifting initiation phase in the Jurassic lead to the deposition of organic rich shales whcih are the known source rock in the basin and shallow marine sands. This period is follwed by marine transgression with the deposition of thick shale sequence in the Cretaceous alternating with shallow marine sands in rotated fault blocks. During the Palaeocene there was a switch of sediment source from Greenland to the Scottish massif which was uplifted. This led to the deposition of sand sequence with shale alternation through out this time. During this time was an extrusive event which lead to the deposition of Kettla tuff and followed by another extrusive event at Balder level (Early Eocene). Continued sedimentation with sand and shale/mud input continued to the Neogene (Figure 7).

The seismostratigraphy (Figure 8) of the Muckle basin, shows major event with very continous reflectors in Post-inversion-Drift stage Eocene to Neogene, Truncations with sigmoidal reflectors (Syn-rift/Post-rift?) Cretaceous to Paleocene and Dipping reflectors (Pre-rift).

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4 Southern Structural Style

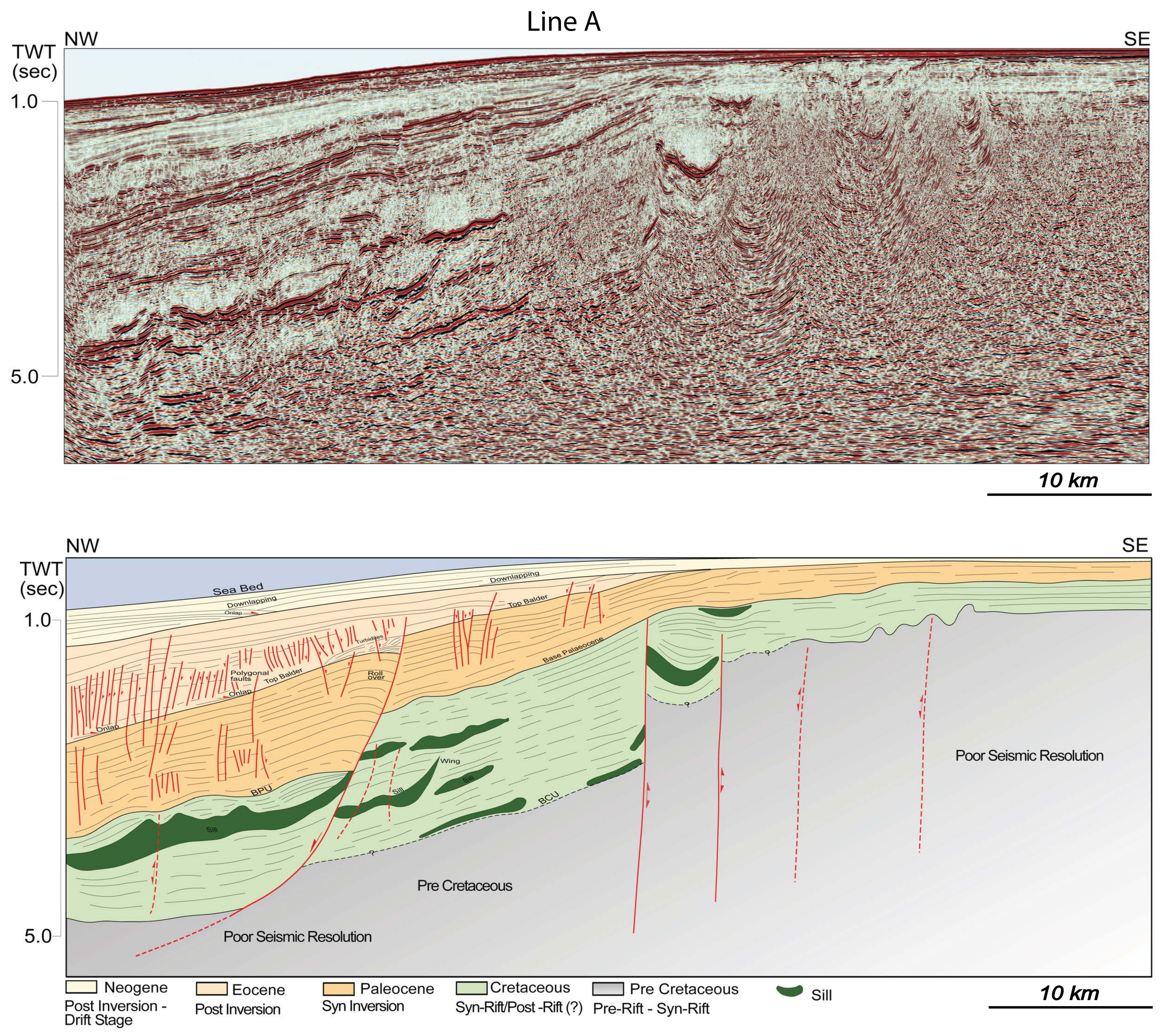

Figure 9a. Uninterpreted and Interpreted 2D line (A) in the Southern part of the study area (See Figure 3). Note the thickness of Palaeocene and Cretaceous sequence in the Southern part comparable to the Central and Northern part.

Structural Style

In the Southern part, the prominent structural style is the listric extensional faulting. They are observed to detach at a low dip angle which is indicative of the presence of a decollement layer. In the Southern part, the Pre-Cretaceous section and Cretaceous section is seen to be stratigraphically thick and dominated by rotated fault blocks and swarm of sills seen predominantly in the Late Cretaceous and Early Palaeocene sequence. The Palaeocene and Eocene section, as seen in (Figure 9a) are dominated by polygonal faults but are seen to be more pronounced with complex network deeper into the basin. The Palaeocene section in the Southern part shows an increase in stratigraphic thickness compared to the Northern part. It is believed from observations that there was continued extension, which created accommodation space where sediments was deposited. In the Northern part, the stratigraphic thickness is thin. This could be interpreted as: (i) a shallower accommodation space prior to deposition, therefore sediments were not deposited. Evidence for this is shallow pockets of sediments ponding in sub-basins; (ii) Non-preservation of sediment and re-mobilization of Palaeocene sediment further into the basin. (iii) another possible interpretation is continuous erosion during deposition of Palaeocene sequence.

Geometries

Figure 9b, shows a typical geometry that predominates the Southern part of the basin. Most of the faults in the Southern part have pronounced roll-over anticline with associated antithetic faults on the crest of the fold. This geometry is caused by faults gliding at a low angle on a decollement layer. In certain cases, these anticlines could be structurally enhanced by later minor inversion.

5 Central Structural Style

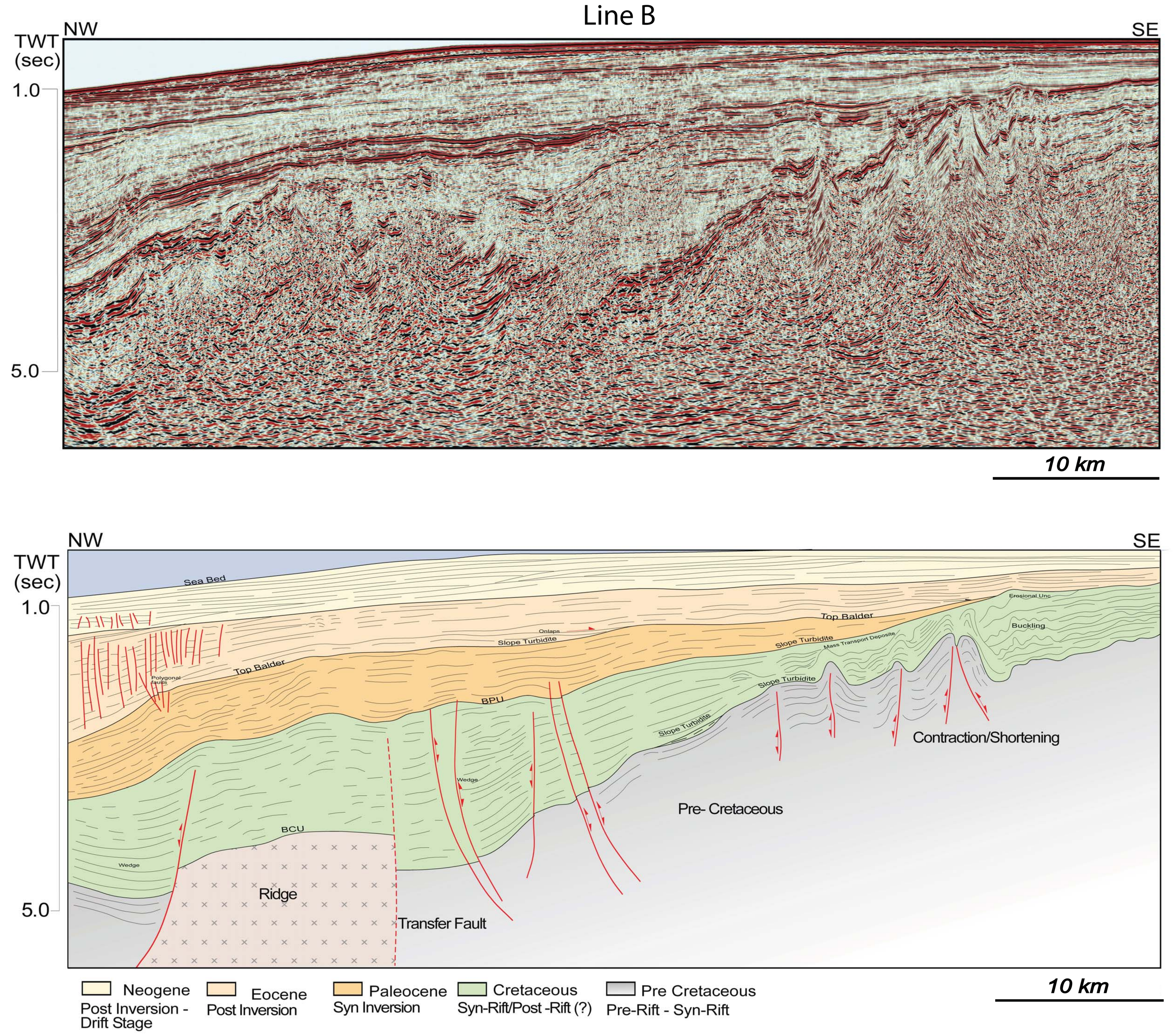

Figure 10a. Uninterpreted and Interpreted 2D line (B) in the Central part of the study area (See Figure 3). Note the thickness of Palaeocene and Cretaceous sequence and also the Eocene and Neogene sequence compared to the Southern part (Figure 9a) and Northern part (Figure 11a and 12a).

Structural Style

In the Central part of the study area, folding and buckling are the dominant structures. They are interpreted to be caused by a combination of transfer fault activity and simultaneous uplift observed locally in the Muckle Basin (Figure 10a). This uplifted/contraction has been identified around the neighbouring basins which includes the Unst Basin as detailed in Johns and Andrew 1985.

In the updip section of the Central part of the study area there is evidence of contraction, sediment buckling and uplift while the down-dip section shows continuous extension with creation of accommodation space where potentially 600-1200m of Jurassic(?) and Cretaceous sequence has been deposited (Johns and Andrew, 1985). In the deeper part of the basin (Figure 10a), the Cretaceous section is seen to be thick with potentially reworked sediments from uplifted areas updip. Strongly inverted faults occur in this area with the presence of polygonal faults mainly in the Eocene section unlike that observed in the Southern part.

Geometries

Figure 10b, shows strong inversion of planar faults thereby forming fold and buckled sediments. These faults have been re-aligned and become very steep which makes them difficult to image on seismic. The geometries within the Central part of the study area are local to the Muckle Sub-Basin.

6 Northern Structural Style

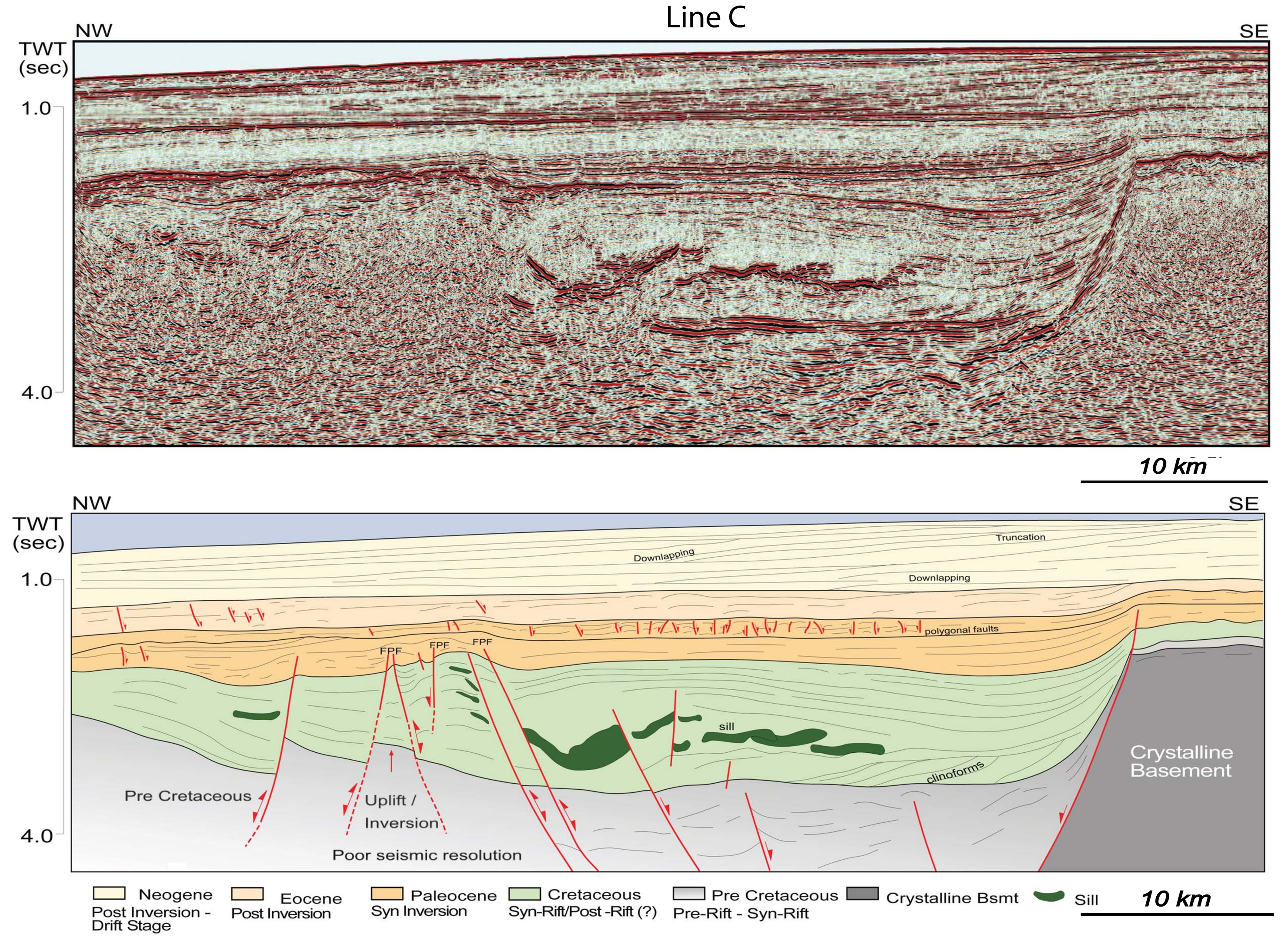

Figure 11a. Uninterpreted and Interpreted 2D line (C) in the Northern part of the study area (See Figure 3). Note the thickness of Palaeocene and Cretaceous sequence and also the Eocene and Neogene sequence compared to the Southern and Central part (Figure 9a and 10a).

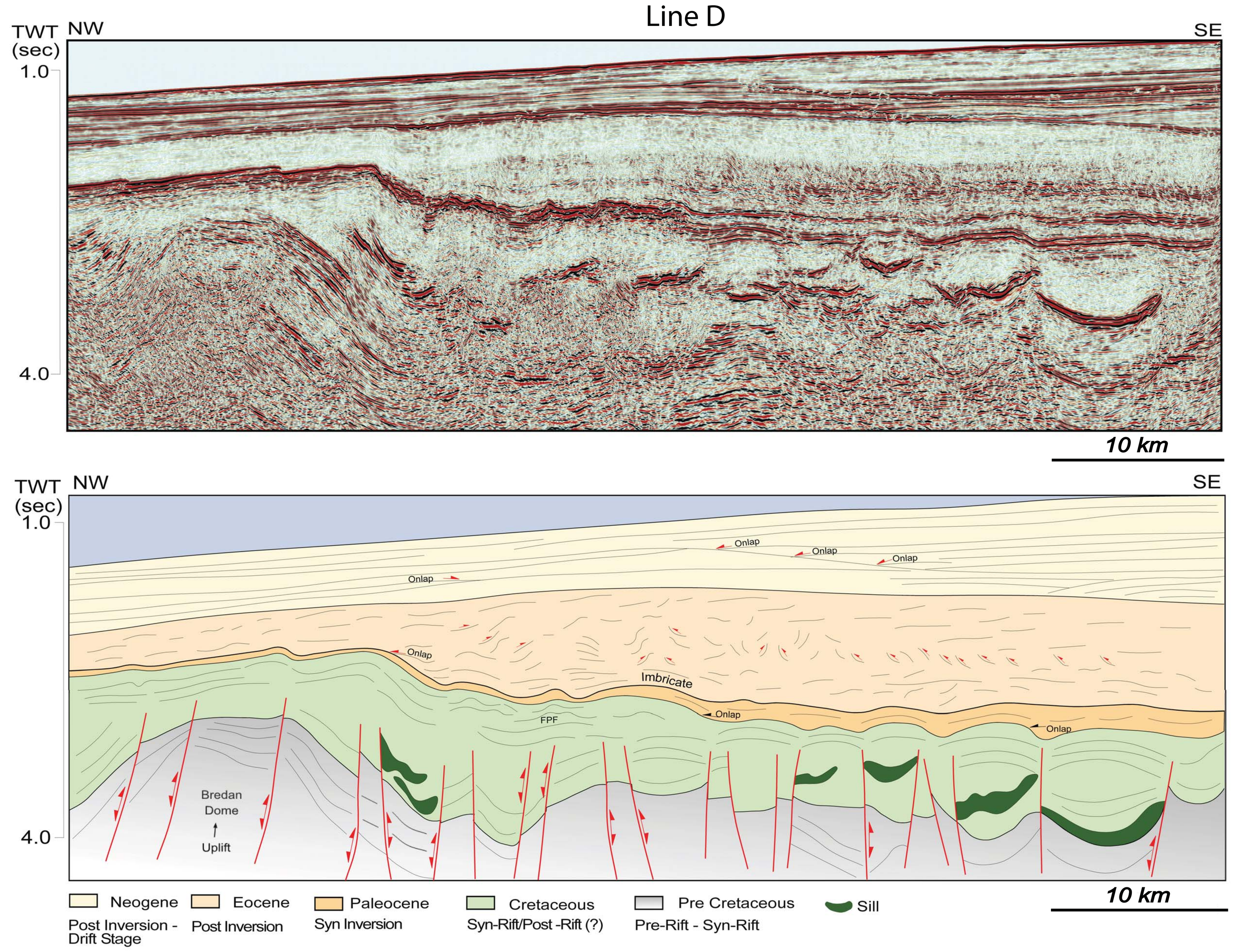

Figure 12a. Uninterpreted and Interpreted 2D line (D) in the Northern part of the study area (See Figure 3). Note the thickness of Palaeocene and Cretaceous sequence and also the Eocene and Neogene sequence compared to the Southern and Central part (Figure 9a and 10a).

Structural Style

In the northern part (Line C), the structural style shows a half graben (Erlend Sub-Basin) with associated volcanic sills and progradation of sediments from the basin flank. Large clinoforms are observed closer to the main border fault in the Cretaceous section (Figure 11a). In the Pre-Cretaceous section, slight folding is observed probably caused by fault propagation folding as a result of inversion during that time. Extension is seen to be dominant in this sub-basin with fault reactivation towards the NW observed as fault propagation fold (FPF). In the Palaeocene, there are little polygonal faults and fluid escape features which could be related to rapid burial/subsidence. A thinner Eocene section is observed in this area which could be explained by either sediment starvation during the Eocene, or could be attributed to non-availability of accommodation space. Another explanation is that the basin was uplifted and sediment stripped off. The latter has yet to be investigated in detail. Neogene shows a time of progradation with downlapping sequence clearly mapped on seismic.

In the Northern part (Line D), there is intense contraction that resulted in more significant inversion producing harpoon structures in the Cretaceous and Palaeocene sections. Imbricate faults associated with the mass transport deposit is prominent during the Cenozoic (Figure 12a) and only oberved in the Northern part. The NW part of the section shows intense uplift around the Brendan dome with steep parallel reflectors with no thickness change which is indicative that the doming took place post deposition of the sequence uplifted. The Southeastern part shows intense inversion with harpoon formation. The timing of this event is probably during the Palaeocene or Early Eocene. This interpretation is based on onlaps that can be observed during this time (Figure 12a). The thickness of the Cretaceous section compared to the Central and Southern parts suggest that the Cretaceous sequence in this area is probably preserved. On the other hand, the Palaeocene section is very thin (condensed sequence) and also truncated in some areas. An explanation which is coherent with the earlier suggestion of uplift during the Palaeocene resulting in starvation and bypass of sediment towards the NE of the Faeroe-Shetland Basin. (Well 219/20-1, to the north of the area shows the presence of Palaeocene age Sullom sands and seismic geometries indicate potential large deposit further into the basin). The Eocene section shows considerable thickness with mass transport deposit (with imbrications) suggested to be from Eastern part of the basin and possibly Norway. The Neogene section has a thicker sequence than that present in the Southern and Central part of the study area.

Geometries

Figure 11b and 12b, shows geometries prominent in the Northern part of the study area. Classic harpoon geometry within the Cretaceous section and imbrication with the Eocene as a result of mass transport deposition are the dominant geometries.

Southern Geometries

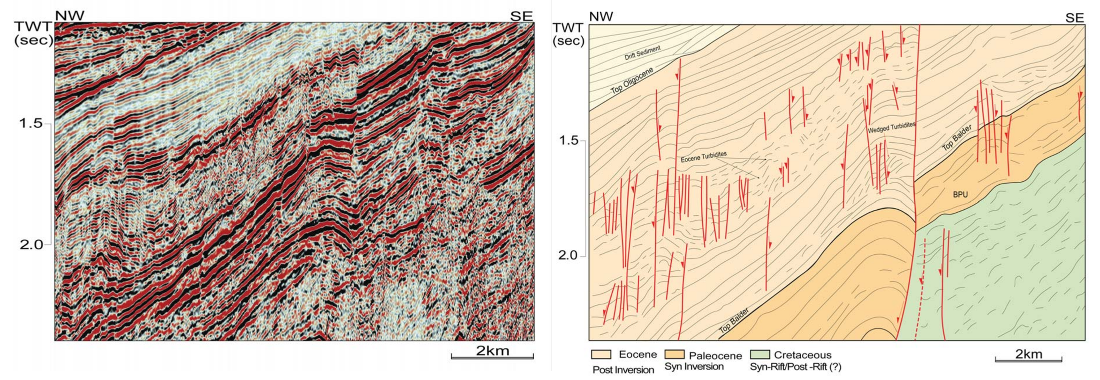

Figure 9b. Roll-over anticline, formed as a result of low angled listric extensional faulting in the Southern part of the study area. Evidence of this geometry is not observed to be prominent towards the Northern part of the study area.

Central Geometries

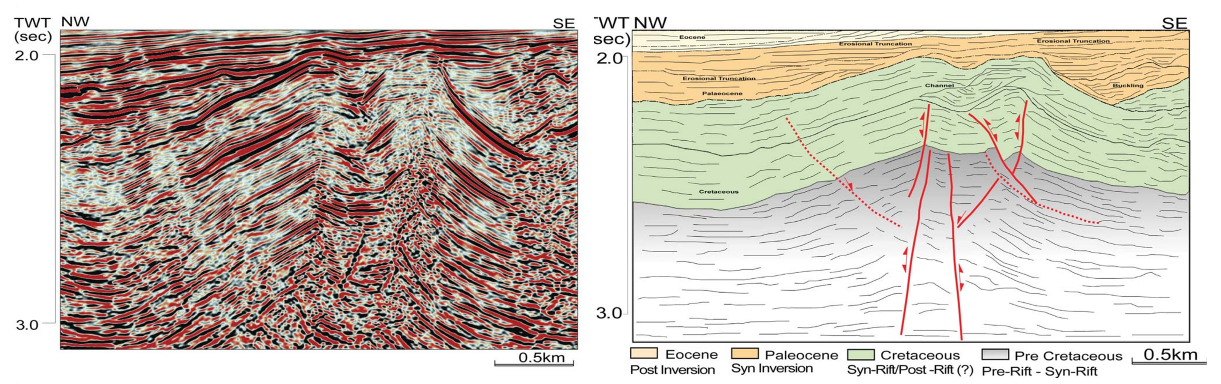

Figure 10b. *Contractional folding and Buckling in the Central part of the study area (Muckle Sub-basin). Contraction is suggested to be caused by the activity of the transfer fault, regional uplift observed to have been initiated in the Jurassic and continued during the Cretaceous. Vitrinite reflectance data analysis from Well 1/4-1 and 1 / 4-2 indicate uplift and erosion in the Unst Basin. This trend has been observed around neighboring basins including the Muckle Sub-Basin which shows contraction and shortening (Figure 10a).*

Northern Geometries

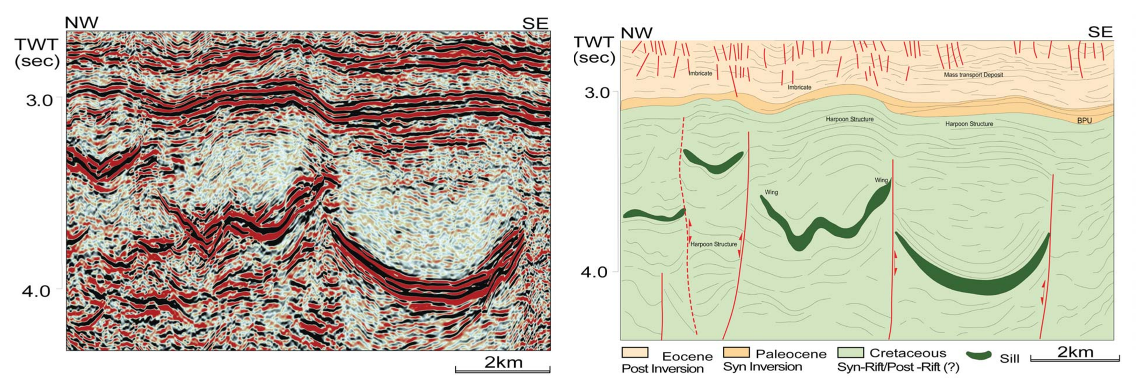

Figure 11b. *Classic harpoon geometry is dominant in the Northern part of the study area. They show 'bulged' seismic pattern and are associated with volcanic sills. With the strong inversion in this part of the basin, most faults have been rotated and become oversteepened making it impossible to image seismically. The harpoon structure aids in identifying the position of the faults.*

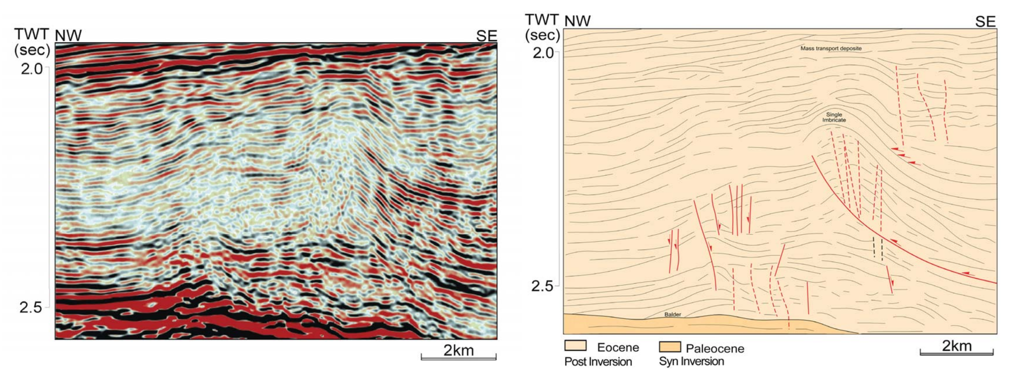

Figure 12b. *Imbrication within the Eocene section in the Northern part of the study area is peculiar in this part and not seen in any other part of the basin. This is as a result of the mass transport deposit from the Eastern part of the basin which is about 1.1 (sec) TWT in vertical thickness towards the core of the depo-centre (Figure 12a).*

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7 Fault Pattern & Architecture

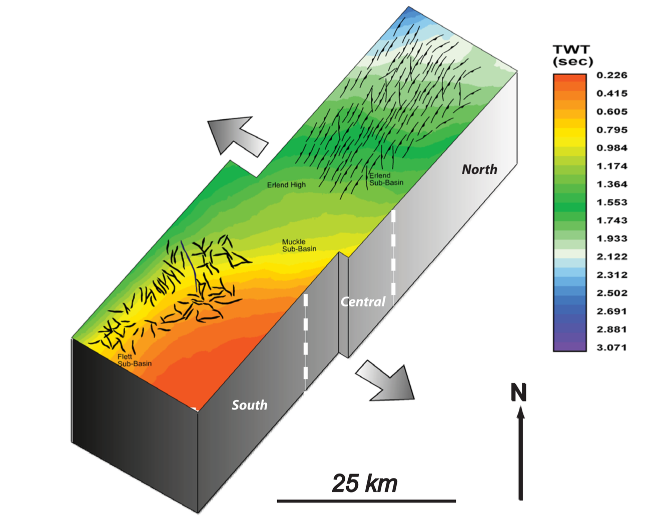

Figure 13. 2D Top Eocene fault pattern in the study area. Two types of fault occur in the Northern, Central (?) and Southern part. Polygonal faults occur in the Southern Part and Imbricate faults in the Northern part of ther study area.

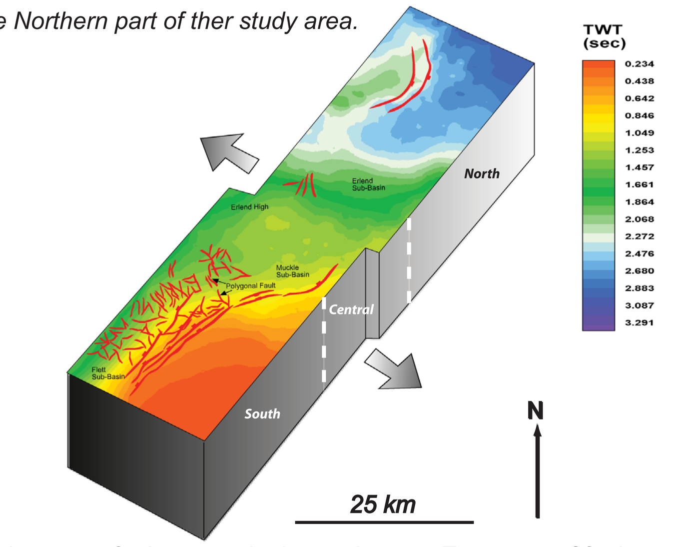

Figure 14. 2D Top Palaeocene fault pattern in the study area. Two types of faults occur from Southern through to the Northern part. Extensional fault dips to the East (in the Northern part), Polygonal faults (Central part) & Extensional and Polygonal faults (Southern part).

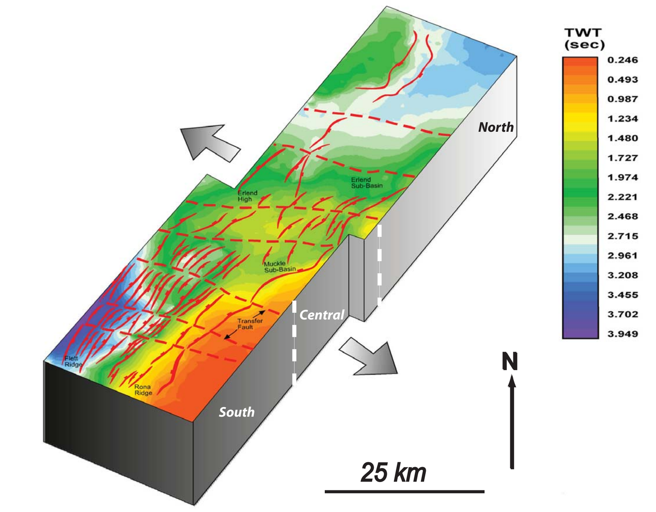

Figure 15. 2D Top Cretaceous fault pattern in the study area. Extensional fault is quite dominant with transfer fault. Combination of tranfser fault movement, polarity switching and fragmentation of faults is observed at this time.

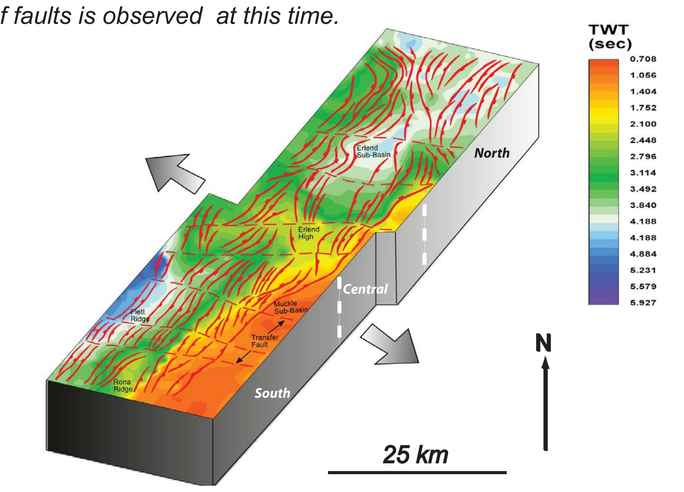

Figure 16. 2D Base Cretaceous fault pattern in the study area. Extensional faults dominant across the study area.

Top Eocene Fault Pattern

The dominant faults in the Eocene are polygonal faults and imbricate faults. Polygonal faults are observed in the Southern part of the study area away from the shallow part of the basin and more in the deeper part (Figure 13). Studies around the Southern part shows a more networked polygonal faulting that are highly linked with observed circular nodes which have been Identified in the North Sea and discussed extensively by Lonergan et. al., 1998 and Berndt et.al., 2003. They have been identified as migration route to reservoirs and also fluid expulsion conduits during de-watering. Their irregular orientation and high connectivity makes them very easy to identify on both 2D and 3D data. Little evidence of polygonal faults is seen in the core of the Central part of the study area. Towards the Northern part, there is a complete change in fault style to imbrication (Imbricate faults). They are observed not to be irregular but tend to maintain a NW trend direction which is consistent with the direction of flow of the mass transport deposit (from the east) and is interpreted to be the cause of imbrication.

Top Palaeocene Fault Pattern

The Palaeocene show little fault presence in the Northern part. Only major faults thought to be inverted around the zone of uplift (Brendan dome area) are observed in the Northern part. This is related to the uplift and erosional effect proposed at this time and dips to the East. The Central part of the study area, shows little presence of polygonal faults. The Southern part shows presence of polygonal faults and extensional faults. The polygonal faults are seen to be highly networked like those seen in the Eocene. The extensional fault orientation is NE-SW and dips in the NW direction creating series of rotated fault blocks. The extensional faults are suggested to be linked at this time. The extension direction at this time is the NW-SE direction.

Top Cretaceous Fault Pattern

The Cretaceous faults shows a distinct difference in orientation and pattern. The subtle activity of the transfer fault as identified in the area and mapped on 3D data within the study area has an effect on the structural pattern. The Northern part shows presence of east dipping faults as seen in the Palaeocene with series of cross cutting transfer faults. These faults are aligned in the NE-SW direction which is in response to streching in the NW-SE direction. The faulting is observed to have segmented the basin, with faults changing polarity and creating accommodation space along strike. In the Southern part, the faults are observed to be denser than in the Central and Northern part. Fault segmentation, transfer fault activity and fault polarity switch is very common and is thought to cause basin segmentation.

Base Cretaceous Fault Pattern

The Base Cretaceous fault pattern, shows similar architecture to the Top Cretaceous surface. In the Northern part, the faults are denser than in the Top Cretaceous, with major faults oriented NNW-SSE. As with the Top Cretaceous segmentation is oberved with intense transfer fault activity from South to North. The faults are observed to be dense throughout the study area. A firm evidence for the activity of transfer faults has been mapped on 3D seismic data. Contraction and buckling in the Muckle Sub-Basin is thought to be caused by transfer fault movement, uplift and extensional fault reactivation. Extensional direction is in the NW-SE direction especially in the Southern part. The orientation of the faults in the Northern part show slight deviation of the stretching direction to the WWN-EES. This could be as a result of local stresses.

8 Discussion

Possible Causes of Along Strike Variation

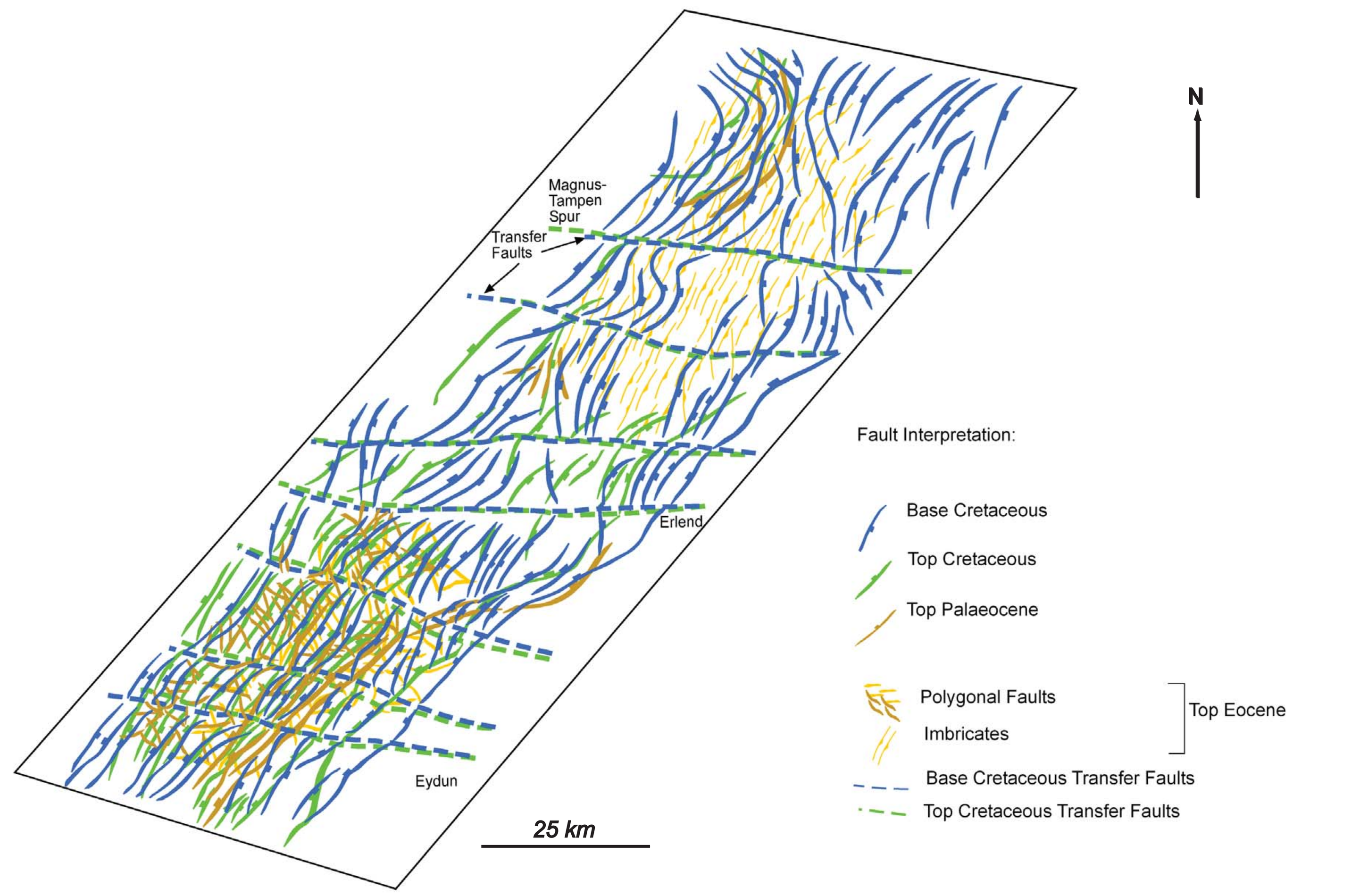

Figure 16. Summary of Fault Pattern from Early Cretaceous to Eocene showing evidence of basin segmentation, transfer fault movement occuring from Pre-Cretaceous to Early Palaeocene with oblique extension corresponding to the opening of the North Atlantic. Polygonal faults/Imbricate faulting indicative of gravitational loading, subsidence and dewatering is observed to occur above the Balder Tuff.

3D Synoptic Evolution Along Strike of Study Area

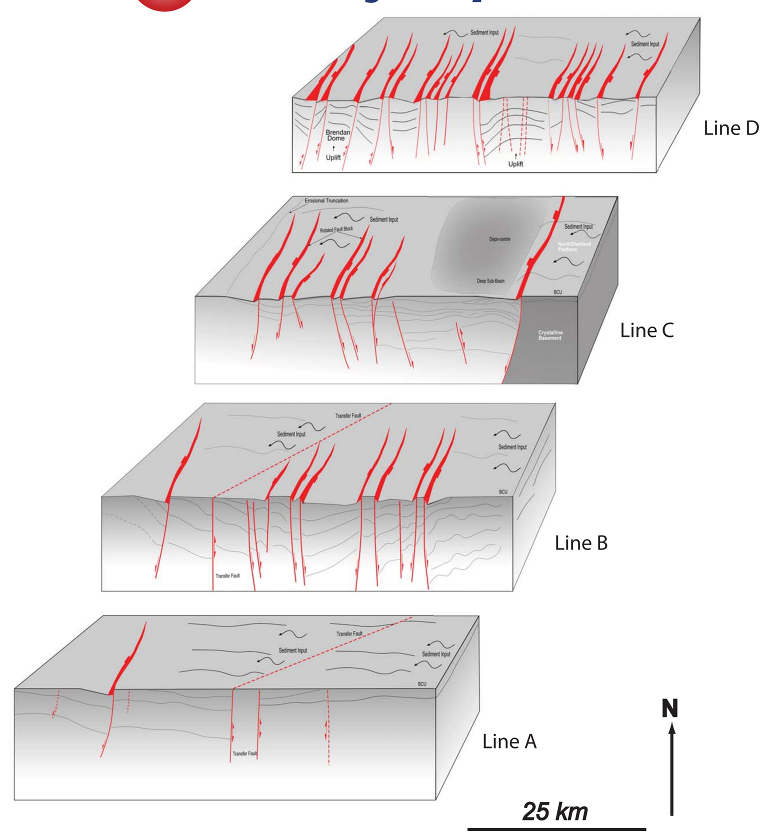

Figure 17. Base Cretaceous evolution constrained by 2D structural restoration. The Pre-Cretaceous shows active faulting with Jurassic(?) uplift/contraction in the Southern to Central part. Further North (Line C) is a half graben and later switches again into a highly inverted basin (Line D).

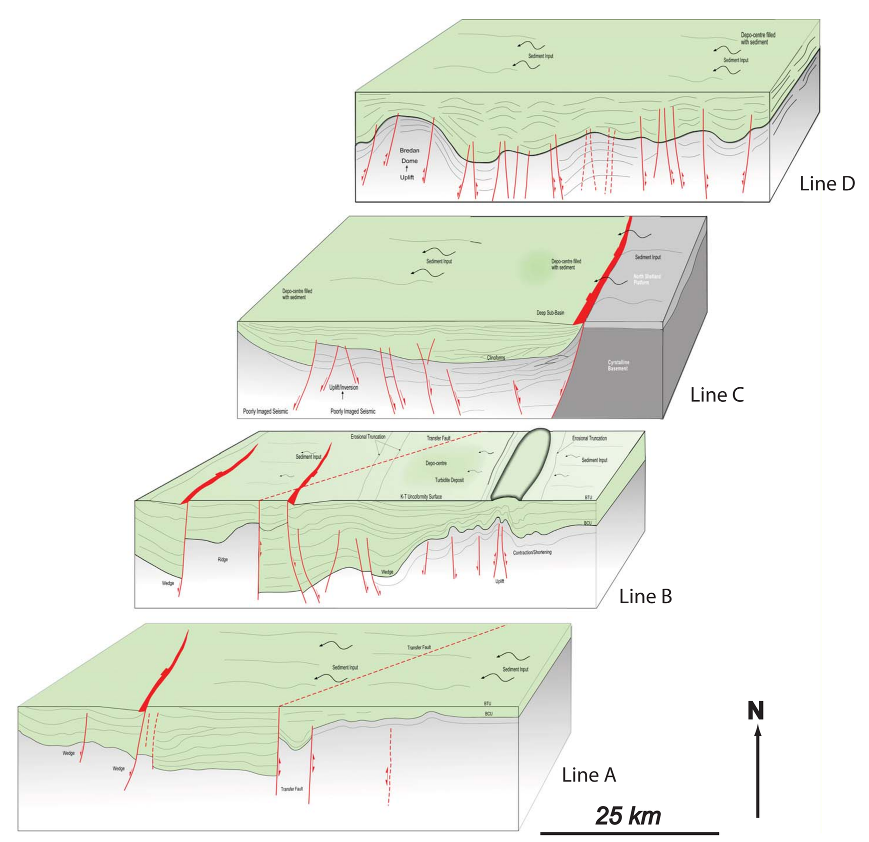

Figure 18. Top Cretaceous evolution constrained by 2D restoration. Cretaceous, shows continued extension in the south, contraction, uplift and erosion taking sediments further into the basin. At this stage the availabilty of accommodation space is important to hold sediment eroded up flank. These are deposited as turbidites. Further North extension in the half graben continues. Massive uplift is observed in the far Northern part with faults reactivation.

Varying Degree of Multi-Phase Deformation Along Strike, Resulting in Basin Segmentation

Fault pattern from the study area, supports that one of the main factors responsible for changes in structural style along strike is the varying degree and intensity of deformation across the basin. This causes some sub-basins to be intensely uplifted and compressed while other sub-basin experience a different type of deformation i.e. extension and subsidence. The result is a dramatic change in structural style and geometry along strike of the basin. Base Cretaceous fault pattern (Figure 15), shows a highly segmented basin at that time. Adding to the complexity of the evolution of the basin from Intra-cratonic pull-apart basin, it is inevitable that varying the degree of deformation, or a switch in deformation style and multi-phased deformation as experienced along strike of the basin can lead to basin segmentation thereby causing variation in structural style along strike

Boundary and Transform Fault Movement

Boundary fault movement and transfer fault activity during the evolution of the basin is seen to be very important in the present day structural style and geometry of the basin. Figure 14 and 15 shows the fault pattern during the Base Cretacoeus and Top Cretaceous time. Offset on faults with simultanous extension has been observed to create smaller sub-basin which changes position along strike.

Complex Evolution of NW Atlantic Margin

The opening of the Northwest Atlantic is known to affect the structural setting of basins within this province. In the North Atlantic, the main phases of plate boundary reorganization that accompanied the late Paleozoic assembly of Pangea and its subsequent disintegration, as described by Ziegler (1993) supports observations of fault pattern in the basin.

The intensity, activity and presence of the transform faults vary from South to North of the study area. It is observed that in the Southern part the transform faults are closely spaced with large vertical and oblique movement than in the Northern part of the study area.

An expression of the complex evolution of the regon is the disappearance of transform fault activity in the Faero-Shetland Basin after the Palaeocene times and their varying activity along strike (Figure 13-16). Obeservations indicate the following: (i) A regional event (porbably introduction of volcanism) overprinted or stopped their activity unlike the Central and Southern Atlantic which is still active. (ii) Active extension with transform fault activity in the Jurassic decreased during the Late Cretaceous and disappeared during the Eocene to Recent. This observation fits into the regional plate tectonic recontruction of the regional.

Rapid Burial, Subsidence, Sediment Gravitational Loading, Mass Transport Deposit & Dewatering

Polygonal faulting in the Southern part of the basin are features that result from rapid burial, subsidence and dewatering. This structures have been studied in detail in the North Sea . Imbrication as seen through the study area is caused by deposition of mass transport deposit and gravitational sliding. This featuer is observed to only occur in the Northern part of the study area.

Emplacement of Volcanics

Inflation anticline, dyke and sills are direct result of the emplacement of volcanic material in the basin. Also, some inversion structures prominent in the Southern part of the study area are direct product of volcanic emplacement. The timing of the emplacement of volcanic material range from 55-53 Ma (Stoker et al., 1993). Current work as yet unpublished indicate earlier intrusions around basin flanks

3D Synoptic Evolution Along Strike of Study Area (cont)

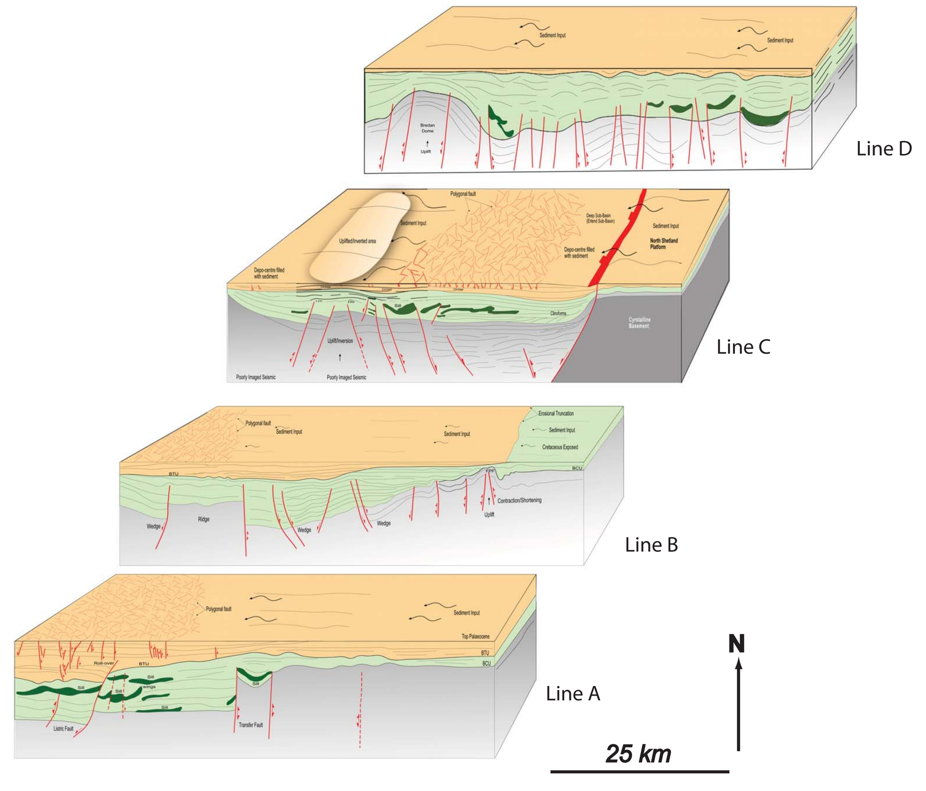

Figure 19. Top Palaeocene evolution constrained by 2D restoration. Palaeocene time shows introduction of volcanics, inversion in many parts of the basin. The Southern part shows more sediment input with polygonal faults dorminant in the Southern part. Uplift in the Central part coupled with erosion caused the Cretaceous section to be exposed and Palaeocene truncated. In the Northern part, uplift and erosion of the Palaeocene section is intensified during this time leaving the most northerly part stripped of Palaeocene sediments.

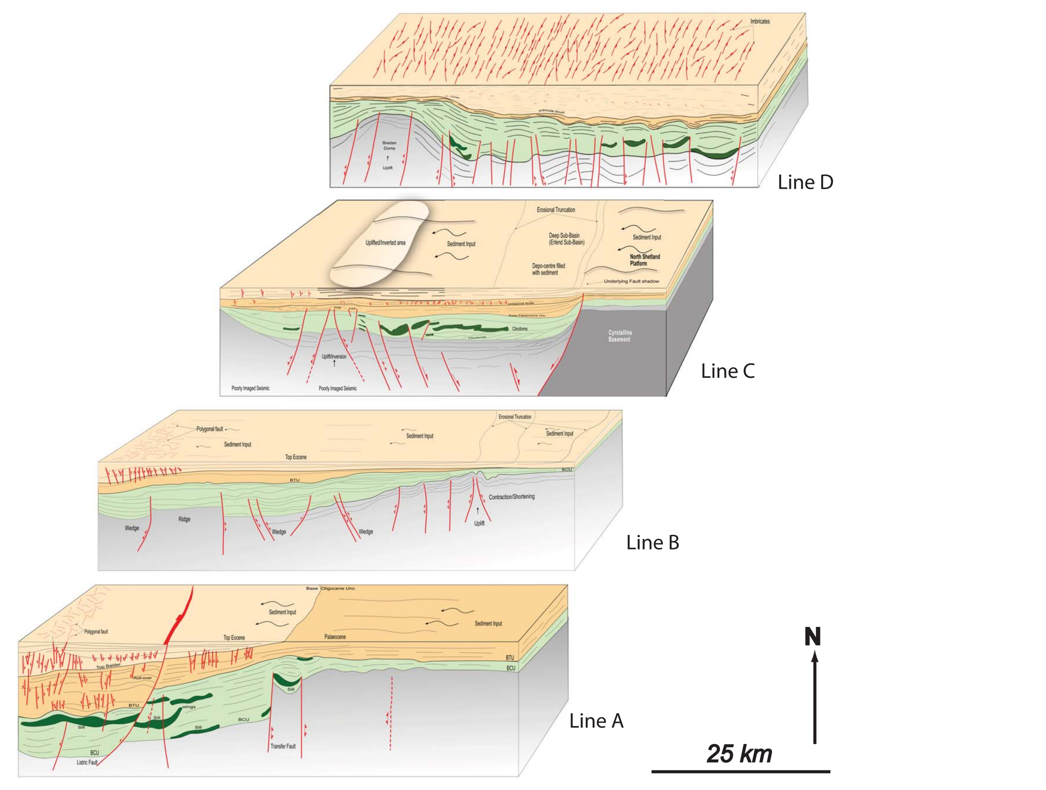

Figure 20. Top Eocene evolution constrained by 2D restoration. Eocene in the Southern part shows a time of basin subsidence with sediment by-pass along the 'starved margin' of the basin. Eocene is to be truncated in the Southern part. In the Central part Eocene sediments are not completely eroded. Polygonal faults are dominant. Further north, subsidence with introduction of huge amount of sediment in the accommodation space created causes formation of imbricates.

Exploration Implication

Reservoir: The Palaeocene deepwater sandstone have been the primary target in the Faeroe-Shetland Basin to date with a high success rate. The thickness variation of the Palaeocene sequence from South to North is a major concern for targets within this sequence. The very thin section in the Northern part (Figure 11a and 12a) makes the Palaeocene less attractive. Nontheless, thinly developed (~3feet) Early Palaeocene Sullom sands have been identified to be present in the Northern part with potential for thicker sequence further into the basin (basin evolution concept). Pre-Cretaceous (Pre-rift and Syn-rift sequence) has been identified to be very promising along the study area. Classic seismic geometries showing large clinoforms and channel deposit indicating an untested play.

Source rock/Migration: The known sourec rock is Kimmerage Clay. Due to basin segmentation, source rock presence in some sub-basin are not guaranteed, as the amount of uplift that occured could have eroded huge section of source material as well as making them immature for generation. Migration of hydrocarbon is from deep basins with Planar/domino faults acting as a conduit. Current observations is indicating another potential source. This is currently been investigated.

Traps and seal: As a result of the inversion and volcanic emplacement that occurred from Jurassic (?) to Recent in certain areas of the basin, traps are often breached and most faults hardly seal. For the Mesozoic section Jurassic base seal is important for targets along the flanks of the study area but their presence are major risk.

9 Conclusions

The reprocessed 2D seismic data has enabled the identification of structural changes from Southern part to the Northern part of the study area. The variable geometry along strike is a result of the complex interaction of extension, fault reactivation, contraction and buckling, uplift, transfer fault movement and dyke and sill emplacement. This interaction has been discussed on a regional scale and has shown to account for the distribution, complexity and distinct structural style and geometry along strike of the UK flank of the Faeroe-Shetland Basin. The varation of structural style has been shown to influence stratigraphy and sediment (reservoir distribution) and has direct implication for hydrocarbon exploration. Analogue modelling of extensional system (Mc Clay, 1990) show similar structural style and response to depositional pattern observed in the study area.

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Aknowledgements

The authors are grateful to TGS for providing the data and GDF SUEZ E & P UK for sponsoring this research. We are also grateful to Fault Dynamic Research Group for valuable inputs. Special thanks to Andy Spencer, Ian Hubbard and Terry Cousins.

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