AN INTEGRATED STUDY OF THE LATE PALEOCENE TO EARLY EOCENE FLETT (T40/T45) AND BALDER (T50) FORMATIONS OF THE FLETT SUB-BASIN, FAROE-SHETLAND AREA, NORTH SCOTLAND.

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ABSTRACT

3D seismic and well data (wireline logs, biostratigraphic information and core photographs) were employed to evaluate the Late Paleocene - Early Eocene Flett (T40/T45) and Balder (T50) Formations with the aim of understanding their depositional setting within the Flett Sub-Basin, located offshore North of Scotland. The thicknesses of the formations varied across the basin, with the Flett and Balder Formations displaying thickness ranges of 0 - 800 m and 0 - 300 m respectively. The wireline signatures showed shale and sandstone as the main lithologies within these formations with volcanics observed in the shallower NE - SW part of the basin. The shales and sandstones of the Lower Flett Formation (T40) were believed to have been deposited on the slope within the deep marine environment during the relative sea level fall. The sediments of the Upper Flett Formation (T45) were deposited on the shallow marine shelf environment. The transition from slope deposit (T40) to shelf deposit (T45) was attributed to the effect of uplift in the Shetland area in the Early Paleocene time. The Balder Formation (T50) were composed of sandstone and interpreted to be deposited on the shelf to deltaic environment. Sedimentological and wireline interpretation indicated that the main sediment source for the Flett Sub-Basin was the Greenland and West Shetland Platform with local inputs from the surrounding structural highs.

Keywords: Flett Sub-Basin, Flett Formation, Balder Formation, Depositional Environment

INTRODUCTION

The Flett Sub-Basin is located offshore of the north of Scotland between the Faroe Islands and Shetland Islands within latitudes 61ºN - 62ºN and longitudes 2º N - 4º N (Fig. 1). Water depths are between 1000 - 1500 m (Mudge and Bujak, 2001). The basin lies within the larger Faroe - Shetland Basin and is bounded by the North Corona Ridge and the Flett Ridge (Fig. 1). It forms an elongate, NE - trending half-graben which is approximately 220 km long and 90 km wide within which sediments of approximately 6.8 km thickness was deposited. These sediments consists of Late Paleozoic to Recent sediments and lavas, including up to 4 km of Cenozoic to Recent, 2.5 km of Lower and Upper Cretaceous, 50 m of Upper Jurassic and 200 m of Devonian strata (British Geological Survey (BGS), 2011).

Knox *et al.* (1997) and Smallwood and Maresh (2002) showed from their regional studies that the Flett Formation is dominated by prograding sandstones and mudstones deposited in paralic to shallow marine environments. Ellis *et al.* (2002) confirmed the presence of paralic facies in the Flett Formation from micropaleontological studies.

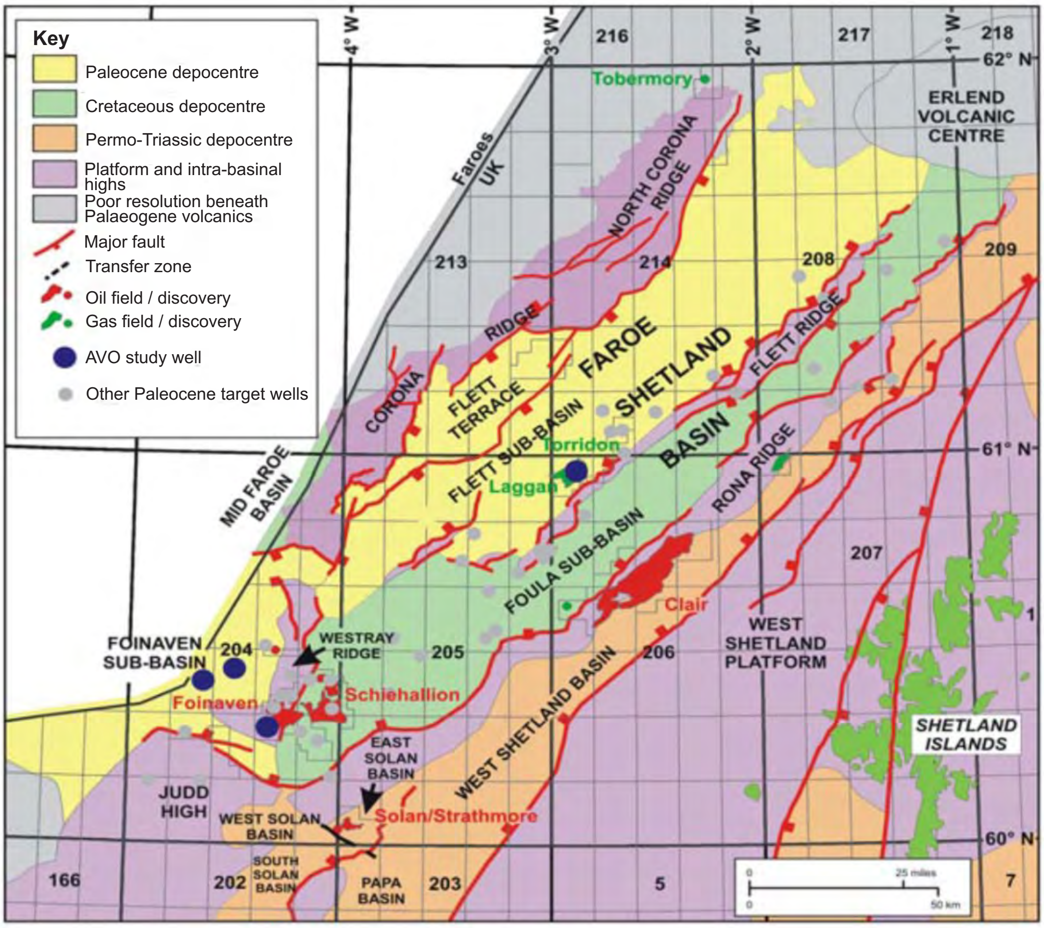

Figure 1: Location of the Flett Sub-Basin within Faroe Shetland Basin Regional Structural Map (Loizou *et al.,* 2008).

Knox *et al.* (1997) showed that the Balder Formation consists predominantly of grey, variably silty, carbonaceous mudstone with abundant layers of grey-green tuff as well as interbeds of sandstone and lignitic coal. Post deposition volcanic activities in the basin have been well documented (Mitchell *et al.*, 1993; Smallwood *et al.*, 2002; Schofield and Holford, 2012). Previous studies on the depositional settings of these formations have been on a regionally scale (Knox *et al.*, 1997; Ellis *et al.*, 2002; Smallwood *et al.*, 2002).

This study therefore employed the integration of 3D seismic volume and well data (wireline and core photographs) from the Flett Sub-Basin to give detailed stratigraphic interpretation of the Late Paleocene to Early Eocene depositional settings of the Flett (T40/T45) and Balder (T50) Formations.

GEOLOGICAL SETTING

The Faroe-Shetland area has undergone a very complex geological development in response to the different phases of the structural evolution of the margin (Knott *et al.*, 1993; Roberts *et al.*, 1999). Three major structural events are of particular importance: the Caledonian Orogeny and the subsequent erosion and extensional collapse of the mountains during the Late Palaeozoic; the Mesozoic to Early Cenozoic rift phase with the deposition of thick Middle Jurassic to Paleocene sediments; and the Eocene opening of the North Atlantic (Knott *et al.*, 1993; Roberts *et al.*, 1999).

The stratigraphy of the Faroe – Shetland Basin, within which the Flett Sub-Basin is located, was influenced by the underlying Cretaceous topography which shows a series of fault bounded basins trending in the northeast - southwest direction (Fig. 1). For the Paleocene to Early Eocene stratigraphic succession, Ebdon *et al.*

(1995) and Statoil (2010) identified thirteen sequences (T10, T22, T25, T28, T31, T32, T34, T35, T36, T38, T40, T45, and T50) in the Faroe-Shetland Basin (Fig. 2). T10 is the Sullom Formation, T22 through to T36 made up the Vaila Formation and T38 is Lamba Formation. The Flett and Balder Formations on which this paper is focussed are composed of T40 - T45 and T50 respectively (Fig. 2).

MATERIALS AND METHOD

The database consists of PGS MegaMerge 3D-seismic surveys and well data (wireline logs, biostratigraphic information and core photographs). The seismic data post-stacked time migrated seismic data has an inline and crossline spacing of 25m. Well data from sixteen wells were used for this study (Fig. 3). The biostratigraphic information was provided by Ichron Limited, while the wireline logs were made available by CGG-Veritas. A core photo for well 214/28-1 was sourced from the BGS.

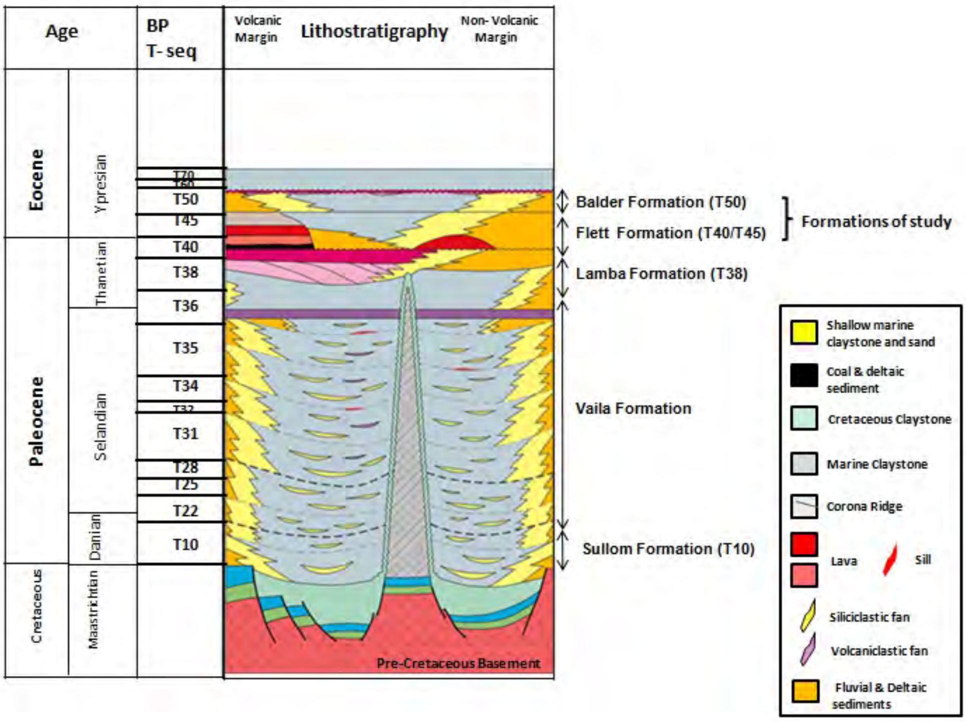

Figure 2: Regional Paleocene Stratigraphy of Faroe-Shetland Basin (Modified from Statoil, 2010).

The seismic interpretation was carried out using IHS Kingdom software. Seismic to well tie was achieved using generated synthetic seismograms. The wireline logs were used to generate well charts with the aid of Oilfield Data Manager (ODM) software. The charts displayed the Depth, Age, Group, Formation, Sequence and log curves (Gamma-ray, Resistivity, Neutron, Porosity, Density, Sonic) for each of the studied wells. The available biostratigraphic information was used to calibrate the T-sequences onto the wireline logs.

The top of the Balder Formation (T50), top of the Flett Formation/base of the Balder Formation (T45) and the base of the Flett Formation (T40) were identified from well data (GR logs) and subsequently tied to the seismic data using generated synthetic seismographs. The identified seismic surfaces were mapped and their time structure maps generated.

RESULTS AND DISCUSSION

Seismic Interpretation

The structure maps showed structural deepening in the northern parts and shallowing in the southern part. This indicates that the centre of the sub-basin is in the northern direction of the study area (Figs. 4, 5 and 6).

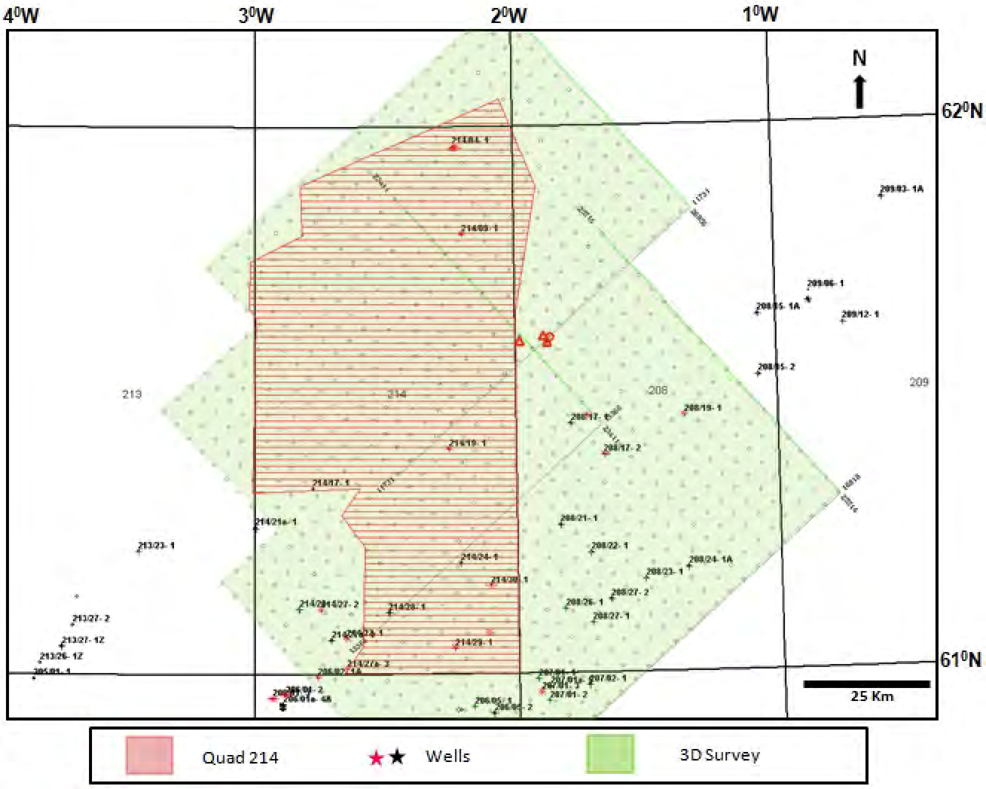

Figure 3: Location Map of the 3D Survey Data and Wells.

The Two-Way Time (TWT) thickness maps generated for T45 and T40 surfaces show that the Flett Formation has a fairly even sediment thickness with average value of about 0.125 TWT seconds (Fig. 7). The TWT thickness map for T50 and T45 surfaces indicate that the Balder Formation displays a relatively large sediment thickness in the northern part, with maximum thickness of up to 0.135 TWT seconds (Fig. 8).

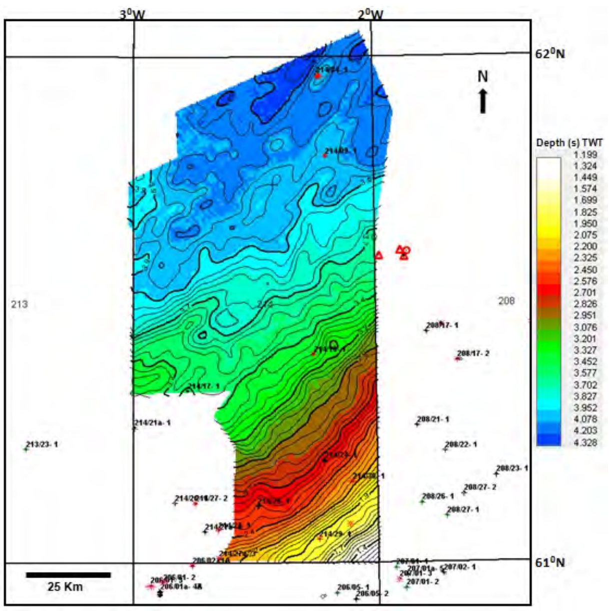

Figure 4: Two-way Time Structure Map of Base of Flett Formation (T40)

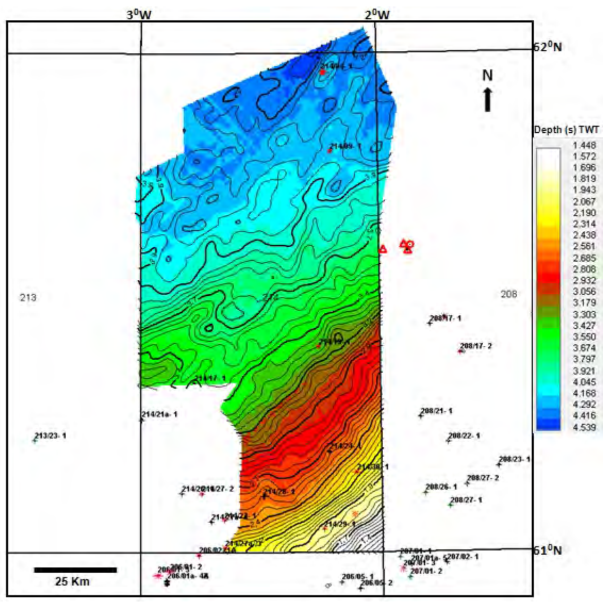

Figure 5: Two- way Time Structure Map of Top of Flett Formation (T45)

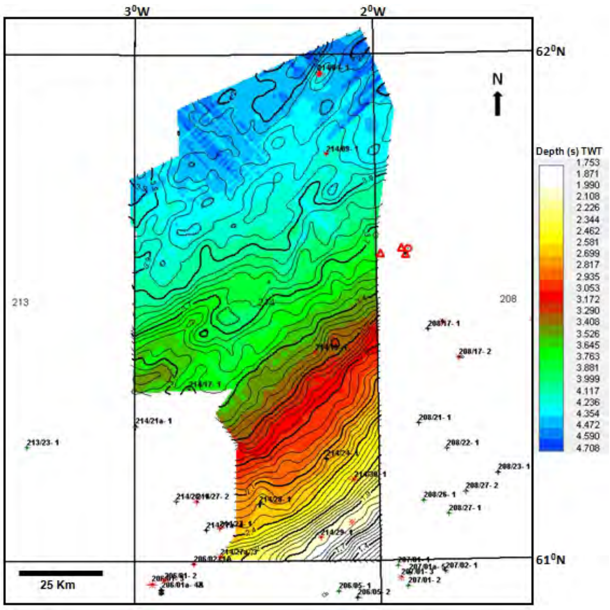

Figure 6: Two-way Time Structure Map of Top of Balder Formation (T50)

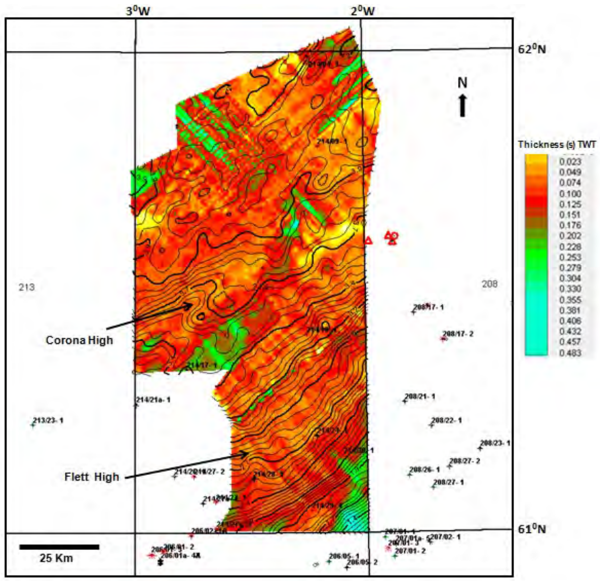

Figure 7: Two-way Time Thickness Map for T45 and T40 Surfaces

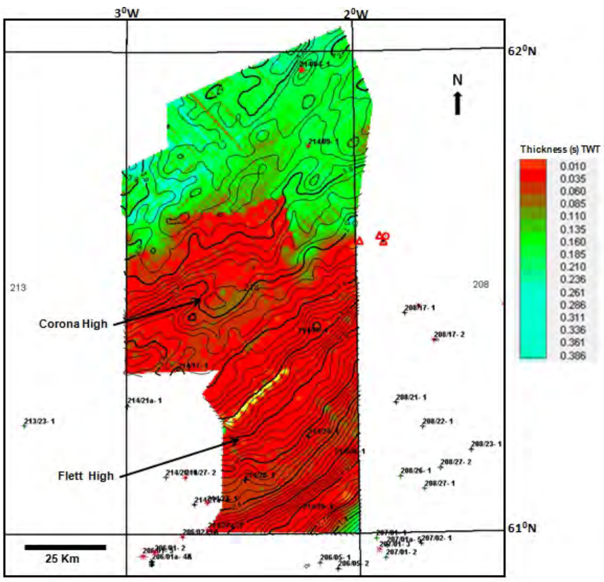

Figure 8: Two-way Time Thickness Map for T50 and T45 Surfaces.

Deductions from Gamma Ray Logs

The gamma ray log was used to interpret the lithology in the formations studied. The log of Well 214/09-1 showed a thickness of 120 m and 70 m for the Flett and Balder Formations respectively (Figs. 9 and 10).

The Balder Formation was interpreted as sandstone with shaly sand intercalation between 3520 m and 3590 m (Fig. 9). The top of the formation with gamma-ray values of between 60 and 65 API is shaly sand unit.

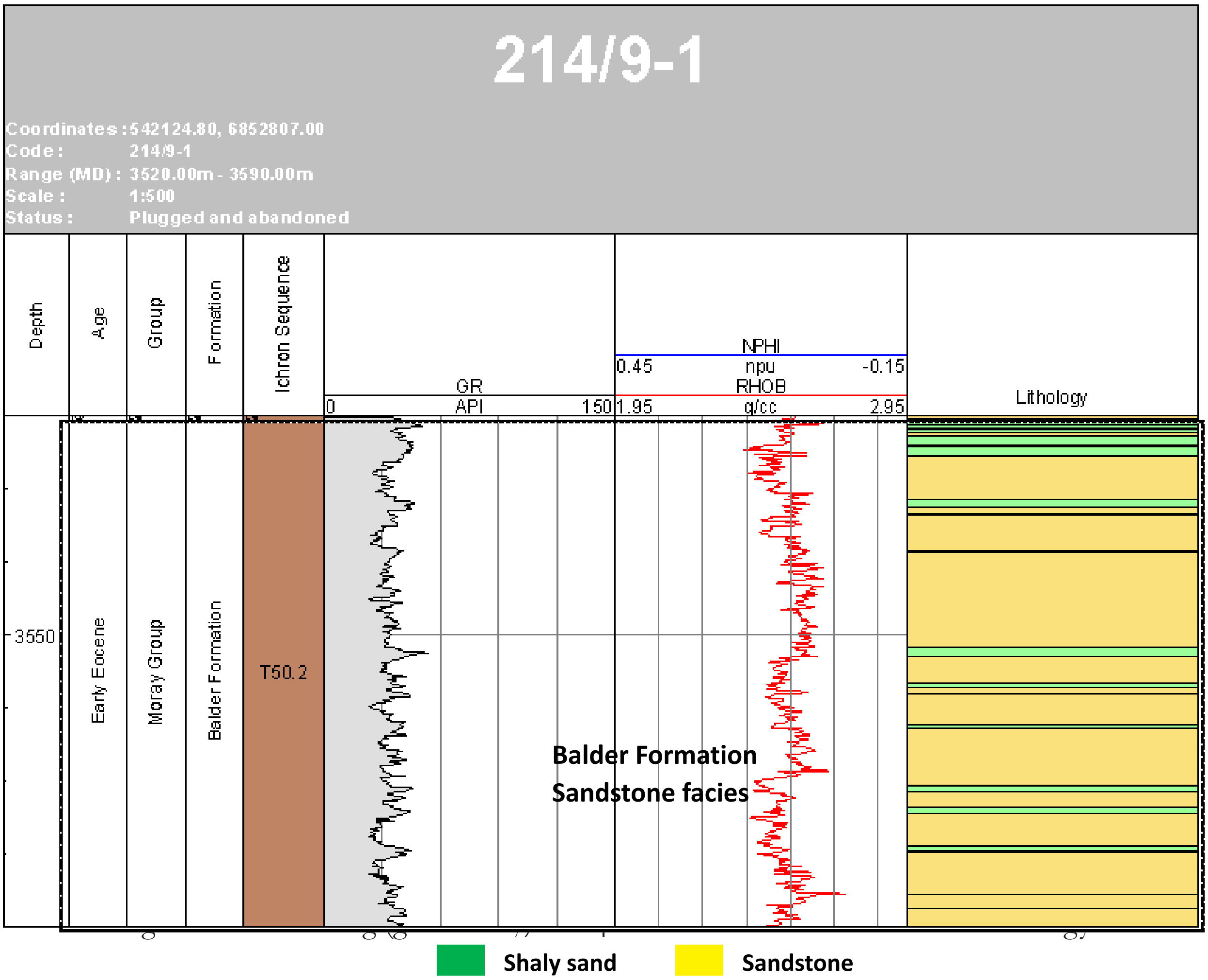

Figure 9: Wireline log (gamma ray) Interpretation of Balder Formation Lithology

The Flett Formation (upper (T45) and lower (T40)) lithology was interpreted to be shaly sand, sandstone and volcanics between 3710 m and 3830 m (Figs. 10 and 11). The upper Flett Formation (T45) showed interbedded sandstone and shaly sand facies characterised with low to high gamma ray values (20 – 80 API) between depths 3720 m and 3780 m. The Lower Flett Formation (T40) interpreted mainly as volcanic (sill) with sandstone and shaly sand units was recognised in the upper section of the wireline log between 3800 m and 3830 m (Fig. 11). The sills in the study area are believed to be dolerite/basalt as interpreted by ExxonMobil (2000) and are important seal above or below a reservoir unit.

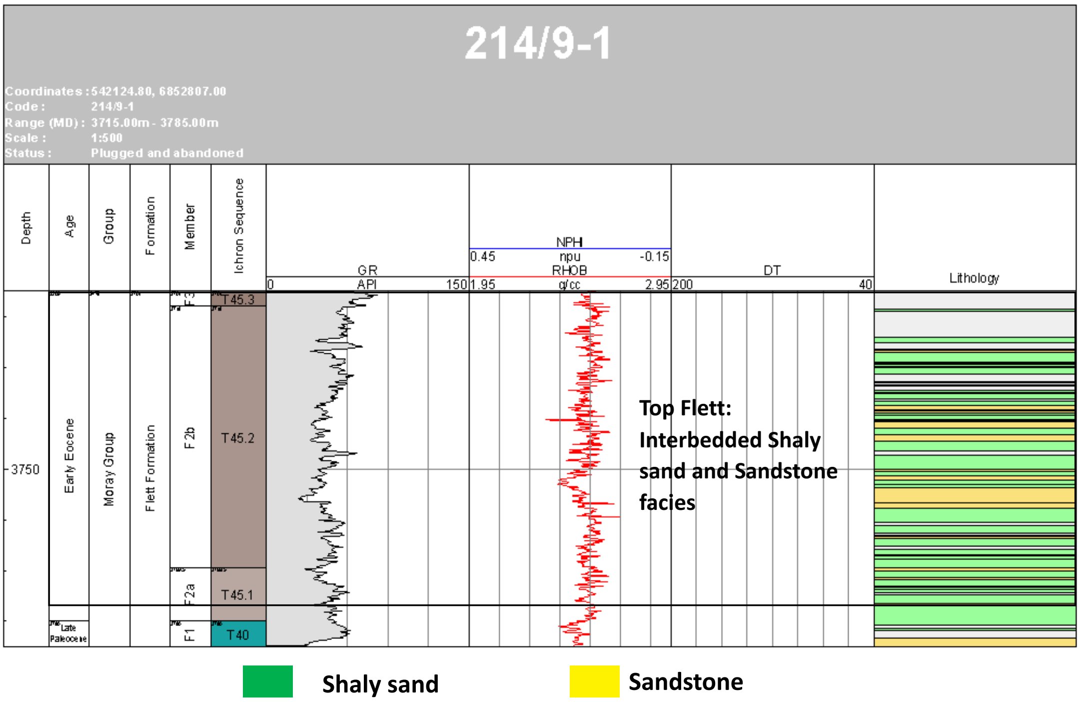

Figure 10: Wireline log (gamma ray) Interpretation of Top Flett Formation Lithology.

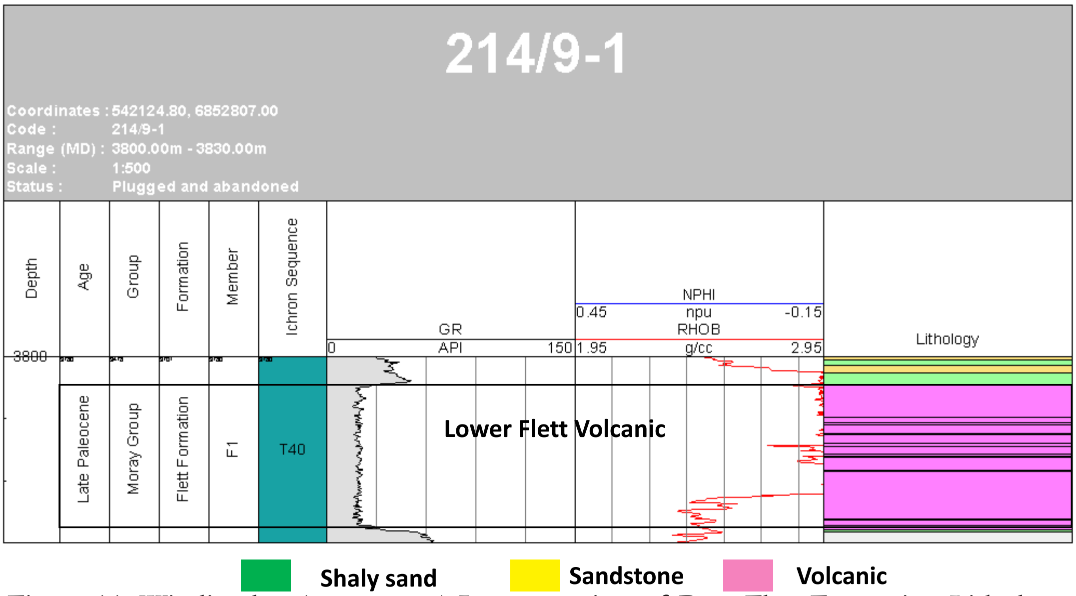

Figure 11: Wireline log (gamma ray) Interpretation of Base Flett Formation Lithology

Sedimentological Interpretations

Well 214/28-1 was selected for sedimentological interpretation because it has a relevant cored interval (35 m) within the Lower Flett Formation (T40) between depths 2551m and 2586 m (Fig. 12). Three lithologies: sandstone, shale and limestone were identified from available core photographs.

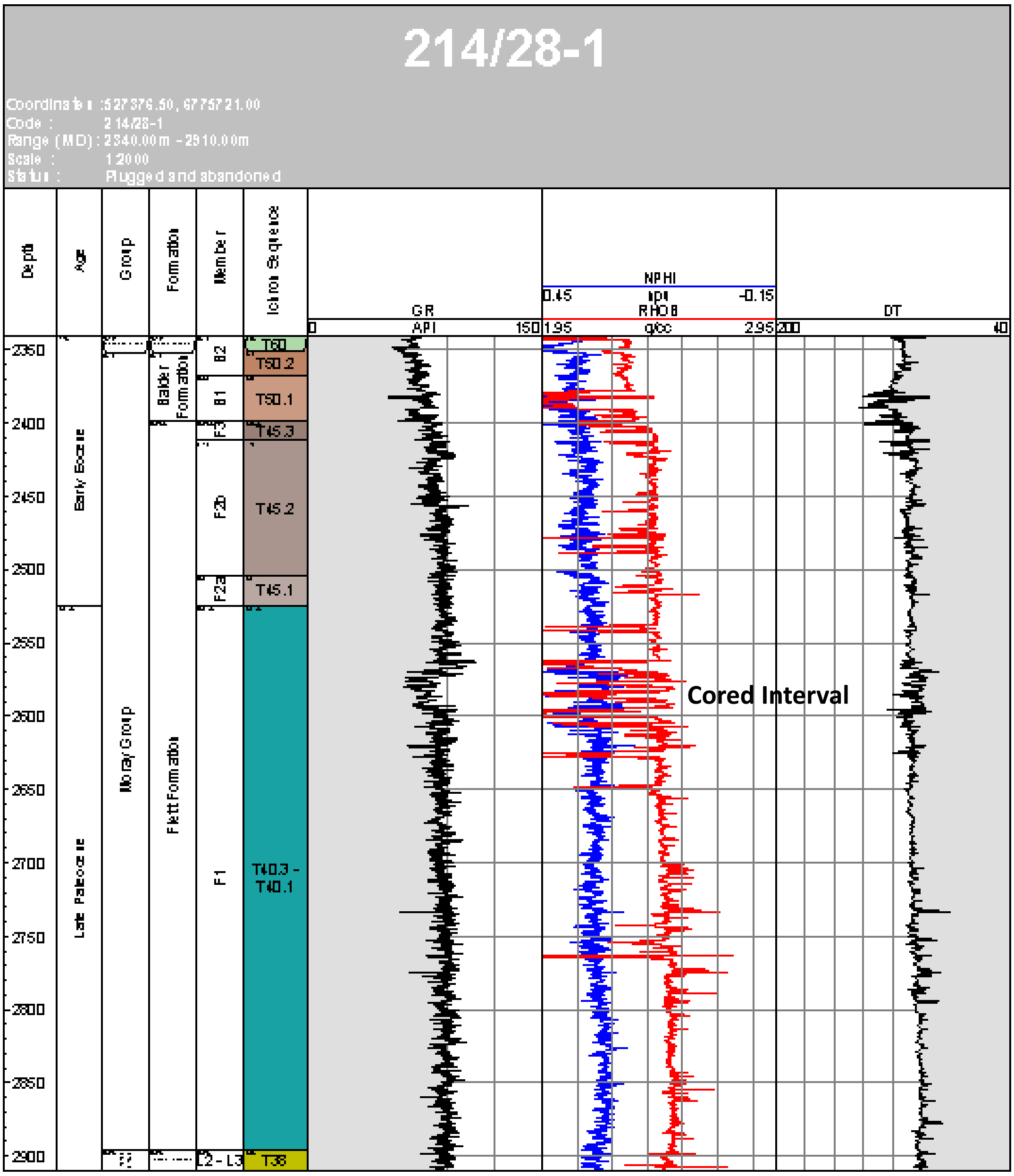

Figure 12: Wireline chart (Gamma Ray, Neutron and Density Curves) of Well 214/28-1 Showing the Cored Interval Between 2551 m and 2586 m.

Sandstone is the most abundant lithology and occurs throughout the cored interval, often interbedded with thin units of shale and limestone. The sandstone is light grey, fine to medium grained and moderately sorted (Fig. 13). Towards the base of the core (between 2581 - 2581.5m) the sandstone shows current ripple structures and shale clasts which signifies a deep water environment. The limestone is of a dark grey, crystalline facies with no visible structures occurring at interval 2555.5 - 2555.7 m. Its presence within the sandstone facies was interpreted as evidence of reworked sediments from the shallow water environment into the deep basin. Interval 2578.4 - 2578.7 m consists of dark grey claystone with parallel lamination (Fig.13) suggesting a deep marine environment of deposition. No bioturbation was observed within the claystone.

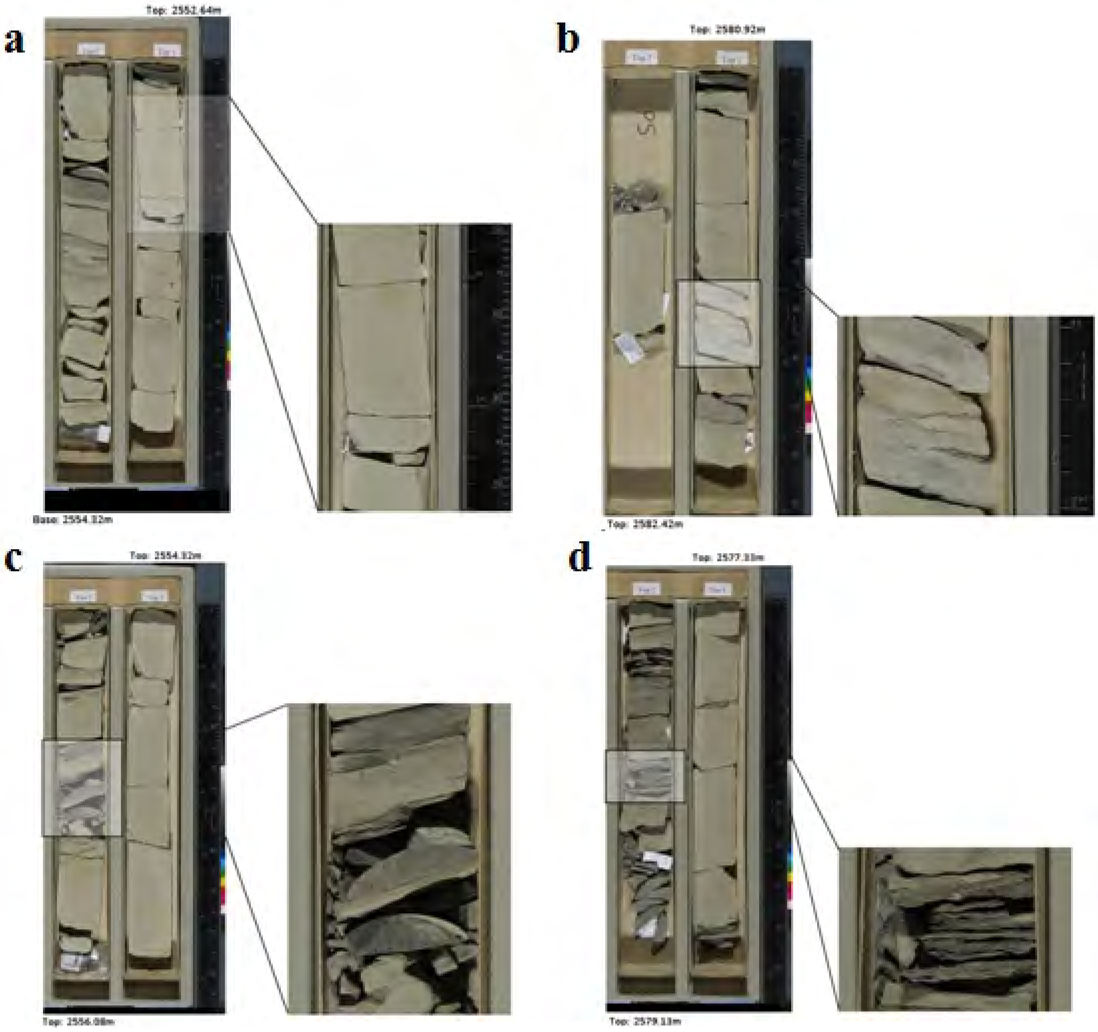

Figure 13: Core Photographs Showing (a) Sandstone Facies between 2552.5 and 2553.0 m (b) Sandstone with Shale Clast and Current Ripple Structures between 2581 and 2581.5 m depth intervals. (c) Limestone Facies between 2555.5 and 2555.7 m Depth Intervals. (d) Shale Facies between 2578.4 and 2578.7 m depth intervals.

The Balder (T50) Formation

The Balder Formation distribution was studied in 16 wells across the area. The thickness of the formation varies from 0 to 300 m with an average thickness of 82 m. The maximum sediment thickness of 300 m was observed in Well 214/04-1 located in the north-eastern part of the study area (Fig. 14). Thickness values from wells in the southern part of the study area indicate relative thin sediment thicknesses of 0 - 100 m.

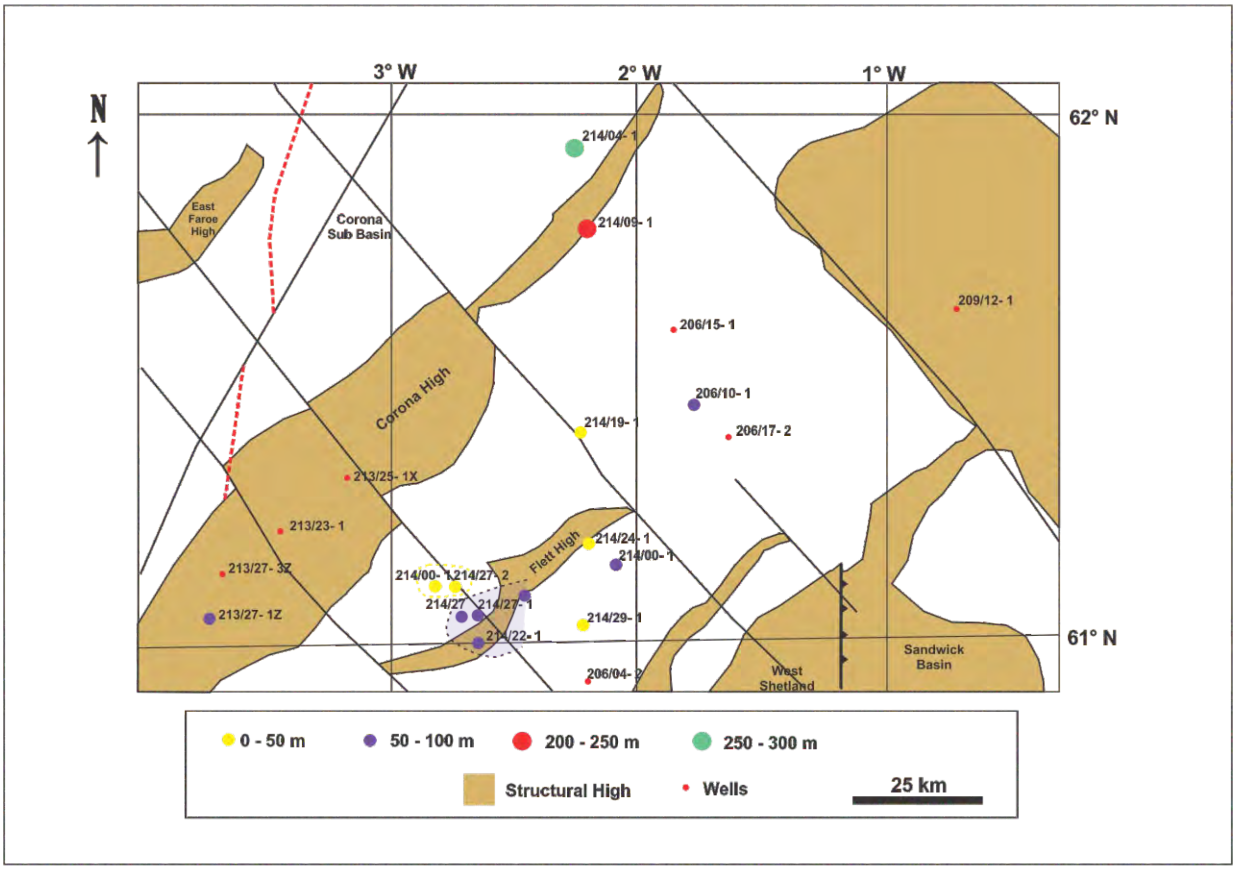

Figure 14: Tectono-Sedimentary Map of Balder Formation Distribution in the Flett Sub-Basin.

The Flett (T45 and T40) Formation

The Flett Formation thickness varies from 0 to 800 m with an average thickness of 250 m in the studied wells. The maximum sediment thickness of 800 m was observed in Well 214/28-1 located in the southern part of the study area (Fig. 15). Sediment thickness values of 100 – 300 m from wells in the northern section indicate relatively thin sediment units. The arrows on the southern part of the study area (Fig. 15) show an increase in the thickness of the Flett Formation away from the Flett High and a decrease in the formation thickness towards the basin between the Flett and Corona Highs. The thickness variations around the Flett High may be due to the position of the faulted blocks of the Flett High after the Early Paleocene uplift.

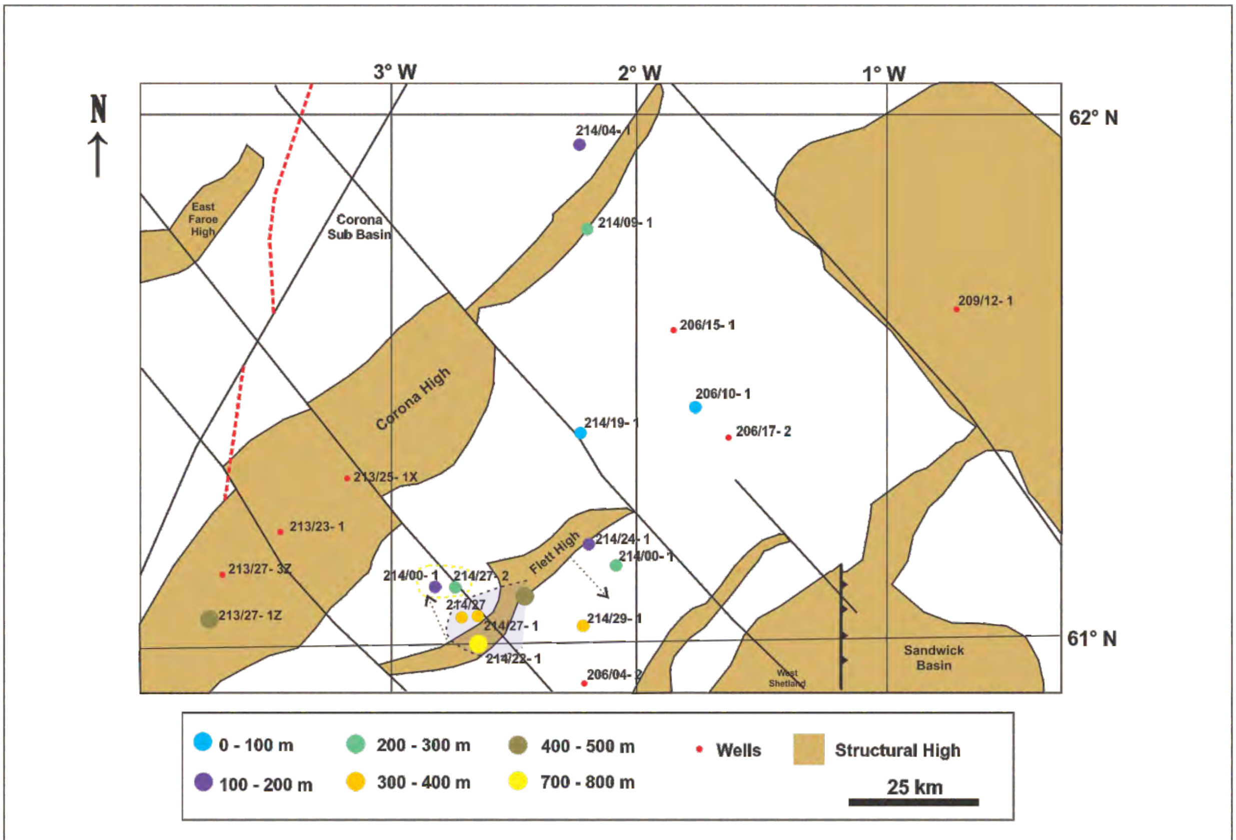

Figure 15: Tectono-Sedimentary Map of Flett Formation Distribution in the Flett Sub-Basin.

Formation Distribution Control

The main control on the Balder and Flett Formations distribution was the shape of the basin at the time of deposition. According to Lamers and Carmichael (1999), the shape of the Flett Sub-Basin suggests that it was formed as a post rift sag basin between the Flett and Corona highs. The thickness maps show that maximum thicknesses of the Flett and Balder Formations were towards the basin centre and around the flanks of the Flett and Corona highs. This means that the highs play a significant role in the distribution of the formations. The sediments could have been sourced from local erosion of the highs during the relative sea level fall in the Paleocene time (Sørensen, 2003). The sediments were then transported to the flanks of the highs and deeper part of the basin. According to Lamers and Carmichael (1999) the relative sea level fall exposed the Shetland platform and surrounding shelf to erosion allowing coarse sediments to be transported directly into the Flett Sub-Basin. Moreso, the sea level rise during the Early Eocene time deposited shale across the basin. Figure 16 shows a block diagram illustrating the direction of the sediment source area into the basin. The possible sediment source area could be Greenland and the West Shetland Platform to the NW-SE part of the study area.

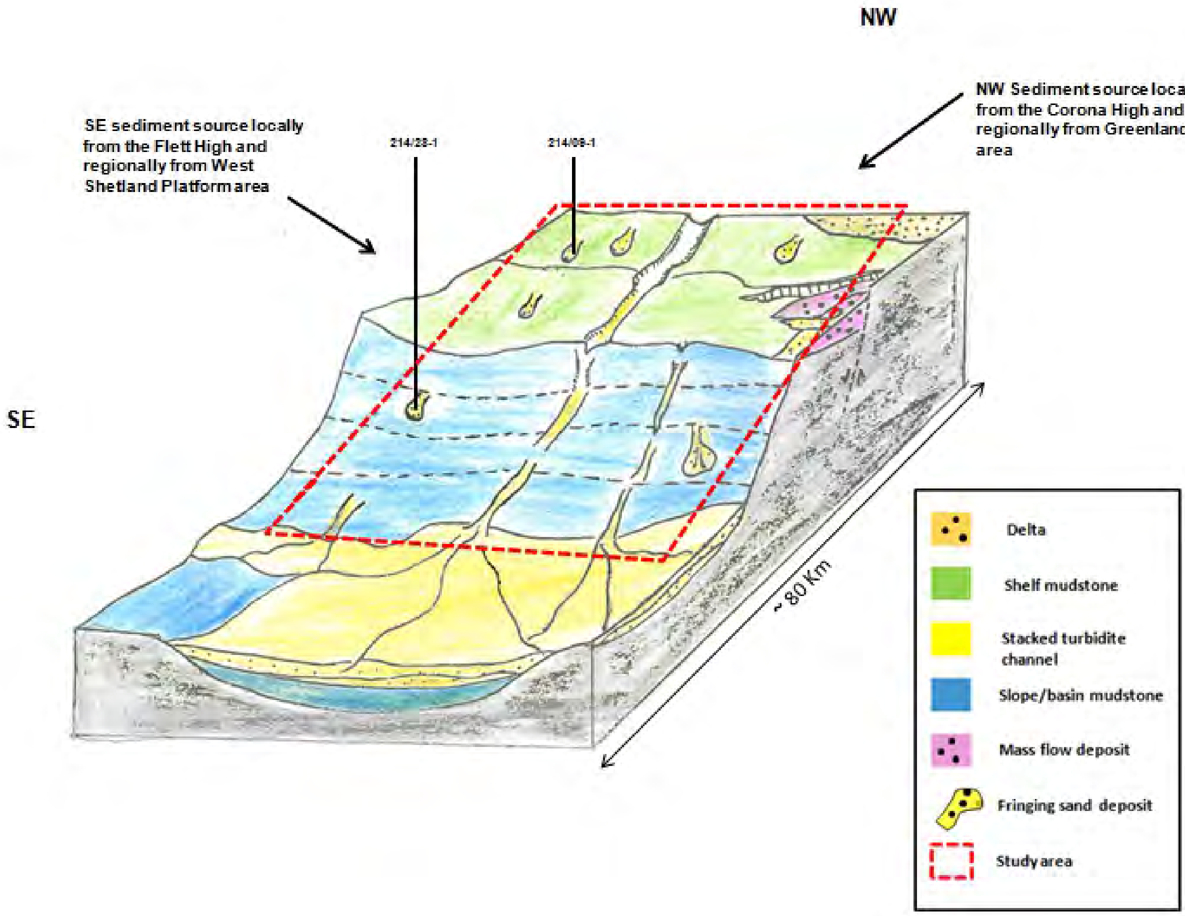

Figure 16: Conceptual Environment of Deposition of the Balder and Flett Formations in the Flett Sub-Basin. The Diagram also showed the Source of Sediments Direction.

CONCLUSIONS

The integration of seismic, wireline and sedimentologic data has shown that the Balder Formation (T50) reached a maximum thickness of 300 m and can be divided into sandstone and siltstone facies. The environment of deposition of this formation has been interpreted as deltaic to shallow marine setting with possible transgressive sands. The Flett Formation (T45/T40), where encountered; in wells, reaches a maximum thickness of 800 m. The rock types interpreted for the formation are interbedded siltstone and sandstone with some volcanics. The Flett Formation is believed to have been deposited in a shallow to deep marine environment. The sediment sources for the basin are locally from the surrounding structural highs and regionally from the north-western and south-eastern part of the Faroe-Shetland area.

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REFERENCES

British Geological Survey. 2011. Geology of the Faroe-Shetland Basin and Adjacent Areas. *BGS Research Report,* pp. 317.

Ebdon, C.C.; Granger, P.J.; Johnson, H.D. and Evans, A.M. 1995. Early Tertiary Evolution and Sequence Stratigraphy of the Faeroe-Shetland Basin: Implications for Hydrocarbon Prospectivity. *Geological Society, Special Publication, London*, 90, 51-69.

Ellis, D.; Bell, B. R.; Jolley, D. W. and O'Callaghan, M. 2002. The Stratigraphy, Environment of Eruption and Age of the Faroes Lava Group, NE Atlantic Ocean. *Geological Society of London Special Publication*, No.197.

ExxonMobil, 2000. Final Geological Well Report and Composite Log of Wells 214/09-1and 213/27-1 & 1Z. (*Unpublished Report*).

Knott, S. D.; Burchell, M. T.; Jolley, E. J. and Fraser, A. J. 1993. Mesozoic to Cenozoic Plate Reconstructions of the North Atlantic and Hydrocarbon Plays of the Atlantic Margins. *Proceedings of the 4th Conference, Geological Society, London*, 953-974.

Knox, R.W.; Holloway, S.; Kirby, G.A. and Bailey, H. E. 1997.Stratigraphic Nomenclature of the UK North West Margin. Early Paleogene Lithostratigraphy and Sequence Stratigraphy. (Keyworth, Nottingham: *British Geological Survey Unpublished Paper*).

Lamers, E. and Carmichael, S.M. 1999. The Paleocene Deepwater Sandstone Play West of Shetland. Petroleum Geology of Northwest Europe: *Proceeding of the 5th Conference, Geological Society, London,* 5, 645-659.

Loizou, N.; Liu, E. and Chapman, M. 2008. AVO Analyses and Spectral Decomposition of Seismic Data from Four Wells, West of Shetland, United Kingdom. *Petroleum Geoscience Journal*, 14, 355 - 368.

Mitchell, S. M.; Beamish, G. W. J.; Wood, M. V.; Malachek, S. J.; Armentrout,J. A.; Damuth, J. E. and Olsen, H. C. 1993. Paleogene Sequence Stratigraphic Framework of the Faroe Basin. *Proceedings of the 4th Conference, Geological Society, London*, 1011-1023.

Mudge, D. C. and Bujak, J. P. 2001. Biostratigraphic Evidence for Evolving Palaeoenvironments in the Lower Paleogene of the Faeroe-Shetland Basin. *Marine and Petroleum Geology*, 18, 577 - 590.

Roberts, D. G.; Thompson, M.; Mitchener, B.; Hossack, J.; Carmichael, S. and Bjornseth, H. M. 1999. Palaeozoic to Tertiary Rift and Basin Dynamics: Mid - Norway to the Bay of Biscay – A New Context for Hydrocarbon Prospectivity in the Deep Water Frontier. Petroleum Geology of Northwest Europe: *Proceeding of the 5th Conference, Geological Society, London*, 5, 7-40.

Schofield, N. and Holford, S. 2012. Igneous Intrusive and Extrusive History of the NE *Faroe-Shetland Basin Report*, 7 - 69.

Smallwood, J. R. and Maresh, J. 2002. The Properties, Morphology and Distribution of Igneous Sills: Modelling, Borehole Data and 3D Seismic from the Faroe-Shetland Area. *Geological Society of London Journal*, 197, 271-306.

Sørensen, A. B. 2003. Cenozoic Basin Development and Stratigraphy of the Faroes Area. *Petroleum Geoscience Journal*, 9, 189-207.

Statoil, 2010. The Hydrocarbon Potential of the Sullom Formation in the Judd Basin, West of Shetland: a Seismic-Stratigraphic Evaluation of the T10 Paleocene Interval. *(Unpublished Report*).