DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2002/35

Faroes offshore mapping

Structural framework and Cenozoic basin development

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Contents

1. Abstract

The present report reviews the geological development of the Faroes offshore area in Cenozoic time. The geology of the area is closely related to the structural development of the Caledonian belt to the east and the NW European Atlantic Margin rift system.

In mid-Paleocene–Early Eocene time flood basalts covered almost all the Faroes designated area. In the offshore area the basalts strongly attenuate seismic reflections from the sedimentary succession underlying the basalts, which makes it very difficult to map the Paleocene and the older Mesozoic basins within the area. An active petroleum system seems to be present in the pre-basalt succession, at least in the Southeastern area. Oil and gas have been generated from mid–Late Jurassic source rocks and reservoired in Paleocene, and probably also, in Lower Eocene fans.

The flood basalts on the shelf form three different facies, (1) an upper flood basalt sequence, underlain by (2) a prograding hyaloclastite sequence, and (3) a basal composite sequence consisting of basalt flows, sills, tuffs and marine sediments. The three sequences have been mapped and depth and isochore maps have been constructed. Maps of sequences underlying the basalts have been made only in the Faroe Bank Basin area.

A major objective for this study was to map the Eocene clastic succession overlying the basalts. In the Judd Basin an up to 700 m thick Lower Eocene succession, primarily consisting of basin slope fans, is present. The depocentre for the Lower Eocene strata coincides with the main Paleocene depocentre of the Judd Basin. New uplift of the basin occurred in early Middle Eocene resulting in a regional unconformity.

A number of maps presenting the Lower Eocene sequences and the Mid-Eocene unconformity have been made.

During the following Lutetian time, a thick transgressive wedge onlapping the Ypressian sediments was deposited. The wedge is disconformably overlain with a Late Eocene succession containing a series of slumps.

In the remaining part of the Faroes area, a much less differentiated succession of Eocene sediments was deposited, and only sandstones belonging to the Lower Eocene Flett and Balder formations are considered prospective.

The Oligocene was a period when uplift and erosion took place in the central part of the Faroes platform. A pronounced unconformity was developed in latest Oligocene–earliest Miocene time, on top of which a Neogene succession was deposited. A structural map of the unconformities, and an isochore map of the Palaeogene succession have been made.

The Neogene was a period of considerable tectonic activity in the Faroes area. In Middle Miocene time the probable impact of the Alpine orogenic compression and/or plate reorganizations in the North Atlantic caused renewed upfolding of the central Faroes area

and development of the Fugloy and Wyville-Thomson Ridges. The Neogene basin development is related to the formation of these ridges, along which depocentres developed. A series of maps illustrating the Neogene development is included in the report.

The Neogene folding and uplift have been of major importance for the development of the petroleum systems of the Faroes.

The greatest impact on the petroleum system of the Faroes after deposition of the basalts was without doubt the inversion of the Judd Basin in Middle Eocene time, which resulted in uplift of the source rocks and the main Paleocene reservoir succession of the basin. Gas expansion and flushing of oil from the uplifted and fractured reservoirs were one of the negative consequences.

A number of amplitude anomalies in the Paleocene and Eocene successions have been observed and are presented on two of the attached maps.

2. Introduction

This report presents the main results of a seismic mapping program carried out in the GEUS' Faroes-Office from August 1998 to May 1999 as a part of a general geological evaluation work for the preparation of the first Faroes licensing round.

The seismic interpretation encompassed almost all of the 2-D speculative seismic data that were acquired by Western Geophysical, Digicon, Geoteam and Nopec, totalling about 28.000 km.

The main purpose of the project was to map the Cenozoic succession down to Top Paleocene, alternatively to Base Basalt level, over the entire Faroes area in order to be able to understand the main depositional systems and the basin development since the start of the eruption of the flood basalts in mid-Paleocene time. In the Faroe Bank Basin area deeper stratigraphic levels, below the basalt formations, of suggested Lower Paleocene and Cretaceous age have also been interpreted.

No detailed prospect mapping has been carried out in conjunction with this study. However the petroleum prospectivity of the individual basins within the mapped area has been briefly commented on.

3. Regional geological setting

3.1 Regional structural framework and transfer zones

The Faroese area is geologically a part of the NW European Atlantic Margin. A number of sedimentary basins have been formed during geological time along the margin. The margin extends from offshore northern Norway to south of Ireland. It includes the Barents Sea, Lofoten Margin and the Vøring, Møre, Faroe-Shetland, Rockall, Hatton and Porcupine basins, see Figures A and B (Doré *et al.* 1999).

The area is located to the west of the old Caledonian front extending from East-Greenland and southwards along the west coast of Scotland and Ireland. The Mesozoic and Cenozoic basin development in the old Caledonian rift area is related both to reactivation of old fault systems and to later rifting which occurred in several phases from the Late Jurassic through the Cretaceous and ending up with the seafloor spreading at the transition between Paleocene and Eocene.

The Faroe-Shetland Trough separates the Faroes area or platform to the west from the Shetland Platform to the east. To the south, the Wyville-Thomson Ridge, associated with one of the Atlantic transfer zones, forms a pronounced geological feature (see Fig. C). The ridge formed a boundary zone during basin development in the area. In the Rockall Basin, a thick Cretaceous sequence is overlain by a relative thin Paleocene and a thick Eocene succession. In the Judd Basin to the north, Cretaceous and thick Paleocene deposits are overlain by an eroded Eocene succession.

As a consequence of the Atlantic break-up which took place only 100-120 km to the W–NW of the Faroes (Larsen et *al.* 1999), a number of transverse faults and transfer zones perpendicular to the central spreading axis formed. The basin development in the Faroe Shetland Channel Basin is to a large extent determined by differential subsidence in different sub-basins caused by movements along the transfer zones in Paleocene and Eocene time, (Rumph *et. al.* 1993; Doré *et al.* 1999 & Roberts *et al.* 1999), see figure D. The most pronounced transfer zones in the Faroes area, from south to north, the Wyville-Thomson, Judd, Westray, Clair and Erlend transfer zones.

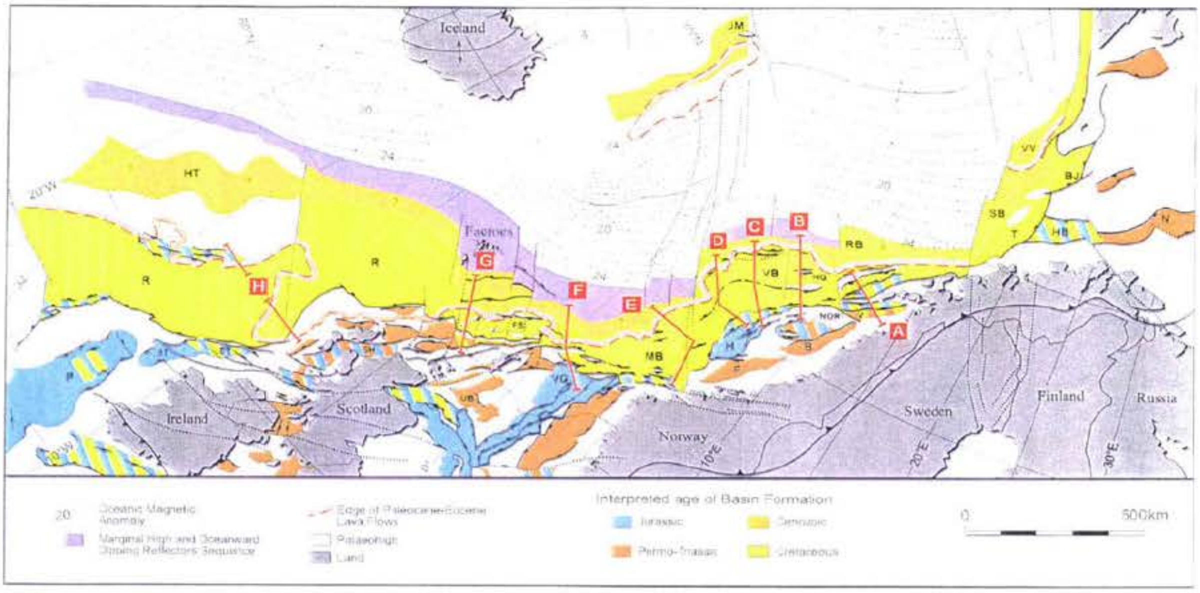

Figure A *Tectonic elements map of the northwest European Atlantic margin and adjacent oceanic crust, western Barents Sea to southwestern Rockall Trough. Basins are coloured according to the principal extensional episodes responsible for their formation. Extent of Paleocene–Eocene lava flows, marginal highs and oceanic magnetic anomalies are also indicated. For abbreviations see Table 1.From Doré et al. 1999.*

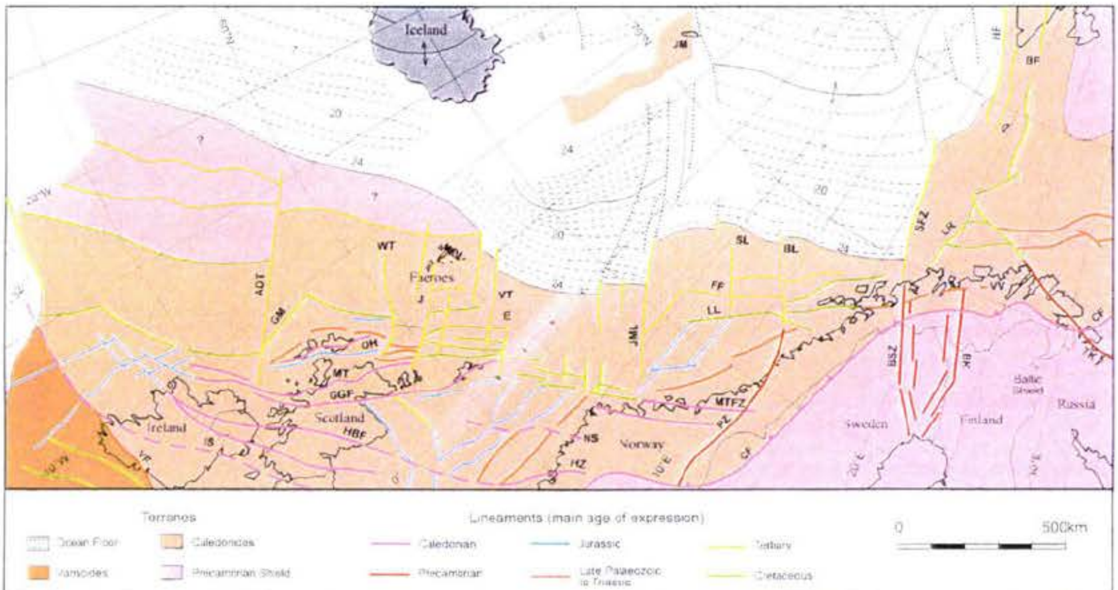

Figure B *Basement terranes and lineaments of the northwest European Atlantic Margin. The lineaments are coloured according to their main observed age of expression as a means of illustrating possible correspondence between onshore features and those in off-shore sedimentary basins. For abbreviations see Table 1. From Doré et al. 1999.*

Table 1

ADT	Anton Dohrn Transfer	JML	Jan Mayen Lineament
E	Erlend Transfer	MB	Møre Basin
EC	Erlend Complex	MT	Moine Thrust
EF	East Faroe High	OH	Outer Hebrides Fault Zone
FD	Faroes Dome	R	Rockall Trough
FS	Faroe-Shetland Basin	VB	Vøring Basin
GGF	Great Glen Fault	VG	Viking Graben
H	Halten Terrace	VT	Victory Transfer
HH	Helland-Hansen Arch	WT	Westray Transfer
HT	Hatton Trough	WTR	Wyville-Thompson Ridge
J	Judd Transfer	YR	Ymir Ridge
JM	Jan Mayen		

Structural Elements of the Faroe-Shetland Trough

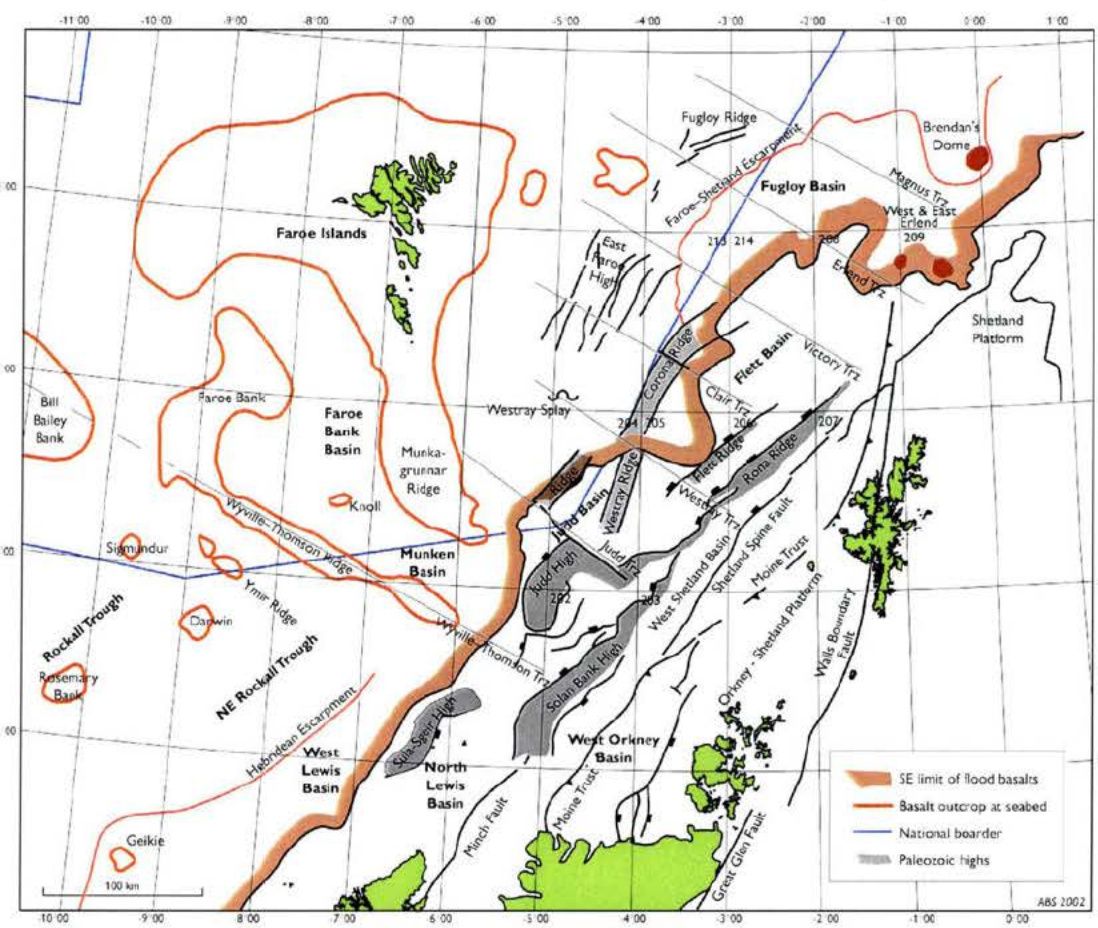

Figure C *The Structural map of the Faroe-Shetland Trough shows Palaeozoic highs, the Escarpments, the extension of the basalt covered area and the set of transfer zones which have influenced sedimentation in Cretacous–Early Palaeogene time. From Sørensen 2003, in press.*

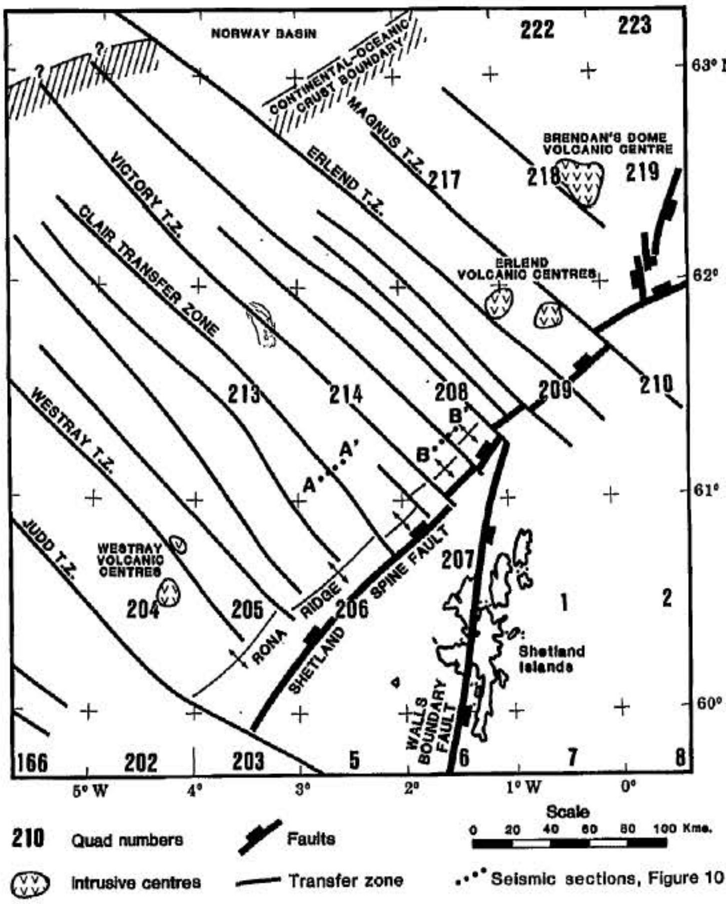

Figure D *Tectonic interpretation showing transfer zones and volcanic centres defined by gravity and magnetic data. From Rumph et al. 1993.*

The Judd Basin is located in between the Judd and Westray transfer zones. The Corona Basin is located further to the north in between the Westray and the Clair transfer zones. The Fugloy Basin is located to the north of the Clair transfer zone. The basin forms the northernmost part of the Faroe-Shetland Trough and is mainly of Oligocene to Recent age, but is presumably underlain by Cretaceous and Paleocene sediments similar to those known from East Greenland and the Flett Basin. The Erlend transfer zone is located at the northern edge of the British Flett basin towards the Fugloy–Erlend Ridge, which separate the Faroe-Shetland Trough from the Møre Basin. The northernmost transfer zone of the Faroese area is the Magnus transfer zone which separates the Fugloy Ridge from the British Brendan volcanic complexes (Fig. C).

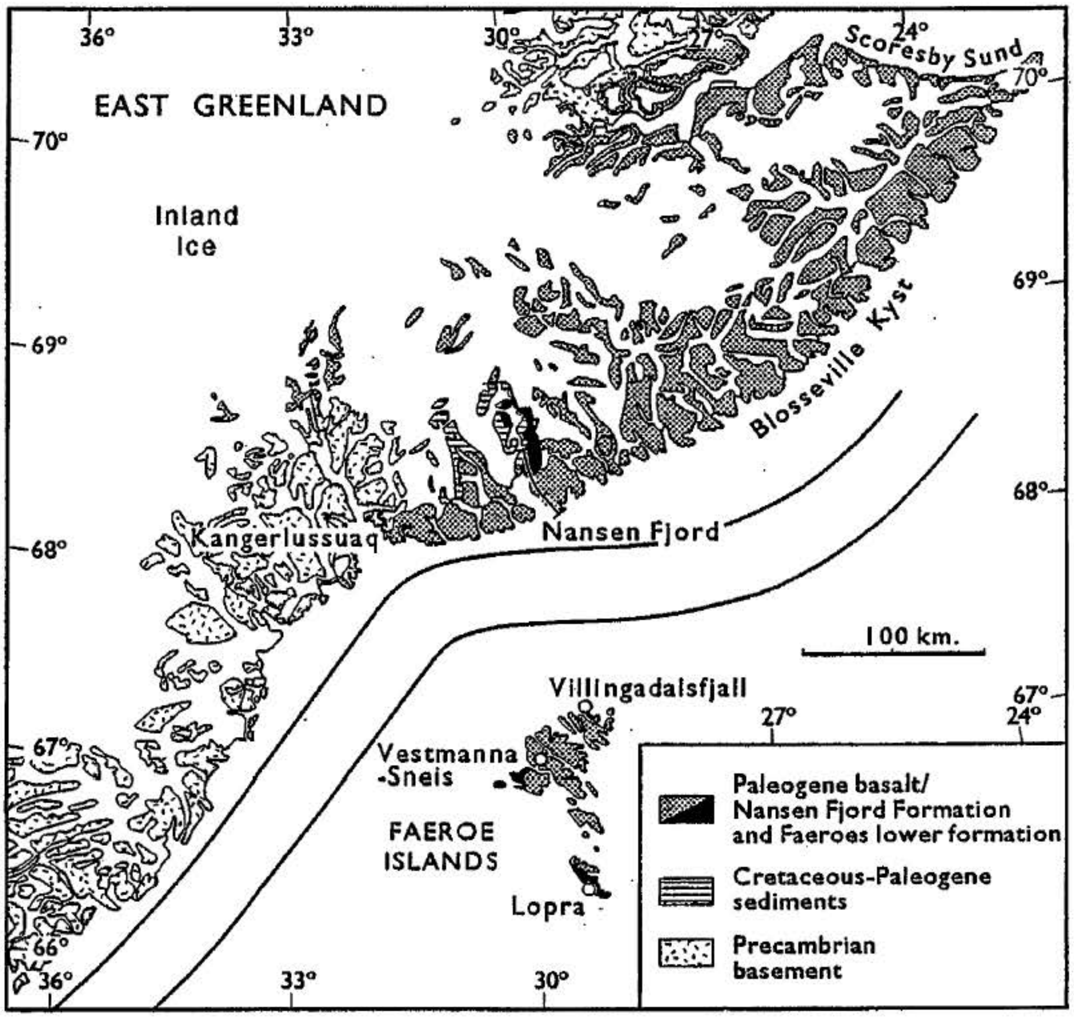

Figure E *Pre-drift reconstruction of central East Greenland and the Faroes block. The geographical net shown is that for the present Greenland side. The pre-breakup N-S distance between Greenland and the Faeroe Islands was in the order of 100-120 km (see text), and in this figure the distance is 100 km. (L. M. Larsen et al. 1999).*

A NE–SW trending ridge of presumed Triassic to Palaeozoic age is located below the basalt cover on the eastern part of the Faroes platform. The ridge seems to be segmented by crossing transfer zones, for example the Clair transfer zone.

The Faroes platform is bounded to the north and west by oceanic crust, present only about 100 km to the NW of the Faroe Islands (Fig. E). The central and NW'ern parts of the platform are covered by basalt layers more than 3500 m thick.

Only the SE part of the Faroese acreage where the basalt layer is thin, and where also deep Mesozoic and Palaeogene basins are located, can be considered of major interest for petroleum exploration, (see e.g. Fig. 60).

3.2 Palaeozoic and Mesozoic geological setting

3.2.1 Palaeozoic and early Mesozoic development

In the Faroe-Shetland area several basins have developed through time. The basins are associated with break-up and faulting processes along the western flank of the former Caledonian orogenic belt (Fig. C and Doré *et al.* 1999). Thus nonmarine sediments, including Devonian Old Red Sandstones and Triassic New Red Sandstones (consisting of erosional products of the Silurian Caledonides to the east), were deposited in troughs along the western margin of the former Scottish–Shetland Highland or Platform.

The reservoir of the Clair oilfield is in Carboniferous and Devonian Sandstones and is located on the Rona ridge at the western rim of the West Shetland Platform. These sandstones are so far not known from the Flett- and the Corona Ridges, where however only a few wells have been drilled (see Fig. C, F and Stoker *et al.* 1993).

On the Faroes Platform no wells have been drilled yet, but it is likely that Old Red Sandstone might constitute a considerable part of the basement highs under the basalt-covered areas.

Along the eastern part of the Faroe-Shetland Trough, Triassic deposits are present in the same areas as the Devonian and Late Carboniferous sediments (see Fig. C, G and Stoker *et al.* 1993). In Triassic time new faulting and subsidence along the Caledonian Front initiated a new phase of basin development within the former basins along the western margin of the Scottish–Shetland Platform.

Triassic claystones and sandstones do not outcrop on the Faroe-Shetland Trough floor to the west of the Rona ridge, but are present southwards in the basins along the West Shetland Spine Fault and down into the West Orkney Basin, where up to 1500 m of Triassic sandstones are present. It is concievable that the Triassic is more widely distributed in the Faroe-Shetland Trough and also extends into the Faroes area, where it might constitute parts of, for example, the East Faroe Ridge and predicted basement ridges on the Faroe Platform.

The Old Red and Triassic sandstones are known to have limited reservoir quality in the Clair Field on the Rona Ridge (Stoker *et al.* 1993). This may also be the case if these sandstones are found in ridges below the Faroe basalt cover.

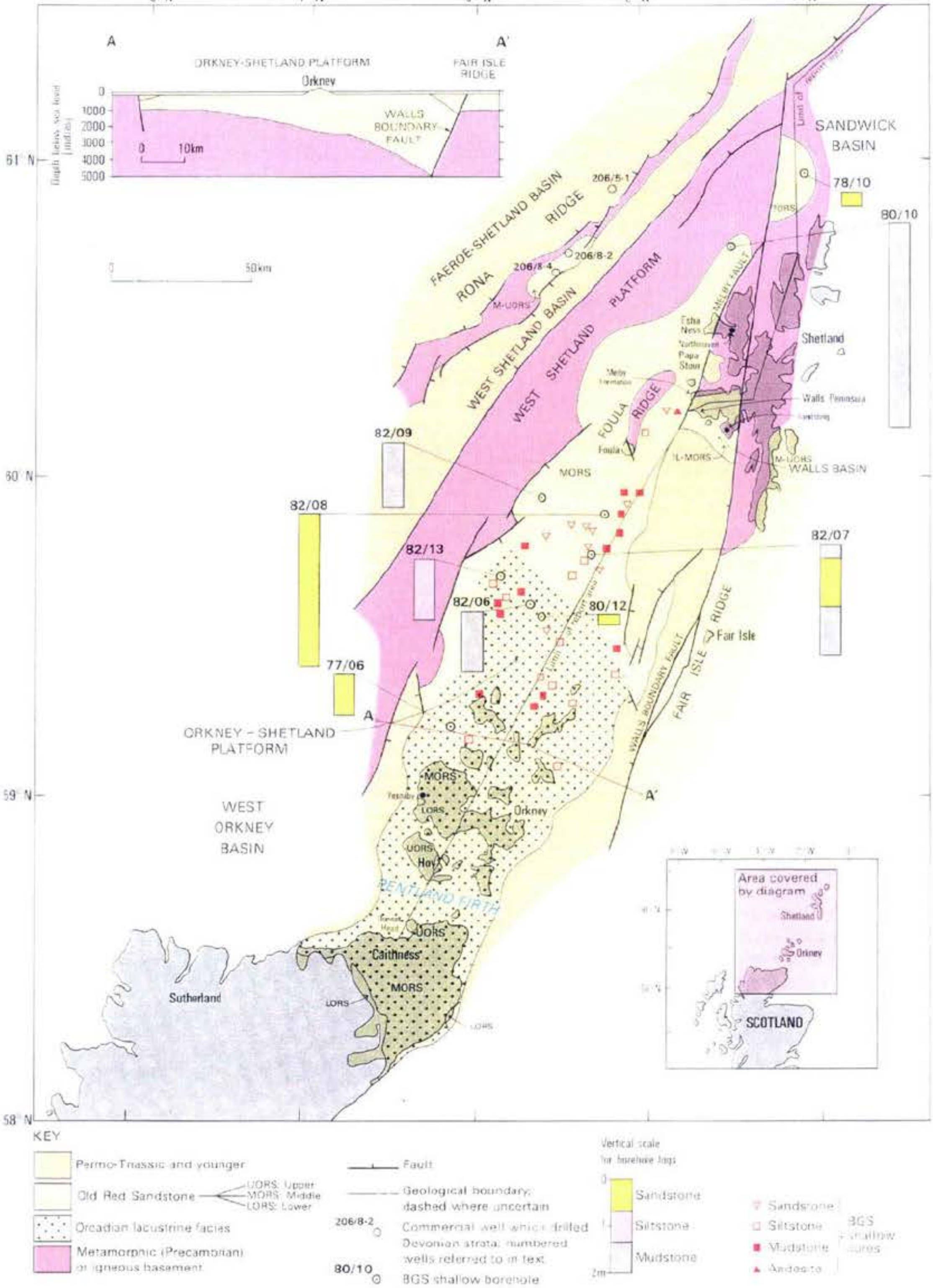

Figure F *Geological setting of the old Red Sandstone around Orkney and Shetland. From Stoker et al. 1993.*

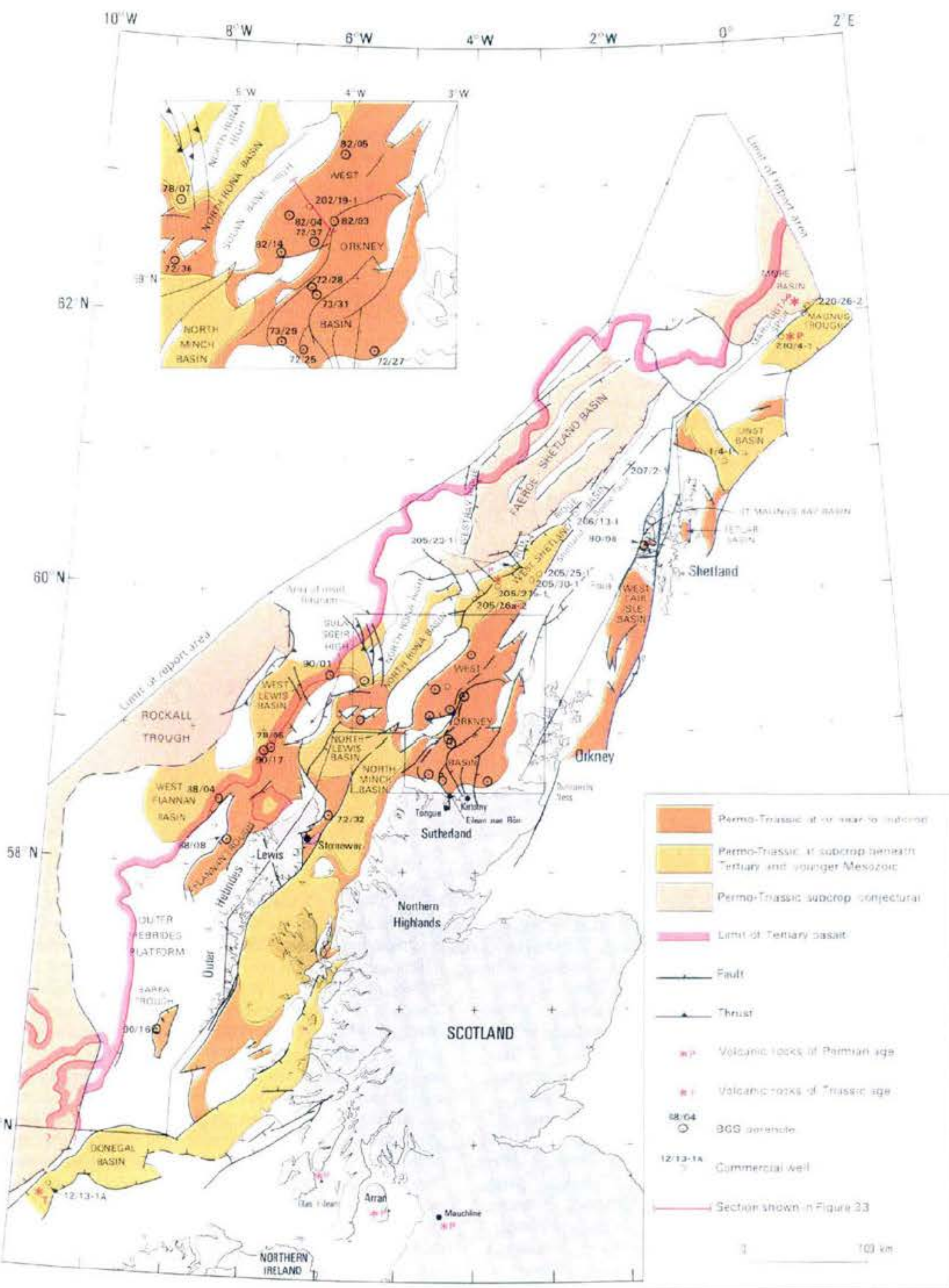

Figure G *Distribution of Permo-Triassic rocks in the NE part of the Faroe-Shetland Trough. From Stoker et al. 1993.*

3.2.2 Jurassic

A major transgression occurred in Late Triassic time, Rhaetian. Most Triassic sedimentary basins in Europe were affected and in the area to the north and southwest of the Shetland Islands and in the Hebrides a shallow epicontinental sea was formed. At the same time a shift occurred from the arid climate typical of the Triassic in this region to more humid conditions. This climatic shift was associated with the deposition of dark marine shale, and in coastal settings also with thin coal measures, lignite and mudstone with plant debris (Hitchen & Ritchie, 1987).

The tectonic development of the area determined the distribution of the Jurassic sediments. The deposition of the Jurassic sediments took place in the same basins as the Triassic sediments, but due to varying rates of subsidence in the different sub-basins, the distribution and thickness of the Jurassic sediments varies considerably.

In the North Lewis and North Minch Basins to the north of the Hebrides, more than 2000 m of sediments were deposited. In the eastern part of the Faroe-Shetland Trough, north of the Rona Ridge, well 206/5-1 penetrated 1054 m of sediments of Early–Late Jurassic age. In Quatrants 202, 204 and 205 in the southern part of the West Shetland Basin, only between a few tens of meters to a maximum of about 200 meters of Late to sometimes Middle Jurassic sediments are present (Stoker *et al.* 1993). Onshore a rather complete Jurassic sedimentary section is present on the island of Skye, which includes the Middle Jurassic Cullaidh shale source rock succession.

Renewed rifting in the Faroe-Shetland Trough, preceeding the later Atlantic spreading took place in the Late Jurassic. This caused a change in the basin development in the Faroe-Shetland area, where the main depocentres shifted westwards (Fig. A).

The rifting in Kimmeridgian caused a major change in the sedimentation in the Faroe-Shetland area. The basin configuration and connection to the open sea changed and deposition of marine mud in shallow basins became dominant (Stoker *et al.* 1993). A change to more anoxic conditions in the sea caused deposition of organic-rich shale.

In Volgian time a very valuable source rock, the "Hot Shale", with an organic content of up to more than 10 %, was deposited. Also the less organic-rich Middle Jurassic shale also has a documented source potential. In the lowermost Middle Jurassic of well 204/22-1 TOC (Total Organic carbon) is 4.5 % and HI (Hydrogen index) is 508 mg HC/g TOC at a depth of 2700 m. In well 205/26-3 at a depth of 2100 m TOC is up to 15 % in the Hot Shale and HI is more than 500 mg HC/g (confidential information from Amerada Hess).

As no wells have been drilled on Faroese acreage so far, nothing is known about the possible presence of Jurassic source rocks in the Faroese subsurface. It is documented that Late Jurassic claystone is present in the Judd Basin (Spencer *et al.* 1999) where it has generated large amounts of oil and gas, which has migrated into and been trapped in overlying Paleocene fans and channel complexes, as for example in the Foinaven and Schiehallion fields (Cooper *et al.* 1999; Leach *et al.* 1999).

3.2.3 Cretaceous

At the beginning of the Cretaceous, a change took place in the tectonic regime in the North Atlantic region (Doré *et. al.* 1999). The E–W stress regime that controlled rifting and basin development during the Kimmeridgian changed to a NW–SE regime in connection with the beginning of Atlantic rifting, which propagated to the north during the Cretaceous. This extensional regime lasted throughout the Cretaceous. The Cretaceous sediments rest disconformably on Jurassic or older strata. In the Cenomanian (early Late Cretaceous) renewed tectonic activity caused tilting and development of a new disconformity (Doré *et. al.* 1999). Tectonic activity continued in the Late Cretaceous and Roberts et al. (1999) have related it to an unstable transtensional regime, which caused not only basinal subsidence but also local compression. This gave rise to structures which could act as a local focus for hydrocarbon migration (e.g. the Clair and Westray Ridges).

In the Faroe-Shetland Trough, Lower Cretaceous deep marine sandstones including fans and slump deposits were deposited. On the Rona Platform and in the East Faroe Basin, the Cretaceous deposits typically occur as fining upward sandstones in the lower part and claystones in the upper part.

In the West Shetland Basin, up to 1140 m of sediment is known from well 205/25-1. Even thicker Lower Cretaceous strata are known from the Faroe Shetland basin, where the depocentre is presumed to be located just southeast of the Fleet Ridge. Here the presence of at least 2000 m sediments has been documented (Stoker *et. al.* 1993).

In the Late Cretaceous, the depocentre had shifted further to the west and very thick sedimentary sequences which blanket underlying structural features, were deposited in the Faroe-Shetland Trough. Well information combined with seismic evidence shows that more than 5000 m of sediment are present close to the Faroe Platform Margin Fault and to the east of the Westray Ridge (Fig. H). In the Faroe Bank Basin, a thick Cretaceous sequence is expected to be present (Figs 44-46 and 48). In the area to the south of the Wyville-Thomson Ridge well information proves the presence of a thick Cretaceous succession, but only thin Paleocene strata (Doré *et al.* 1999; Tate *et al.* 1999).

The Late Cretaceous sediments, typically dark claystones with some isolated carbonate stringers (Stoker *et al.* 1993; Roberts *et al.* 1999), reflect open marine transgressive or high stand conditions. The source rock potential of the Cretaceous claystones is usually poor with low TOC and HI (confidential oilcompany information). Due to the open marine conditions in the Late Cretaceous only small variations in the sedimentary environment are envisaged in the different parts of the Faroe-Shetland Trough.

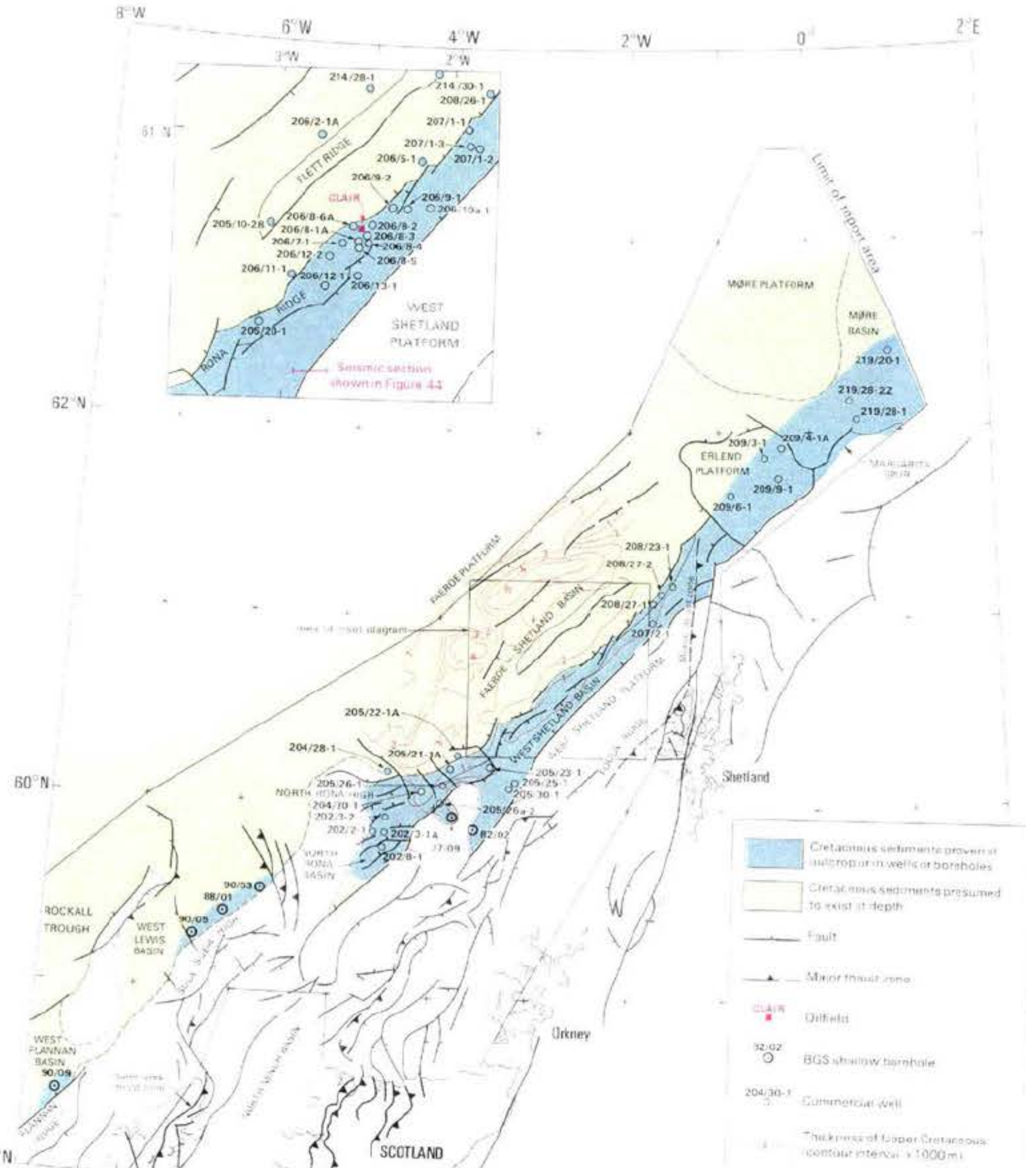

Figure H *Distribution of Cretaceous strata in the northern part of the Faroe-Shetland Trough. From Stoker et al. 1993.*

3.3 Early Paleogene geological development

3.3.1 Faroe-Bank Basin and the Munken Basin

The basalts are expected to be underlain by Paleocene sediments in the whole SW Faroes area. The basin configuration and the age of the sediments below the Paleocene basalts are only sparsely known, and in local areas Paleocene sediments may be absent.

In the Judd Basin, a thick Paleocene sedimentary succession is deposited, but further south in the NE Rockall Trough, a somewhat thinner Paleocene succession overlies a thick Cretaceous succession (Tate *et al.* 1999; Waddams & Cordingly 1999). The NE Rockall Trough is here considered to be the southernmost part of the Judd Basin. The Wyville-Thomson Ridge is the feature separating the two basins. In the Faroe Bank Basin area an up to 1000 m thick Paleocene sequence is interpreted to be present. This succession may be anticipated to be related to the thick sedimentary succession of the Judd Basin, than to the thin succession in the northern part of the North Rockall Trough, which may thin or even pinch out against the Wyville-Thomson transfer zone.

It seems that there is a major change in the geological setting from the Judd Basin to the Northern Rockall Trough south of the Wyville-Thomson Ridge.

A number of intrusions are known from the Danian and Upper Cretaceous in the Faroe-Bank Channel area. They may be related to contemporaneous rifting or be a result of the first intrusive activity of the Icelandic plume in the Late Danian at 62 Ma. The plume may also have caused later uplift of the area and new possibility for erosion and deposition of both fine and cause clastic sediments in the area (White & Lowel 1997).

3.3.2 Faroe-Shetland Trough

In Paleocene time, deposition continued in the Faroe-Shetland Trough where rifting due to new extensional pulses reactivated old faults and initiated new depocentres. The renewed rifting and the related transverse movements along the Judd, Westray and Clair Transfer zones have determined the location of the Paleocene depocentres.

In the Faroe-Shetland Trough the area between the Flett Ridge and the Corona Ridge, the Flett Basin, became a depocentre. To the SW, other basins, the Judd - and the Corona Basins, formed depocentres.

In the Flett basin over 3000 m of Paleocene sediments have been deposited in the area near the well 206/2-1A, (Stoker *et al.* 1993). In the Judd basin no drilling has taken place in Faroes waters, but based on UK wells and seismic evidence thicknesses of up to 2000–2500 m may be expected.

Seismic evidence suggests that the Paleocene formations continue from the Judd Basin to the N and NW below the Faroes Basalts and into the Corona Basin. To the south and southwest the Paleocene layers also seem to be present in the Faroe Bank Channel. Cretaceous layers here underlie the Paleocene. The basalts cover all of the southern part of the Faroes platform and continue further southwards into the UK area, where a well, 164/7-1, penetrated 1200 m of basalt (confidential information).

The Judd basin has so far been the most petroleum prolific area in the Faroe-Shetland Trough. The large discoveries such as the mid-Paleocene (T31-34) Foinaven and Schiehallion fields are all made in stratigraphic traps, which makes exploration difficult compared to areas where oil and gas have been trapped within structural closures. About 100 exploration wells in UK waters in the Faroe-Shetland Trough were drilled into Mesozoic fault blocks where sandstones of Devonian–Lower Cretaceous age and claystones, including Kimmeridge shale, were drilled. However, only three small discoveries were made in Mesozoic sandstones, Victory, Loyal and Strathmore.

In contrast to the Cretaceous, very rapid subsidence took place in the Judd- and Flett Basins of the Faroe-Shetland Trough in Paleocene time. During the 70 million years of the Cretaceous, the basins subsided about 2500 m as compared with 3000 m in the 10 million years of the Paleocene. In late Paleocene time the subsidence rate was considerably lower than in the early Paleocene (Fig. I). The sedimentation was cyclic and a number of sequences were deposited (Mitchell *et al.* 1993). The Paleocene comprises Sequences No.10 to 90 and the Eocene sequences Nos 100 to 160. One of the Eocene and four Paleocene sequences are considered to be multiple sequences or sequence sets (Mitchell et *al.* 1993, Fig. J).

Based on seismic evidence, including the use of inverted seismics, it seems that the Paleocene in the Judd Basin has thick sequence sets in the mid-Paleocene (sequences 20 and 30, Mitchell 1993), and thinner sequences in the Late Paleocene.

Rasmussen (1998) documented the presence of basin floor fans in the Faroese part of the Judd basin at proposed T32 or T34 level (Ebdon 1995). In the uppermost Paleocene, in the top of the T38–T40 sequences, a canalised pattern can be seen (Figs 59 to 61). The uplift and formation of the two sequence boundaries (unconformities) (T35sb and T45sb) in Late Paleocene in the Faroe-Shetland Trough Area may have been caused by intrusion of magma (underplating) by the Icelandic mantle plume (White & Lowell 1997). Two other unconformities are present in the Early Paleocene at the top and base of the Danian. They can be correlated with general falls in sea level (Mitchell *et al.* 1993).

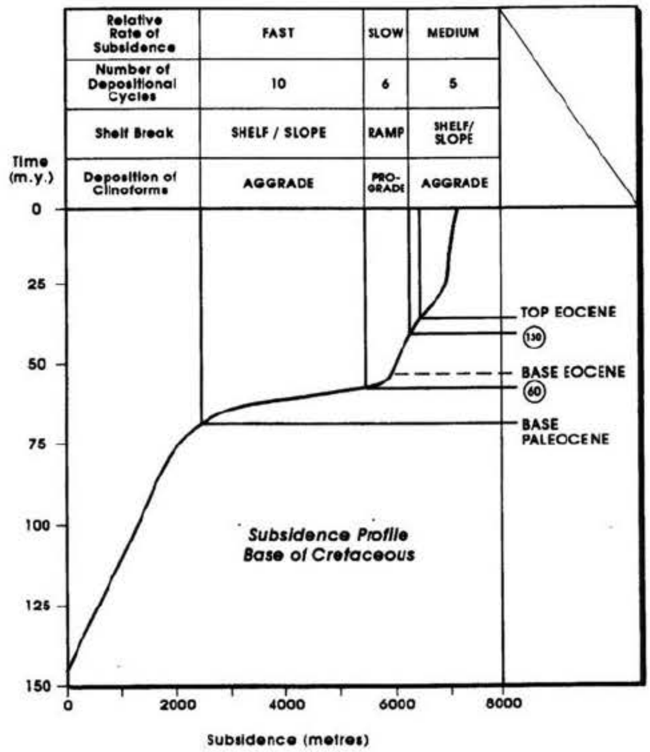

Figure I *Subsidence profile from the Faeroe Basin showing the relationship between the relative rate of subsidence and the style of sequence development in the Palaeogene. From Mitchell et al. 1993.*

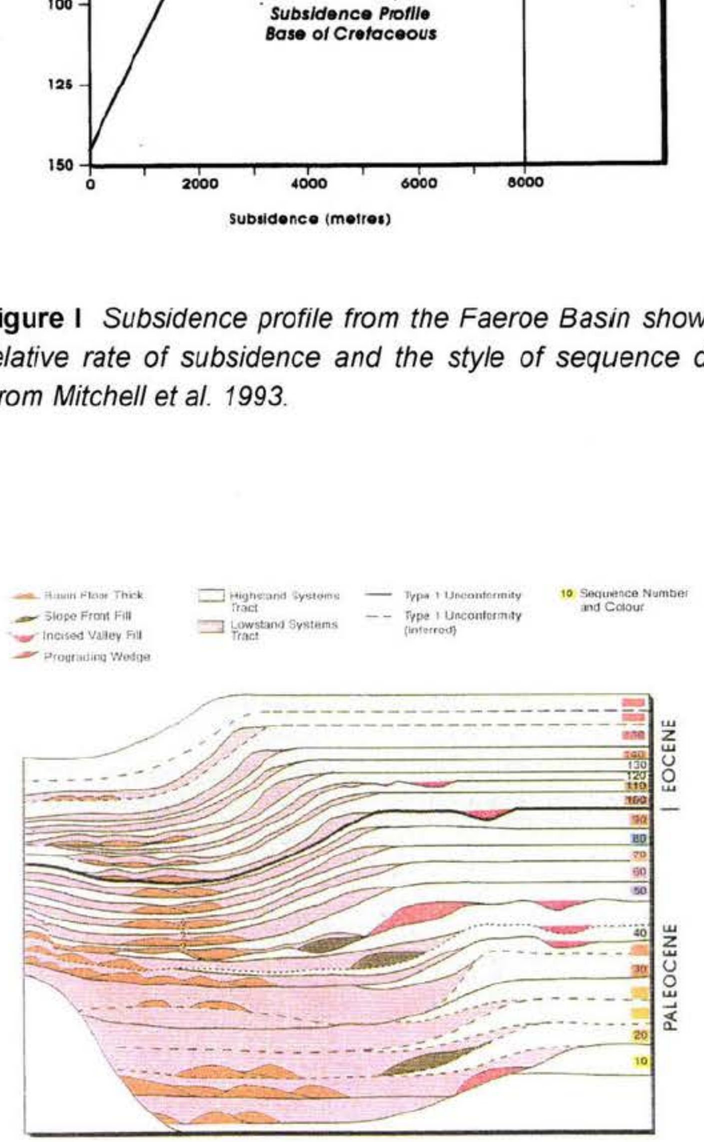

Figure J *Schematic profile oriented NW-SE across the Faeroe Basin showing the stacking order of the Palaeogene sequences and lowstand subdivisions recognized in each. From Mitchell et al. 1993.*

3.3.3 Paleocene-Eocene Transition

In the Late Paleocene the depositional system changed from an aggradational to a progradational regime with much lower sedimentation rates, (Mitchell *et al.* 1993). The lower and mid-Paleocene sequences 10 to 40 (T10-T34) consist of deep-water sediments, claystones and turbidites. After deposition of sequence 40 (T34) a very erosive unconformity developed in the Faroe Bank Basin. In the Late Paleocene the depositional system changed and deposition of prograding sediments began from the east, (seq. 50 and 60 or T35,36,38 and 40). At the end of the Paleocene, subsidence in the Judd Basin ceased and the basin was finally filled up. A last phase of uplift and formation of a land bridge between the Faroes and Shetland followed, and a lacuna, which comprises parts of the T40 and T45 sequences, was formed in the sedimentary succession. This unconformity is the best marker horizon for the Paleocene–Eocene boundary in the Judd Basin area. The depositional environment changed from marine to brackish, lacustrine or fluviatile conditions.

3.3.4 Eocene

As a consequence of the uplift at the beginning of the Eocene epoch, a deep canelised drainage pattern developed in the top of the T40 sediments after the inversion of the Judd Basin. After the retreat of the sea, a limnic sequence, T45, with coal and fluviatile sediments was deposited, which, in the UK part of the Faroe-Shetland Trough, is correlated to the upper part of the Flett Formation. On top of these limnic layers, the transgressive Balder Formation with tuffs and tuffaceus mudstones in the lower part was deposited (sequences 70 to 100, equivalent to T50, Mitchell *et al.* 1993). The Balder Formation that was deposited in most of the North Sea area immediately after the start of the North Atlantic break-up is a clayey highstand deposit (Mudge & Bujak, 1994 and 1996a+b) with some shelf sands. The tuffs in the lower part of the formation are equivalent to the "askelag" of the "moler" deposits in the Danish Basin.

The top of the Balder sequence is characterised by a maximum condensation surface believed to represent the maximum phase of the Ypressian transgression, which also changed the North Sea Basin to fully marine conditions with deposition of up to 400 m of mudstones belonging to the Frigg sequence. In the Judd Basin an up to 700 m thick lower Eocene slope fan succession was deposited.

The London Clay transgression in the southern North Sea is contemporaneous with this event. The western part of the Scandinavian shelf in the North Sea was also transgressed and the Paleocene sandstone sequences belonging to the Lista and Seele formations, as known from the Danish Siri and Nini fields, were overlain by deepwater claystones of the Ypressian Frigg sequence also known as the Horda Formation.

4. Mapping of the Faroes license area

4.1 Seismic database

The present interpretation has been carried out using non-proprietary seismic data acquired by Western Geophysical, Nopec, Geoteam and Digicon.

The following surveys were included in the database:

Western Geophysical:	OF94, 54 lines (whole survey, 6700 km)
Western Geophysical:	OF95, 78 lines (whole survey, 6850 km)
Western Geophysical:	OF95, 13 lines (whole survey, 774 km)
Western Geophysical:	NA74, 5 reprocessed lines
Western Geophysical:	OH74, 4 reprocessed lines
Western Geophysical:	OS73-75, 5 reprocessed lines
Digicon:	DEL93, 19 lines (White Zone tie-lines to W. of Shetland. area)
Digicon:	DGH95, 1 line
Digicon:	GWT97, 20 lines (whole survey, 1500 km)
Digicon:	DGSF97, 67 lines (whole survey, 7200 km)
Nopec:	SFE95, 32 lines and parts of lines
Geoteam :	NWZ96, 27 lines (whole survey, about 2300 km)

This totals just around 27000 km of 2-D seismic lines.

The three 2-D surveys in the southern Faroese area by Geoteam SWF97, Geoteam YMR97 and Digicon DGH95 (except one line) were not available for the present study for technical reasons.

The quality of the lines is normally good down to Top Basalt. The resolution in the Neogene formations is very good. In the Palaeogene formations the resolution is normally good in the Lower Eocene succession, and bad to very bad in the Middle–Upper Eocene and the Oligocene successions due to the disturbance of the layering of the formations which is caused by inversion tectonics, compression and dewatering of the formations.

The basalt succession is well immaged in part of the Faroes area; especially to the NE at the "Escarpment". In the Faroe Bank Basin area the imaging quality is also rather good. In areas with a very thick basalt sequence the resolution is normally very bad.

4.2 Well Database

For this study 13 released UK wells from west of Shetland were available. Nine of these wells (204/19-1, 204/23-1, 204/28-1, 205/14-1, 205/16-1, 206/1-2, 206/2-1a, 214/27-1, 214/28-1 and 214/30-1) have so far been calibrated and sonic and gamma logs could thus be displayed on the DEL93 seismic lines. However, only four of these lines tie into seismic surveys in the Faroes area. Because of the rather bad data quality in the mid–late-Eocene and Palaeocene formations, the well-ties were of limited value.

For six of these nine wells, some stratigraphic information was available; from three wells in Quadrant 204, two in Quadrant 206 plus 214/27-1. No 2-D seismic tie lines were available for the three Quadrant 204 wells. The stratigraphy of the six wells was taken from Knox *et al.* (1997). This stratigraphy is based on normal lithostratigraphical principles and no stratigraphy based on sequence stratigraphical principles was available for the present study.

4.3 The interpretation, purpose and principles

The purpose of the present study was to map the extent of the main basalt and post-basalt Palaeogene formations on the Faroese Shelf. There was, as mentioned above, no well control within the Faroes area. Single tie lines crossing the Corona Ridge into the Flett Basin were available, but they were of limited value because of the lack of detailed stratigraphic data in the wells.

The interpretation was carried out on the Landmark workstation in Jardfrødisavnid in Tórshavn. In the autumn of 2000 additional interpretations on the BP reprocessed and merged 3-D 1999 survey covering the central part of the Judd basin were carried out at GEUS. Normally all horizons were interpreted in minimum (red trough) but sometimes the quality of the seismic was too poor always to follow this principle.

In the central part of the Faroes basalt covered area, the basalt crops out at the seabed or is exposed on land. The location of the basalt outcrops has been marked on all seismic lines. A brown line showing the extent of basalt outcrops at seabed has been constructed and plotted on all maps. The basalt also crops out to the SW on the Faroe Bank, Wyville-Thomson Ridge, a small area of the Ymir Ridge, the Faroe Bank Knoll and Bill Bailey Bank.

In the Faroe Bank Basin, between the Faroe Bank and the Munkagrunnar Ridge, the Neogene and pre-Basalt sequences were also included in the interpretation in order to evaluate the possible prospectivity of the area. The Neogene was also interpreted on the Faroes NE shelf around the Faroe-Shetland Escarpment and in the Faroe Bank Basin to reconstruct the faulting and uplift history of these areas.

The sediments deposited on the Faroese shelf during Palaeogene and Neogene times can be subdivided in seven main sequences which are separated by five unconformities, related to uplift and erosion of the shelf. The presumed geological ages of the horizons and disconformities are listed below. All ages are tentative because no well ties were available on the Faroese shelf for dating. Various informations from some of the wells shown in Figure 51 were used, partly official BGS datings and partly scouting information. Comparison with interpreted seismic sections from the Shetland shelf published by BGS (Stoker *et al.* 1993; Knox *et al.* 1997) have also been carried out.

Interpreted horizon	**Related unconformity**
Top Pleistocene	Seabed
Internal Pliocene	Early Pliocene Unc.
Top Lower Miocene	Middle-Miocene Unc.
Top Paleogene	Base Miocene Unc.
Top Lower Eocene	Base Middle Eocene Unc.
Top Balder Fm.	Int. Lower Eocene Unc.
Top Basalt/Paleocene	Top Basalt/ Top T40

The geological history related to these main phases of structural development is reviewed and discussed below. 15 seismic sections, 50 structural maps and 4 other maps have been attached to this report to describe the geologic development of the Faroes Cenozoicum. A line location map (Fig. 51) is also included.

5. Interpretations in this study

5.1 Interpreted horizons

Seabed
Internal Pliocene unconformity (Faroe Bank Basin and Fugloy Basin)
Middle Miocene unconf. (Faroe Bank Basin and Fugloy Basin)

Top Palaeogene (L. Eocene–Oligocene) unc.
Top Eocene unconf. (Faroe Bank Basin and Munken Basin)
Opal precipitation horizon (Fugloy Basin only)
Middle-Eocene Unconf. 1 (Late Lutetian), Judd basin
Base middle-Eocene unconformity (Near Top Ypressian), Judd Basin
Intra-Low. Eocene Unc. 3
Intra-Low. Eocene Unc. 2
Intra-Low. Eocene Unc. 1
Top Balder Formation
Top Intra Balder (Balder Tuff ?)

Top Basalt
Basalt intra-1 (Faroe Bank Basin only)
Top lower Faroes basalt formation (A horizon ? / Coal bed ?), SE of Suduroy
Base upper flood basalts
Base prograding basalt series (Hyaloclastites)
Base Basalt

Top Lower Paleocene Fan A
Top Lower Paleocene Fans B + C
Top Cretaceous
Intra Cretaceous 1
Intra Cretaceous 2

Most of the interpreted horizons have been depth converted using a simple layer-cake model and constant velocities as no well information was available to calculate depth dependent velocity relations. The velocities used are listed below:

Seawater	1480 m/sec.
Neogene	2000 m/sec.
Eocene + Oligocene	2300 m/sec.
Basalt formations	5000 m/sec.
Paleocene (Faroe Bank Basin)	3000 m/sec.

All maps have been compiled in Landmark Z-map and the colour coding for the colour filled contours has been adjusted manually to give the best possible impression of the structural setting or the thickness variation of the mapped formation. Red colour equals shallow in time/depth maps and thin in isochore maps. Blue colour equals deep or thick formation, respectively.

5.2 Cretaceous and Paleocene in the Faroe Bank Basin and Munken Basin

Five reflections, two of suggested Paleocene and three of suggested Cretaceous age have been interpreted in the Faroe Bank Basin.

No information exists about the sediments below the basalts in the Faroe Bank Channel area. However, some scouting information was available from UK wells south of the Wyville-Thomson Ridge. It is thus expected that the basalts are underlain by a relatively thin Lower Paleocene succession overlying Cretaceous sediments. Two horizons in the assumed Paleocene sequence were interpreted, a horizon named Fan A and another horizon comprising two fans, B+C. Fan A is interpreted as a large basin floor fan, (upper green horizon in Fig. 55 and the maps of Figs. 42, 47 and 49). The fan was deposited possibly from a NE direction. Some amplitude anomalies seem to be present internally in the fan. However, the internal structure of the fan has not been studied in detail. Fig. 43 shows a TWT map of two other possible basin floor fans, B and C. If all the interpreted sedimentary structures are indeed Paleocene fans there must have been exposed land areas not very far away. They could have been fault blocks or ridges forming islands between the Shetland Platform and Greenland.

The reflection interpreted as Top Cretaceous (red on Figs. 55–57) can be mapped throughout the Faroe Bank Basin. The reflection presumably represents a level around Top Cretaceous, but the assumed age is very dependent on the interpretations of the geology to the south of the Wyville-Thomson Ridge.

The base of the basalt (light blue on the Figs 55 to 57) seems to be a rather well-defined event mappaple over most of the area to the south of the Wyville-Thomson Ridge. The Base Basalt can be mapped with confidence. If the basalt turn out to be thicker than interpreted here the exploration potential of the area must be significantly downgraded because of the increased depth to possible reservoir intervals.

Below the near Top Cretaceous reflection two other reflections are mapped named Intra Cretaceous 1 and 2. Other horizons than the two interpreted can lso be mapped.

The late Late Cretaceous is a pronounced global highstand period and sedimentation of mudstones with carbonates probably took place in the whole Faroes area. However, Lower Cretaceous reservoir intervals may be present in the Faroe Bank Channel area. A theoretical possibility also exists for the presence of Turonian source rocks in the area.

5.3 Basalts

The Top Basalt reflection is the most pronounced reflection (dark blue) and is easy to interpret on all the seismic lines used in this study (e.g. Figs 5 and 11). To the SE in the Judd Basin, there is a small area without flood basalt. The outer limit of the basalt-covered area is not very well defined. The reason for that is that the basalt margin probably consists of individual flows, which interfinger with the sediments. Furthermore there is often a large number of dykes and sills in the boundary zone which makes it very difficult to distinguish horizontal basalt layers and tuffs from normal sediments. In this study an attempt was made to map the extension of the basalt towards the SE in the Judd Basin. The boundary is shown on the Top Basalt map (Fig. 5).

Due to the limited time available, it was not possible to interpret all faults systematically at Top Basalt level and to make a complete structural map of the horizon.

On the Faroes shelf, the basalts can normally be subdivided into three sub-layers or facies, e.g. Andersen *et al.* (1998). The relation of this subdivision to the classical subdivision (Waagstein 1988) of the Faroese flood basalt sequence in three series or formations is not yet fully established. The top layer constitutes of flood-basalts (Figs 31, 34 and 36), the middle part consists of foreset beds, a mixture of flood-basalts and hyaloclastites (Figs 32, 35 and 37; & Larsen *et al.* 1999; Kiørboe 1999) all anticipated to belong to the upper and middle Faroese basalt formations. The bottom layer, which seems to consist of a number of discontinuous layers, is interpreted as basalt beds interlayered with tuffs and marine claystones, intruded or underlain by sills and dykes. During the present work an extensive interpretation of the Base Basalt horizon was performed to determine the total extent and thickness of the basalts in the Faroes area (Figs 6, 12 and 18).

The Top Basalt reflection has been interpreted on all the lines included in the project. Both a time- and a depth map was prepared (Figs 5 and 11). The basalt is crops out at seabed inside a line around the Faroe Islands. This outcrop line is printed on most of the maps in this report as a geographic reference. At the outcrop line, the basalt dips away from the Faroes plateau and an increasing thickness of Eocene sediments are present down-dip on top of the basalts. A thick Neogene succession of sediments directly overlie the basalt only on parts of the Fugloy Ridge. The Neogene is present over almost all of the Faroes off-shore but it is very thin or absent in the area between the Faroes coastline and the basalt outcrop line. No or very little Neogene sediments are covering the Basalt on the Faroe Bank. On the Fugloy Ridge only small areas are present where basalt crops out at the sea-bed.

A small mound, the Knoll volcano, is located In the Faroe Bank Channel. The Knoll seems to be a rather young feature and it must have formed after the initiation of the seafloor spreading as part of the latest volcanic activity connected with eruption of the upper basalt formation. It may have formed as late as the start of the compression phase where the Judd Inversion and presumably also the Wyville-Thomson Ridge was formed.

5.3.1 Interpretation of the Base Basalt reflection

An attempt has been made to interpret the Base Basalt horizon over the whole Faroes area. The only exeption is in the areas where the basalts crop out at the seabed. In the latter areas the imaging of both internal basalt reflectors and a possible Base Basalt reflection is extremely poor.

To be able to interpret the base of the basalt, it is important to have an understanding of the internal bedding. The presence of dykes and sills also has a large effect on the seismic signal. The Base Basalt reflection is often difficult to identify because of the shifting lithologies or facies at the boundary. Extensive seismic energy absorption in the basalt package also deteriorates the possibility of getting a good reflection from the base of the basalt. Another problem is that the acquisition parameters of the seismic have not always been optimal for getting a good Base Basalt reflection, and streamer cables have normally been too short to receive maximum reflected energy from below the basalts.

In the Faroe Bank Basin the Base Basalt has been interpreted as an unconformity that can best be identified in the NE part of the basin. Gravity measurements and modelling done by different oil companies (confidential information) confirm this interpretation. Further support is gained from seismic interpretations and well information from British license area to the south of the Wyville Thomson Ridge, (Tate *et al.* 1999).

5.4 Eocene in the Faroe Bank Channel

In the Faroe Bank Channel both a Palaeogene and a Neogene succession overlie the basalts. The Palaeogene is bounded upwards by an unconformity, below which is a relative thin sequence, bounded downwards by another unconformity (orange on Figs 56, 57, 59). The latter unconformity is assumed to represent Base Oligocene/Top Eocene. In the British area, Stoker (1999) has documented a corresponding time equivalent unconformity, the LOEMU.

It can be difficult to distinguish the Top Eocene unconformity from the Top Palaeogene (Top Oligocene) unconformity. Fig. 40 shows the mapped extent of the Top Eocene unconformity in the Faroe Bank Basin and the Munken Basin, which is here called the Base Oligocene reflection. Along the flanks of the basin and channel, a real unconformiity can be identified, but in more distal parts, only a conformity can be seen. Well information from the UK sector confirms that only a thin Oligocene sequence is present in the SW part of the Judd Basin.

The Top Palaeogene unconformity can be related to an uplift of the Faroese platform in mid–late-Oligocene time. The length of the lacuna has not been documented, but information from wells in the Judd Basin indicates that it could be of rather long duration in the area around the Judd inversion structure. The unconformity was probably caused by both non-deposition and erosion. The unconformity is clearly seen in the Faroe Bank Channel, but because of very deep erosion into the Eocene in the Judd Basin, it cannot be traced across the Judd Inversion within Faroes area. Over the central part of the inversion, it coincides with the seabed.

As mentioned above, an Oligocene formation suggested is to be present in the Faroe Bank- and Munken Basin (Fig. 40 and seismic sections Figs 56, 57 and 59). The formation has a thickness of up to 300 m.

5.5 The Top Palaeogene unconformity and Oligocene & Middle–Late Eocene sediments in the Faroe-Shetland Trough

The Top Palaeogene reflection is a very pronounced unconformity, and in most areas it represents the top of the Oligocene. It is here named the Top Palaeogene unconformity because of the problems of distinguishing between Late Eocene and Oligocene sediments in many parts of the Faroes shelf: e.g. over the mid-Eocene inversion structure in the Judd Basin, the Oligocene is totally missing. The Top Paleogene unconformity is developed as a normal unconformity over most of the eastern Faroes Shelf. In the deeper part of the Fugloy Basin another reflection, originating from a diagenetic layer of precipitated opal (Davies 2001) often truncates or overlies the Top Palaeogene unconformity. It is often very difficult to distinguish what is the normal unconformity, and what is a reflection from the opal layer. Reprocessing or redisplay of one of the surveys, NWZ26, has shown that this studys interpretation of the Top Palaeogene reflection in the Fugloy Basin area may be improved.

The opal horizon may have formed during the mid-Miocene period of uplift at the time for the inversion of the Fugloy Ridge, i.e. before a renewed sea level rise (or isostatic subsidence of the Faroes) and deposition of the next sequence of Upper Miocene–early Lower-Pliocene age; time equivalent to the Utsira formation of the Mid North Sea.

It is obvious that the Top Paleogene unconformity in most of the areas is an erosional unconformity. It is easy to trace except in areas with the above mentioned complications or in areas such as e.g. the Faroe Bank Channel, where the Palaeogene unconformity is truncated by the mid-Miocene unconformity or itself truncates the Top Eocene unconformity.

The Top Paleogene unconformity has been mapped over the entire Faroes shelf (Figs 4, 10 and 16). The Eocene–Oligocene sediments constitute the greatest volume of sediments on the Faroes shelf. Their total thickness is up to 2000 m in the Faroe-Shetland Trough (seismic sections Figs 63–67). The original layering of most of the mid-Eocene–Oligocene strata is strongly disturbed, and they are presumably heterolithic sediments. It is believed that the release of water caused by compaction of the sediments has caused the break-up of the original internal bedding. The layering of the Lower Eocene is almost undisturbed (Figs 60–63). No detailed mapping of the mid–late-Eocene succession was attempted for this study.

The Palaeogene succession pinches out towards the inner part of the Faroes shelf where the basalt crops out at the seabed. The pinch out boundary is marked by a brown line in the figures attached to this report. Neogene sediments directly overlie the basalt in a small area to the northeast on the Fugloy Ridge where deep erosion removed the Palaeogene succession (Fig. 4). At the SE tip of the Munkagrunnar Ridge, a thin layer of Eocene–Oligocene sediments covers a small area of the very flat top of the ridge. The Palaeogene sediments normally have a relative steep dip along the pinch out. TWT and depth maps of the Top Palaeogene are attached as Figs 4 and 10.

It is believed that the Late Oligocene lacuna is caused by uplift and change in sea level as documented for the North Sea (Mitchell *et. al.* 1993), where the hiatus in the sedimentary record marks a change from an environment with sedimentation of fine clastic to course clastic sediments. This change probably relates to the impact of the Pyrenean orogenic phase, (Doré & Lundin 1996). The second uplift and folding on the Faroes Platform in mid- Miocene time may be caused by the Alpine orogenic phase or plate reorganizations in the North Atlantic. It is not possible to distinguish between the erosive effects of the two uplift phases within the central Faroes area. Andersen et al. (in press) used volume calculations to try to estimate the possible timing and extent of erosion.

The petroleum potential of the mid–late Eocene succession on the Faroes shelf must be considered to be very limited. The greatest risk is the sealing of the potential reservoirs. The presence of an active petroleum system seems to be documented in more areas by small seismic amplitude anomalies related to minor gas accumulations in the lower part of the Eocene succession. An mid-Eocene fan gas prospect has been drilled in block 214/4 in the UK area.

5.5.1 Alternative Interpretation of the Top Palaeogene

Figs 2, 8 and 14 show an alternative interpretation of the Base Neogene boundary where it is defined at a higher stratigraphic level in order to be contemporaneous with the anticipated second, mid-Miocene, inversion phase of the Fugloy Ridge. This definition implies that the proposed late Upper Oligocene–Lower Miocene sequence (C) shown on the maps (Figs 3, 9 and 15) would be included in the Palaeogene.

Over large areas of the deep Faroes shelf, it could be simpler to use the latter definition for the Neogene–Palaeogene boundary, because the later mid-Miocene unconformity is often a more pronounced unconformity than the Late Oligocene one. In that case the base Neogene is defined as the second unconformity (the dark pink layer boundary on the seismic sections) below the seabed. In deeper water where there is more continuous sedimentation, a correlative conformity must be used as the boundary. It can be seen on Figs 64–66 that, because of the compression-structures, it sometimes can be difficult to trace the Top Lower Miocene reflector from the upper part of the shelf to the deeper areas of the Faroe-Shetland Trough.

Two or three conformable reflectors are present at the stratigraphic level around the Top Oligocene in the deepest part of the Fugloy basin in the northern part of the Faroe-Shetland Trough. As described above, it is not always possible to trace the Palaeogene–Neogene boundary from the southern Faroese shelf and to the northern part of the Faroe Bank Basin with certainty without the help of biostratigraphic datings, irrespective of which definition is chosen.

5.5.2 Mid-Eocene inversion and deposition in the Judd Basin

The Judd Basin was inverted in early Middle Eocene (early Lutetian) time. An unconformity in the succession constitutes an very important change in the basin development; a change from subsidence to inversion. This is the earliest documented change from extensive to compressive conditions of the tectonic regime in the Faroes area since the start of the Atlantic opening. After maximum subsidence of the Judd Basin at the end of the Ypressian inversion took place in the earliest Lutetian. Deposition of a transgressive succession onlapping the inversion structure followed in the Lutetian. Late Eocene (Bartonian to Priabonian) sediments are missing on top of the inversion structure, because non-deposition or erosion were still taking place. One of the transgressive sequence boundaries, mapped as the Internal mid-Eocene unconformity, can be seen (orange-brown) on the seismic lines in Figs 60–63 and the maps in Figs 19 & 26. The formation is present only to the north of the Judd inversion structure. This means that there was an asymmetric basin development to the north and south of the inversion structure. The mid-Eocene succession is thin to the south, but rather thick in the northern part of the Faroe Shetland Trough.

Figs 68 and 69 show the onlapping mid-Eocene succession in the UK part of the Judd Basin. One level was mapped (orange-brown) to illustrate how the transgressive Lutetian wedge was deposited.

It is difficult on 2-D seismic lines in the Faroes area to correlate the mid-Eocene unconformity from the southern flank of the Judd inversion and to the north. Further down flank to the East in the UK area it is simple. More unconformities can be identified at higher levels in the mid-Eocene sequence and it is anticipated that an almost complete lower–mid-Eocene succession is present in the northern part of the Judd and in the Corona basins. The boundary to the Oligocene cannot be precisely identified, but it is anticipated to be located near to the light blue reflection (Figs 68, 69), which appears to be a regional unconformity. On top of this unconformity a series of basin floor fans can be mapped. One of these fans can be seen on the Figures 68 and 69. In the UK area, a bigger stacked fan-complex is present.

5.5.3 Early Eocene in the Judd Basin

A number of Lower Eocene sequences have been interpreted in the Judd Basin. All observed boundaries interpreted are erosional unconformities at least in parts of the area where they was mapped. So they are therefore sequence boundaries.

Lower Eocene sediments are present primarily in the Faroe Shetland Trough, especially in the Judd and Corona Basin areas. The Mid-Eocene unconformity bounds the Lower Eocene upwards. The unconformity is easy to interpret (light green) on the seismic sections, (Figs 59–64). The unconformity has been dated by Hjortkjær (1999) in wells in the Judd Basin to be of early Middle Eocene age. On the Figures 63 and 64 it can be seen that the thickness of the Lower Eocene sediments decreases to the northeast. Therefore the relatively thick Eocene–Oligocene sediments, up to 2000 m, in the northern part of the Faroe-

Shetland Trough are primarily of mid-late Eocene and Oligocene age. On the maps in Figs 16 and 27, it can be seen that the inverted area, with possible present erosion into the Lower Eocene, is located to the east as a prolongation of the southern tip of the Munkagrunnar Ridge.

Five horizons have been interpreted within the Lower Eocene: Balder Tuff?, Top Balder Formation, and three unconformities.

The maps Figs 21–25 show the horizons interpreted internally in the Lower Eocene. The Top Balder Formation (Fig. 24) and the unconformity (Fig. 23) are pronounced unconformities eroded deeply into their substratum. The horizon shown in Fig. 25 is anticipated to be a tuff layer or a coal seam in the lower Balder Formation or uppermost Flett Formation.

5.6 Neogene

The Neogene formations were not a primary interpretation target for this study, so they have only been interpreted so far as they were anticipated to be important for interpretation of the general structural development of the Faroes area. The Palaeogene–Neogene boundary at the Faroes may be defined in two different ways, on a pure biostratigraphic basis or by use of a combined biostratigraphic and structural approach. The boundary is in this study defined primarily on a structural basis as the Top Palaeogene unconformity. A very pronounced structural feature in the Faroes subsurface is the Fugloy Ridge which is thought to be Oligocene– mid–Miocene of age. In late Oligocene and in mid-Miocene time uplift and folding of the ridge followed due to compression. Therefore the Neogene of the Faroes can be subdivided into successions related to different tectonic phases.

The mid-Miocene folding is anticipated to have had the greatest impact on the Faroes, and the land areas are believed to have been uplifted about 1000 m more than the present relief indicates, (Andersen et al. in press; Fig. K).

Another major unconformity anticipated to be of early Pliocene age, can be documented in sediments deposited on the upper part of the Faroes shelf.

Most of the Faroe-Shetland Trough has been a marine area throughout the Palaeogene and Neogene, only the southernpart is known to have been a land area at the transition between Paleocene and Eocene time. Therefore a succession of Neogene sediments is present over most of the Faroes shelf-area. An exception is on top of the Fugloy Ridge and in the inverted area in the Judd Basin, where an early Eocene land bridge existed. A Neogene succession is missing here because of the inversion. Erosion, by bottom currents, was probably accelerated because of the ongoing inversion of the area.

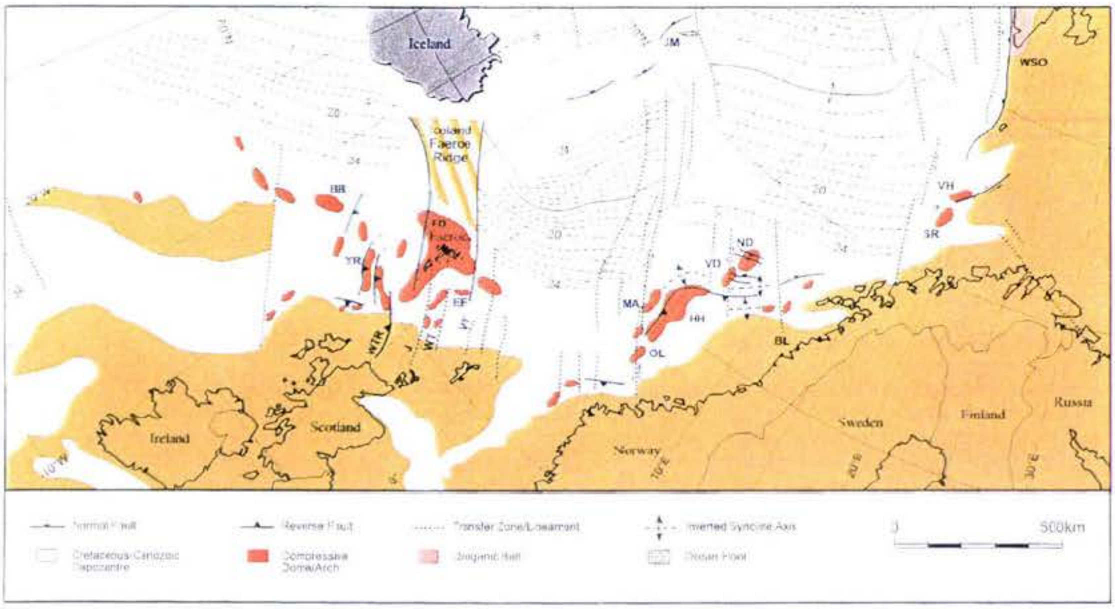

Figure K *Map of intra-Cenozoic inversions and related structures in Cretaceous-Cenozoic depocentres on the Northwest European Atlantic margin. Note the probable relationship between compressive domes and major transfer zones such as the Jan Mayen Lineament, Judd Transfer and Wyville-Thompson Ridge. For abbreviations see Table 1. Doré et al. 1999.*

It is anticipated that the Faroe-Shetland Trough has had its current form during most of the Neogene. The deepening to its present depth has been a process that continued since the Oligocene due to active rifting, opening and deepening of the northern part of the Trough by extension and anticlockwise rotation of the Faroese Platform, which also has caused local inversion along the SE part of the platform along the Wyville-Thomson Ridge.

5.6.1 The early Pliocene unconformity and the overlying late Neogene sequences, D2 and D3.

The uppermost i unconformity nterpreted in this study, Fig. 39, is a reflection, which is presumed to represent a late Miocene–early Pliocene sequence boundary and, which is overlain by one, or in places by two, sedimentary sequences (Fig. L). This reflection has been mapped only in the Faroe Bank Basin Area and to the SE of the Faroe-Shetland Escarpment (Figs 56 and 67), but is believed to be present over greater areas of the Faroes offshore. It can be seen (light pink reflector) on some of the enclosed seismic sections. Stoker (1999, 2002), has documented two corresponding formations, the Middle and Upper Nordland Formations, that overlie an unconformity (INU) at the neighbouring UK area. The two formations are dated to be of late Pliocene–Pleistocene age. The unconformity act as downlap surface for an overlying prograding succession (D2) anticipated to have been deposited as a consequence of (1), a regional early–mid Pliocene uplift event and (2), a later sea-level fall caused by the climatic cooling by the onset of the major glaciations at 3.2–2.8 Ma.

On the Norwegian shelf late Pliocene deposits is documented to be underlain by a thin condensed succession of mid–late Pliocene age. Prograding sediment sequences are present along the flanks of the Munkagrunnar Ridge and to the south of the Fugloy Ridge (Fig. 60), as well as in the northeastern part of the Faroe Bank Basin (Fig. 55). The prograding fan seen in the Figs 61 and 62 also presumably belongs to this time interval.

An upper Pleistocene sequence, D3, is identified only locally on the Faroes shelf and is anticipated to have been deposited after the sea level fall caused by the onset of the maximum glaciation about .8 Myr ago. The Glacial unconformity, the unconformity that bounds downwards for the upper Pleistocene sequence, has not been mapped consistently in this study. Stoker (1999) has documented a corresponding unconformity that downwards bounds the Upper Nordland Formation in the British part of the Faroe-Shetland Trough.

The mid-Pliocene–Pleistocene sequences are normally tectonically undisturbed plane parallel layers, but e.g. slumping also occurs.

In the Faroe-Bank Basin an up to 400 m thick upper Pliocene–Pleistocene succession is found (Figs 55 and 56).

5.6.2 Upper Miocene–Lower Pliocene, mid-Neogene (D1), sequence

The upper Miocene–early lower-Pliocene sequence, was only mapped systematically in the Faroe Bank Basin and the Fugloy Basin (Figs 55, 56, 66 and 67). The boundary to the overlying mid-Pliocene–Pleistocene sequences normally occur as an erosional unconformity, the early Pliocene unconformity (light-pink on the Figs), but at the shelf east–northeast of the Munkagrunnar Ridge it is often a conformity and difficult to interpret consistently.

The Upper Miocene–Pleistocene succession, deposited after the inversion of the Fugloy Ridge in mid-Miocene time primarily constitutes of undisturbed plane parallel layers, but some disturbance of the layering can be seen on the slope and down into the deeper part of the Faroe-Shetland Trough. The succession is considered to correspond with the time equivalent Norwegian Utsira Formation, also deposited after a relative sea-level fall in the mid-Miocene, documented in the mid North Sea area.

Faroe–Shetland Channel, Stratigraphic correlation diagram

Epoch	Time	Present paper: Horizon	Present paper: Sequence	Andersen et al. 2000: Horizon	Andersen et al. 2000: Sequence	Stoker 1999: Horizon	Stoker 1999: Lithostrat
Pleistocene	2	Glacial unc.	D3	CN-050	D3	Glacial unc.	Upper Nordland
Pliocene	6	Pliocene unc.	D2	CN-040	D2	INU	Middle Nordland
Miocene	11 16 24	M. Miocene unc.	D1 C	CN-030	D1 C		Lower Nordland
Oligocene	34	Top Palaeogene unc.		CN-010	B4	LOEMU	Westray Group
Eocene	49 55	Top Eocene Mid Eocene unc. Top Balder Form Top Balder tuff Top basalt	B	CP 100 CP 010	B3 B2 B1		Stronsay Group
Paleocene	65	Base flodd basalts Base Hyaloclast. Base Basalts					ABS 2001

Figure L *The main horizons interpreted in this study are listed. The naming of the sequences follows the naming used in Andersen et al. 2000. The lacunae marked in grey between the sequences are developed differently in different locations. The lacunae are short or missing in the deep-seated areas in the Faroe-Shetland Trough, and longer in more shallow areas on the shelf, e.g. the Fugloy Ridge and on the Judd Inversion structure. The early Mid-Eocene unconformity represents a major lacuna formed as a result of the inversion of the Judd Basin. Modified from Sørensen 2003, in press.*

In the Faroe Bank Basin an up to 500 m thick succession of Upper Miocene–Pliocene sediments are present in two sub-basins (Fig.14). In the Faroe-Shetland Trough two depocentres are located to the East of Suduroy and at the Faroe-Shetland Escarpment. Up to 600 m of mid-late Neogene sediments were deposited in these basins (Fig. 14).

5.6.3 The mid-Miocene unconformity and the Lower Miocene sequence (C).

The second interpreted horizon is a pronounced unconformity in both the Faroe Bank Basin area and on the eastern shelf. The reflection is an unconformity that is interpreted as the Top Neogene before the mid-Miocene uplift of the Faroes area and the related inversion of the Fugloy Ridge took place. The underlying sediments are therefore believed to be primarily Early Miocene in age but probably range down into the Oligocene. The reflection (dark pink reflection) is here named the mid-Miocene unconformity because it can be correlated, using the 214/4-1 well, with a horizon that in the UK area represents a lacuna in the Middle Miocene, (Cloke et. al 2000, Davies et al. 2001). Stoker (1999, 2002) does not document this unconformity in the British part of the Faroe-Shetland Trough. Stoker interprets the lacuna related to the INU to last from late Early Miocene– early Pliocene.

The internal layering of the Lower Miocene is often strongly deformed by inversion movements.

It is not possible to trace the mid-Miocene unconformity from the northern Fugloy Basin to the south and into the Faroe Bank Basin because the Lower Miocene sequence is absent in the middle part of the Faroe-Shetland Trough. Common truncations of the unconformities also complicate the correlation in the area around the Judd inversion structure. The Upper Oligocene–Lower Miocene sequence (C) can be mapped over a large area of the Fugloy Basin, where it was recently drilled by the UK well 214/14-1. Biostratigraphic dating in this well indicate that the sequence may be of primarily latest Oligocene age. Reworking may have taken place and caused problems for the biostrat-datings of the sequence.

Further research must determine how long the mid-Miocene lacuna lasted.

If the lacuna takes up most of Middle Miocene time, this is a new argument for defining the Top Palaeogene at this level and not as done in this study, at the base of the late Upper Oligocene–Lower Miocene sequence.

The mid-Miocene unconformity is mapped (Figs 3, 9, 15) and twt and depth maps have been made.

The up to 250 m thick Lower Miocene succession is only present in the western part of the Faroe Bank Basin, see e.g. Figs 15 and 56. The main depocentre for the Lower Miocene is the central east shelf south of the Fugloy Ridge. A depocentre with 500 m of Lower Miocene sediments is present (Fig. 15) in the basin to the north of the SW–NE striking East Faroe High.

No Neogene sediments are present along the central axis of the Fugloy Ridge. This makes correlation difficult between the Neogene sequences deposited on the two flanks of the ridge. However an attempt has been made, and a sequence in between the Top Palaeogene and a pronounced unconformity in the succession on the North flank of the Ridge is correlated with the Lower Miocene sequence at the south flank of the ridge, see Fig. 72. The Top Paleogene (red) unconformity is an important marker that helps in correlating the Neogene sequences, underlain by Oligocene strata with the characteristic sedimentary structures formed by compaction and dewatering. Because of very deep erosion (Fig. 67) Lower Eocene sediments underlie the Neogene on the north flank of the ridge at the Escarpment.

6. Paleocene Stratigraphy and depositional sequences of the Faroes

The hydrocarbon traps in the Paleocene of the Judd Basin are all stratigraphic. Therefore it is not possible to use only a classic lithostratigraphical approach to subdivide the Paleocene to form a basis for lithological predictions of sands. A sequence stratigraphic approach must be applied. Andsbjerg and Sørensen (1999) have made a preliminary sequence stratigraphic subdivision, based on log interpretation, core descriptions and seismic interpretations of the Paleocene section in 8 wells in the Faroe-Shetland Trough. The stratigraphy (Fig. M) is based on definitions by Ebdon *et al.* (1995), Mitchell *et al.* (1993) and others.

The stratigraphy of the Faroe-Shetland Trough is closely related to the stratigraphy of the neighbouring North Sea. Several authors have dealt with these relations, e.g. Knox (1996) and Neal (1996). Reviews of the definitions of the sequence stratigraphic principles have been made by Van Wagoner et al. (1990), and more recently by Nystuen (1998).

According to Nystuen the basic seismic stratigraphic unit, a *sedimentary sequence*, can be defined as a succession of genetically related strata that can be delineated chronologically and spatially and which possess some characteristic property that defines the sequence as a particular product of the total geological history with respect to events and processes. The sequence is bounded by unconformities as well as conformities, or by combinations of these surfaces.

The sequence consists of different characteristic sedimentary units belonging to different parts of the sedimentary cycle lasting through the lifetime of the sequence from lowstand through a transgressive facies to highstand and further through a regressive phase back to new lowstand conditions. Mitchell *et al.* (1993) of Mobil Oil Ltd have interpreted the unconformities that bound all sequences in the Faroe-Shetland Trough as beeing of type 1.

Mitchell *et al.* (1993) considered that sedimentation during Eocene and Paleocene time was cyclic and they were able to subdivide the sedimentary record into nine Paleocene and six Eocene packages or sequences (Fig. J). Further detailed studies made it clear that some of the sequences were multiple sequence sets.

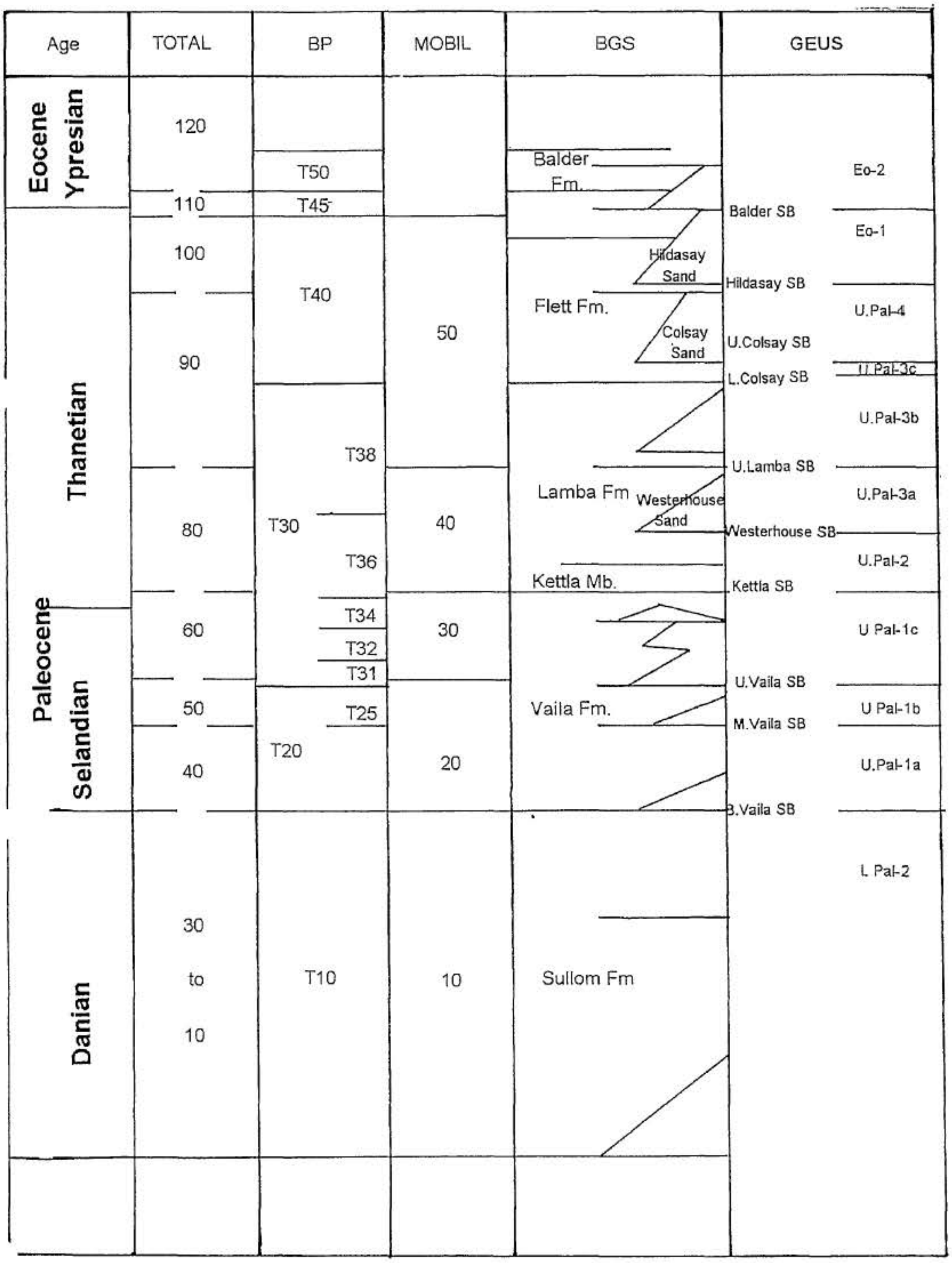

Figure M *Early Paleogene sequence stratigraphic correlation diagram. Andsbjerg & Sørensen 1999.*

Characteristic sedimentary units in the sedimentary cycle or sequence important for petroleum exploration are basin floor "thicks" or fans, slope front fills and incised valley fills all belonging to the lowstand systems tract, which also in some cases can include prograding wedges or fluvial deltaic deposits.

These sedimentary units belonging to the lowstand systems tracts are believed to be a likely and interesting target in hydrocarbon exploration on the Faroese shelf.

Mudge & Bujak (1996a+b) presents an integrated stratigraphy for the Paleocene and Eocene of the North Sea. Four stratigraphic sequences (Ekofisk, Maureen, Lista and Forties), bounded by surfaces of maximum condensation, gamma log maximums, are defined in the Paleocene. In the Eocene 5 stratigraphic sequences (Dornoch, Balder, Frigg, Alba and Grid) are defined. The sequences has been further subdevided, the Paleocene into 7 sequences and subsequences and the Eocene into 10 put together into 3 lithostratigraphic formations, (1), the Dornoch and (2) Balder or Beauly formations belonging to the Moray group and (3) the Horda Fm. or the Lower, Middle and Upper Mousa Fm. belonging to the Stronsay Group, figure N.

In The Faroe Shetland Channel the T45 and T50, the upper part of the Flett Fm. and the Balder Fm are equivalents to Dornoch and Balder Fm. in the North Sea.

It is sometimes difficult to compare exactly the stratigraphy developed by Mitchell (1993) and Ebdon (1995) with the new more detailed BP (Lamers & Carmichael, 1999) and AMG (Naylor *et al.* 1999) stratigraphy.

The lower four sequences or sequence sets 10-40 (Mitchell 1993) in the Lower and Middle Paleocene seems to correspond with the T10, 20 and T30-31-32-34 of Lamers & Carmichael (1999). The Upper Paleocene T35-36-38-40 must correspond with Mitchell's sequences no. 50-60 (+ 70 of AMG) fig. M, O, P.

The sequences No. 70-100 correspond to T45-T50. A biomarker at the base of seq. 100 dates it to be equivalent to the Balder Fm in the North Sea (Deegan & Scull 1977). The associated seismic event, in this study the Top Balder Tuff, is one of the most easy mapable reflectors in the Lower Tertiary section. The top T50 (Top Balder Fm.) is an erosional unconformity.

The horizontal extension and lithological composition of the different Paleocene sedimentary sequences are determined by the Caledonian transtensional tectonic regime, the subsidence of the different sub-basins, and the available sediment supply. Therefore the different sequences are not present over the whole area (Mitchell *et al.* 1993).

In the Faroes area, an almost complete Paleocene succession is presumed to be present in the Judd Basin area, and probably also in the Corona basin further north. It is more difficult to envisage how the anticipated Paleocene in the Faroe Bank Basin is developed.

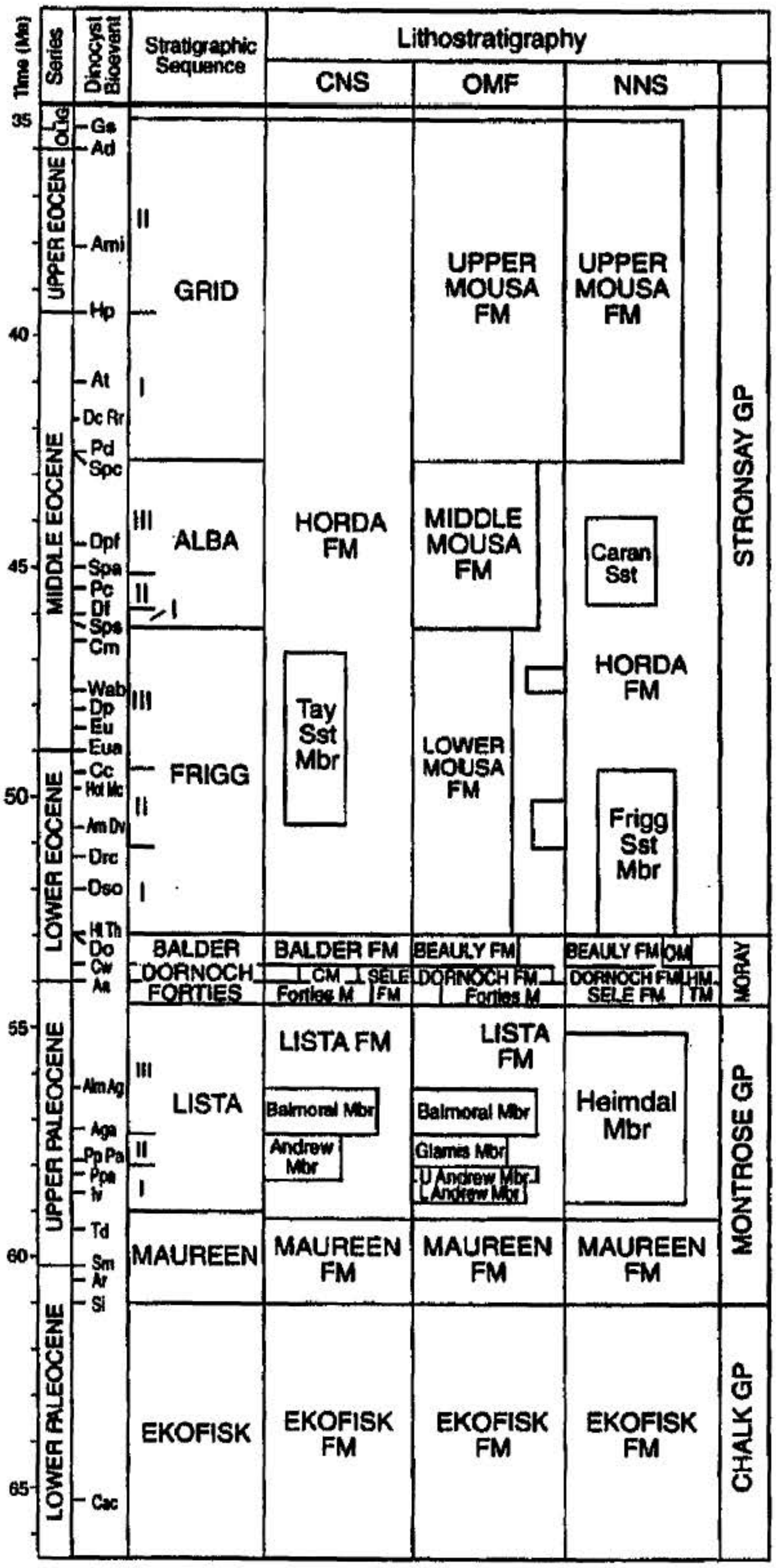

Figure N *North Sea Paleocene-Eocene lithostratigraphy integrated with stratigraphic sequences and bioevents. Mudge & Bujak 1996b.*

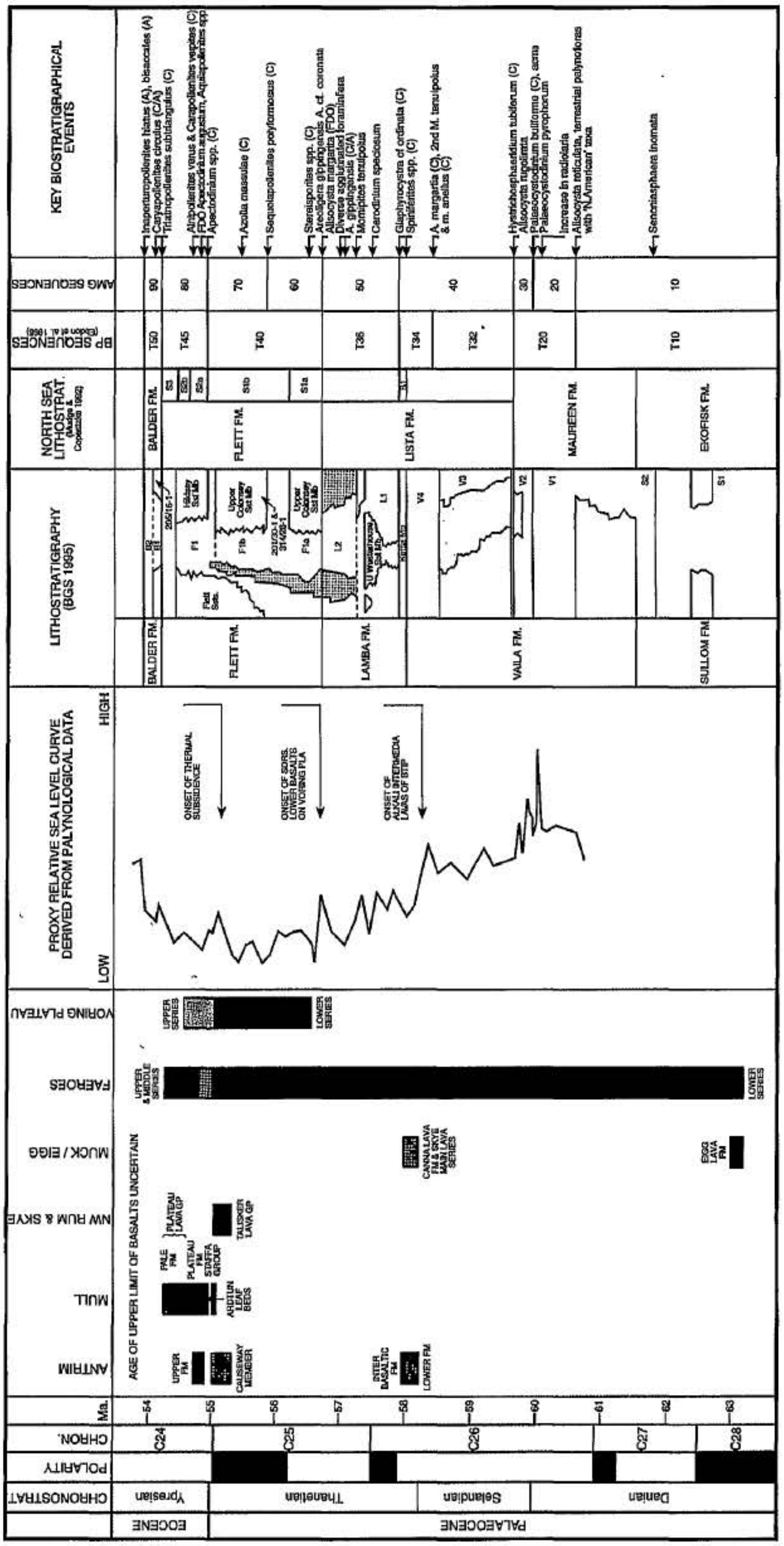

Figure O *Summary of biostratigraphic and sequence stratigraphic data for the British Tertiary Igneous Province, the Faeroe-Shetland Basin, the North Sea Basin and the Faeroe Islands (using the geomagnetic timescale of Cande & Kent 1995). Naylor et al. 1999.*

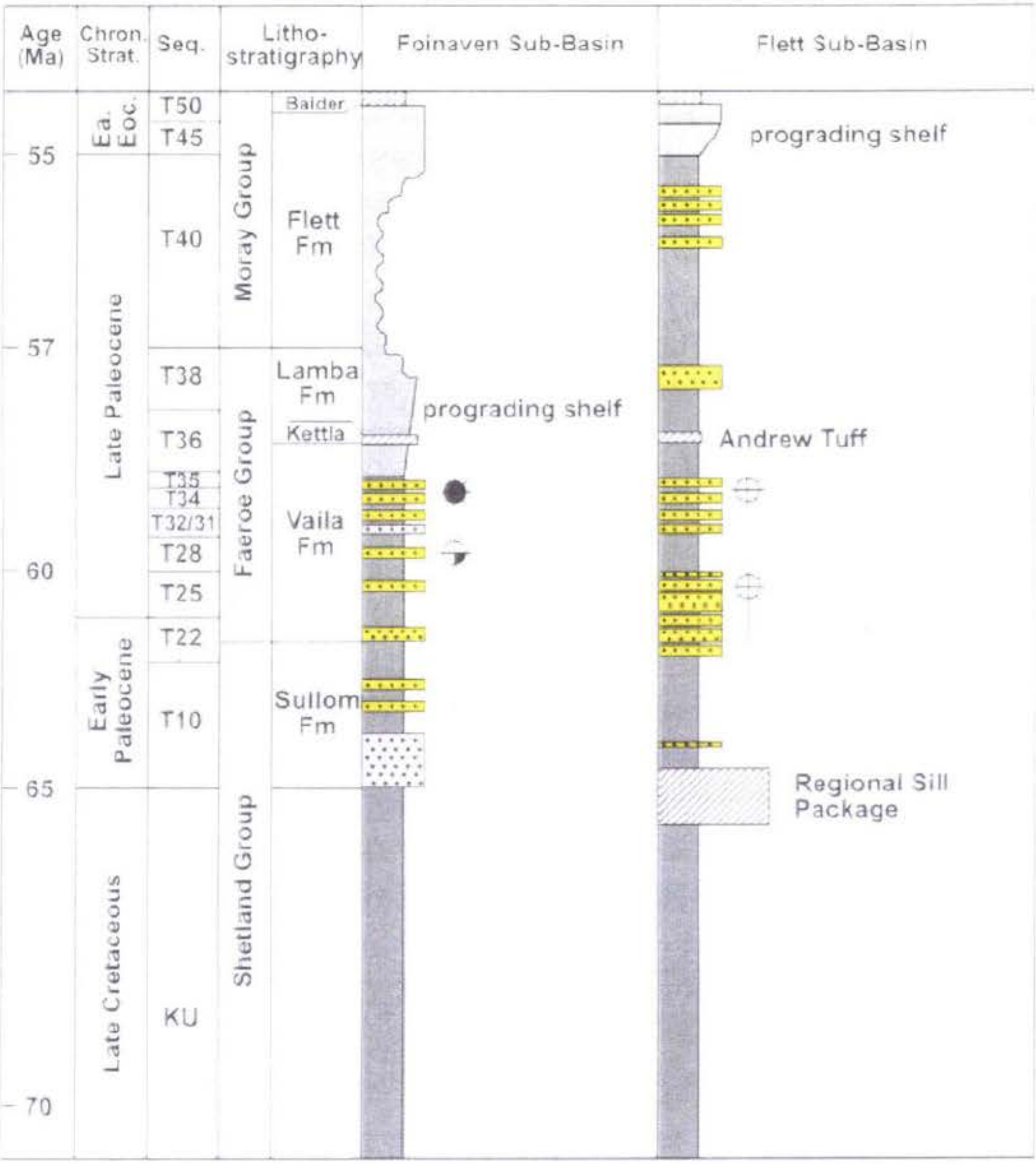

Figure P *Paleocene stratigraphy. Laniers & Carmichael 1999.*

7. Petroleum prospectivity and area assessment

7.1 Introduction

The evaluation of hydrocarbon prospectivity is based on the present seismic mapping supplemented by well information from the UK sector and by confidential oil company data concerning source rock quality and basin modelling results

7.2 Hydrocarbon provinces

The interpreted area can be subdivided into 4 different hydrocarbon provinces:

1: The SE part of the Faroes offshore with the Judd and Corona Basin containing a thick prospective Paleocene succession.

2: The Lower Eocene sequences overlying the Basalts in the Judd and Corona Basin Area.

3: The area to the SE of the Faroe Shetland Escarpment and around the East Faroe High. Sub basalt prospects and Flett or Balder Formation sands are present here.

4: In the Faroe Bank Basin, possibilities exist for the presence of a deep-seated Paleocene play below the basalts.

7.3 Reservoir rocks

Potential reservoir rocks are abundant in the area at a wide range of stratigraphic levels. The most important potential reservoir rocks are Lower Palaeogene sandstones. In the wells in the British Judd and Flett Basins many sandstones deposited in different marine and marginal marine environments are present. Most important are the submarine fan systems including stacked channel sands known from the Foinaven and Schiehallion fields where three major canelised fan-systems are present in the Upper Paleocene succession. Also shallow marine prograding sequences and delta to coastal plain sandstones are found in the Upper Paleocene. In the Lower Eocene succession submarine fan sandstones are common. The sedimentary environments of the Faroese sector are not thought to vary much from those of the British part of the Judd Basin or the Flett Basin. The same types of sandstones are likely to be present. The major risk factors in connection with the reservoir sequences are poor reservoir properties due to the presence of volcaniclastic sediments or cementation due to large burial depth.

Lower Cretaceous and early Upper Cretaceous marine sandstones may also be present. However, these may be too deeply buried to be a primary exploration target.

7.4 Source rocks and maturity

Both Middle Jurassic and Upper Jurassic source rocks are thought to be present. The most important source rock is the Upper Jurassic Kimmeridge Clay equivalent that occur in both "hot" and "cool" facies variations. It may have TOC values of up to 15 % and HI values up to 500 and is thus considered to be a very good source rock (confidential oil company information).

Oil generation may at present take place mainly along the flanks of the structural highs because of too deep burial of the source rock sequences in the basin centres. In the basin centres the Kimmeridge Clay equivalent source rock passed into the oil window during the Late Cretaceous. Further out the oil window was passed during the Paleocene (confidential oil company information). In the central parts of the basins, the source rock must be considered to be overcooked, but gas generation may take place at intermediate levels in e.g. the Judd Basin and probably also in the Faroe Bank Basin

7.5 Play types and leads

The most important play types are related to reservoirs of Late Paleocene–Early Eocene age occurring as slope and basin floor fans, as large feeder channel infill and possibly as channel fill in submarine slump scars. Both structural traps and stratigraphic traps such as fan pinch-outs and combination traps with both a structural and a stratigraphic element may occur. Top seals consist of intra-fan pelagic and hemi-pelagic mudstones, or the reservoirs may be sealed against faults.

Shallow marine, delta-top and coastal plain sandstones of the lowermost Eocene may constitute the reservoir rocks of some post-basalt plays. Major risks are sealing properties of the mudstones, leakage through faults due to inversion and poor reservoir properties caused by possible presence of coals and volcaniclastic sediments or cementation.

Lower–mid-Cretaceous sandstones are often too deeply buried to have retained good reservoir properties. Top seal for Lower–mid-Cretaceous reservoirs can be provided by thick Upper Cretaceous mudstones.

7.5.1 Leads

A number of possible hydrocarbon leads or amplitude anomalies has been observed on the seismic sections interpreted in this study.

Faroe Bank Channel: Probable Lower Paleocene fans. See seismic section (Fig. 55) and the maps (Figs 42, 43, 47 and 49).

Judd Basin: Possible large Upper Paleocene fans. See seismic sections (Fig. 59 and 53).

Possible large Upper Paleocene fans on the SE flank of East Faroe High. See seismic line DGSF 97-064 and the map Fig. 53.

Upper Paleocene fan at the crest of East Faroe High. See Fig. 53.
Sub-basalt amplitude anomaly on top of the structure shown on the seismic section in Fig. 63 and the map Fig. 53.

Top Paleocene channel fill on top of an inversion structure. See seismic sections Figs 59, 60 (shot-points 10000 – 10500 at 2050 msec.) and Fig. 62 (shot points 500 – 1000 at 2000-2250 msec).

Sand filled erosional depression in the Eocene succession. See Fig. 60.

Combined structural/stratigraphic trap with amplitude anomaly at internal Eocene unconformity. See seismic section Fig. 60, shotpoints 12250–12750 at 1680 msec. and at the westernmost edge of map Fig. 21).

Amplitude anomaly with elements of structural closure. See seismic section (Fig. 60, shot points 10000–10600, 1900 msec.

Faroe-Shetland Trough: Gas migration through fault zone in basalts. See seismic section (Fig. 66) and map (Fig. 54).

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9. Figures and maps

9.1 Regional maps, whole Faroes area:

9.1.1 TWT maps :

Fig. 1. *Seabed*

The seabed map has been compiled exclusively by interpretation of the seismic database. The Faroe Islands are surrounded by a shelf; an inner one with basalt at the seabed, and an outer shelf with a water depth up to about 400 m. To a great extent Neogene sediments forms the outer shelf, but Palaeogene sediments are at the seabed in two areas, at the southeastern part of the Faroes shelf and on part of the Fugloy ridge. The form of the present seabed resembles that of the Late Palaeogene. The deepest part is to the north in the Faroe-Shetland Trough, the Fugloy Basin. The Faroe Bank Channel constitutes the other main basin. See also caption for Fig. 7

Fig. 2. *Base Upper Miocene – Pleistocene*

The map represents the base of the Neogene formations, interpreted to have been deposited after the mid-Miocene compression and uplift. The map also shows the approximate maximum extension of the Neogene formations on the Faroese offshore area. Neogene deposits are missing over the Judd inversion to the SE, and in areas over the Fugloy Ridge, where erosion still may be taking place. The Faroe Bank Basin and the Fugloy Basin constituted the deepest basins in mid-Miocene time. See also caption for Figs 8 and 14.

Fig. 3. *Top Lower Miocene, (mid-Miocene Unconformity)*

Early Miocene sediments were deposited primarily to the south of the Faroe–Fugloy Ridge, which were uplifted in Late Oligocene. Lower Neogene sediments therefore consists to a great extent of reworked Eocene and Oligocene sediments. At the SE part of the Faroese area, Lower Neogene sediments may have a greater extension than shown on this map. In the Faroe Bank Basin, Lower Miocene has been mapped only in the southwestern sub-basin. See also caption for Fig. 9

Fig. 4. *Top Palaeogene unconformity; (Top Low. Eocene – Oligocene.)*

The Palaeogene succession which is up to 2000 m thick is the most prominent sedimentary succession of the Faroes offshore except for the basalts. Strong erosion took place after repetitive uplift and folding in mid-Eocene–Miocene time, and all sediments overlying the basalts were completely eroded from the central part of the Faroes platform. The basalt sequences presently cropping out at the seabed were also eroded. Therefore Neogene sediments deposited on the Faroes platform are primarily reworked older deposited on the Faroes platform are primarily reworked older Palaeogene deposits. See also caption for Fig. 10.

Fig. 5. *Top Basalt*

The map shows the depth to Top Basalt in the areas where the basalt sequences are overlain by Eocene to Neogene sediments. Around the Faroe Islands, at the Faroe Bank etc. the basalts outcrop at the seabed. The basalts pinch out to the SE. The pinch-out is drawn in grey colour. The Faroe-Shetland Escarpment, the old coast line, at the time of deposition of the upper basalt formation, is marked by the dark pink line, which bounds the Eocene depocentre in the northern part of the Faroe-Shetland Trough. Note the depression over the sub-basalt Corona basin and the presence of the faults of the East Faroe High, which divide the Neogene deposits (Fig. 13) in two depocentres. The Fugloy Ridge is subdivided into two highs that probably represent volcanic centres or the presence of the Erlend transfer zone. The Knoll Volcano, which outcrops at the seabed, subdivides the Faroe Bank Channel into two basins, the Munken Basin and the Faroe Bank basin. The shallow area between the Bill Bailey Bank and the Faroe Bank is believed to be a contouring artefact due to lack of seismic data. See also caption for Fig. 11.

Fig. 6. *Base Basalt*

The Base Basalt reflection was interpreted only outside the area where the basalt crops out at the seabed, because of very poor reflections from base basalt and pre-basalt levels in areas without sediments at the seabed. Normally no distinct reflection is generated from the base of the basalt. A number of basalt dykes is often present around base basalt level, which can help to identify the location of the basalt/sediment interface. See also caption for Fig. 12.

9.1.2 Depth Maps

Fig. 7. *Seabed*

See caption for Fig. 1. Depth conversion has been performed using a seismic velocity of 1500 m/sec. Lower Eocene sediments is present at the seabed in the Judd Basin at the top of the inversion structure. This indicates that structural movements still go on in the area. The Faroe-Shetland Trough probably still widens and subsides to the North where the depth exceeds 1750 m. Remark the erosional scar on top of the late Neogene sediments at the seabed at the shelf SE of Sandoy.

Fig. 8. *Base Upper Miocene – Pleistocene*

See caption for Fig. 2. An interval velocity of 2000 m/sec has been used to depth convert the Neogene succession.

Fig. 9. *Top Lower Miocene (mid-Miocene Unconformity)*

See caption for Fig. 3. The top of the formation is very uneven in the main depocentre to the south of the Fugloy Ridge because of the strong influence of the underlying East Faroe High, which was faulted and folded in the following mid-Miocene epoch.

Fig. 10. *Top Palaeogene unconformity.*
(Top Low Eocene – Oligocene; LOEMU unconf. equiv.)
See caption for Fig. 4. The top Palaeogene is very deep seated to the NE, about 2700 m, in the centre of the Fugloy Basin, where it is overlain by an up to 1000 m thick Neogene succession. The Palaeogene sediments are absent on the western parts of the Fugloy Ridge. In these areas Neogene sediments overlies the basalts. In a small area to the NE the Palaeogene sediments are completely eroded away and the basalt is outcropping at the seabed. Remark the great depression, East of Suduroy, and the small one further South, which may have been formed in the Middle Miocene in connection with the up folding of the Faroes, and filled up with sediments afterwards in Late Miocene to present time.

Fig. 11. *Top Basalt*
A layer cake depth conversion of the top Basalt horizon has been performed using a velocity of 2300 m/sec. for the Palaeogene and 2000 m/sec for the Neogene succession. In the SW part of the map some contouring artefacts are present, because of lack of data. Note the Knoll volcanic centre in the Faroe Bank Channel and the other two; one outcropping at the seabed, that are presumed volcanic centres on the Fugloy Ridge. The high to the SE of Suduroy is interpreted to be a dome formed by compression. See also caption for Fig. 5.

Fig. 12. *Base Basalt*
See caption for Fig. 6. In the Northeastern part of the Faroes area three depressions are present. Movements along transfer zones may have pulled these basins away from each other, at the Clair transfer zone at the southern limit of the Escarpment, and by Erlend further north. The Westray transfer zone bounds the southern basin to the north. See also caption for Fig. 18.

9.1.3 Isochore maps:

Fig. 13. *Neogene, Isochore*
The Neogene succession was deposited in two main depocentres south of the Fugloy Ridge and in the Faroe Bank Basin. A middle–upper Neogene, primarily prograding succession, are present near to the Faroe Islands east and west of Suduroy. Early Miocene sequences are thickest at more distal locations in the Fugloy- and the SW part of the Faroe Bank Basin. No extensive Neogene successions were deposited over the Judd Inversion and along the crest of the Fugloy Ridge and in parts of the Munken Basin. Faults of the East Faroe High separate the Neogene basins to the south of the Fugloy Ridge (see also Fig. 11).

Fig. 14. *Base Upper Miocene – Seabed Isochore*
The map shows the thickness of the Neogene succession deposited after the mid-Miocene compression.

Figure 15. *Lower Miocene Isochore*

The interpreted Lower Miocene depocentres are located at proximal locations south of the Fugloy Ridge, indicating that the deposition took place after the first uplift of the ridge in Late Oligocene time. In late Miocene to Recent time, the depocentres shifted to more distal locations in the central part of the Faroe-Shetland Trough and east and west of the central Faroese area (see also Fig.14). On the north flank of the Fugloy Ridge, the Neogene formations constitutes a continuous transgressive succession, interrupted by two or three interpreted lowstands. Only the anticipated mid-Miocene unconformity (lowstand) has been interpreted north of the ridge in this study.

Figure 16. *Palaeogene post-basalt isochore (Top Basalt–Top Oligocene),*

An Eocene–Oligocene sediment succession overlies the basalts. The middle–upper Eocene depocentres are located in the Faroe-Shetland Trough, the Faroe Bank Basin and the Munken Basin. The lower Eocene depocentre with an up to 700 m thick succession is located in the Judd Basin and terminates against the Westray splay or transfer zone, which appears as a small ridge further NW. Neogene sediments onlap the ridge. This indicates that there were movements along the transfer zone at the end of Palaeogene time (Late Oligocene). The Lower Eocene succession thins northwards (Figs 63, 64), where the mid-Late Eocene depocentre is located in the Fugloy Basin to the SE of the Escarpment (Figs. 16, 66, 67).

Figure 17. *Post Basalt isochore (Top Basalt to Seabed)*

The major depocentre of post-basalt sediments is the northern part of the Faroe Bank Basin SE of the Escarpment, where more than 2500 m sediments are present. A secondary depocentre is the Faroe Bank Basin with up to 2200 m of sediments. Note the Neogene depocentres to the south of the Fugloy Ridge and the thin sediment succession on top of the Judd inversion structure.

At 61° in the Faroe Bank Channel a small depocentre is present where the Paleocene Corona Basin underlies the Basalts. A pronounced fold belonging to the East Faroe High separates the two Neogene basins to the south of the Fugloy ridge. The Knoll volcano in the middle of the Faroe Bank Channel is also a pronounced feature. Lack of data makes the contouring of the area to the south of the Wyville-Thomson Ridge unreliable.

Figure 18. *Basalt formations, isochore*

The base basalt reflection is not resolved on the central part of the Faroese basalt plateau, however the maximum thickness of the basalt formations at the central part of the platform is estimated to be about 5000 m. The basalt formations generally thin to the SE and pinch out in the middle of the Faroe-Shetland Trough, where e.g. the 205/9-1 well penetrates a Paleocene succession with single basalt beds, tuffs and volcaniclastic sandstones. To the north a thick succession of seaward dipping basalt reflectors is present. An estimate of the position of the base basalt reflection must be extrapolated from areas with greater confidence; from areas where the internal stratigraphy of the basalts including the basal transition zone, to areas with bad resolution. The Lopra well, which is thought to have TD´d near to the base of the basalt succession, and the relative good resolution of the lower part of the basalt succession in the Faroe Bank Basin and on the northwestern part of the Fugloy ridge are key points for the interpretation. A conservative strategy that interprets few structural highs and lows at base basalt level has been adopted. The map shows only a rough estimate of the thickness of the basalt at the Faroes shelf.

9.2 Maps in The Judd Basin part of the Faroe Shetland Channel

9.2.1 TWT maps :

Figure 19. *Internal Mid-Late Eocene Unconformity. 1*
After inversion in the Judd Basin a transgressive wedge of sediments was deposited during the Lutetian. The interpreted horizon is one of the upper boundaries in the Lutetian succession. Because of the internal structure of the wedge, it is difficult to pick the reflection consistent. As far as posible the horizon is picked at the unconformity, but in some areas an unconformity cannot be identified. The interpreted reflection downlaps onto the mid-Eocene unconformity to the north and east, Figs 60–63, and pinches out westwards against the Judd Inversion. The mid-Lutetian succession is interpreted only within the central part of the Judd Basin and the depocentre for the sediments is located to the north and east of the depocentre for the Lower Eocene succession, see e.g. Fig 60. The mid-Eocene succession is disconformably overlain by a new transgressive succession of late-Eocene age, Fig. 62. The mid-Eocene succession can be tied into e.g. the British borehole 99/3. See also Fig. 26.

Figure 20. *Base Mid Eocene Unconformity.*
The horizon can be interpreted within the Judd Basin where the lower Eocene succession constitutes a set of fans. The horizon forms a downlap surface for the overlying mid-Lutetian transgressive wedge. The Eocene is strongly eroded on top of the W–E trending Judd Inversion, Figs 60 and 61. Consequently, Lower Eocene sediments are exposed at the seabed. The early mid-Eocene unconformity represents the maximum subsidence stage in the Judd Basin. The succession was deposited during thermal cooling and subsidence following eruption of the upper Faroes basalt formation. The deposition of the succession is closely related to the deposition of the underlying Paleocene sequences, i.e. the last phase of the Paleocene rifting and subsidence phase in the Faroe-Shetland Trough. Lower Eocene sediments extend outside the Judd Basin, but here only about 200 m is present, whereas up to about 700 m were deposited in the Judd Basin. The unconformity is developed only in the Judd Basin; see seismic lines Figs 59–64. See also fig. 27.

Figure 21.

Internal Lower Eocene Unconformity. 3

The mid-Eocene unconformity is underlain by four sequences, interpreted to be basin slope fans, deposited from a S–SE direction. The fans are often deeply eroded into the underlying fan, and amplitude anomalies that are related to horizontal lithological variations are commonly seen. The fans may be interlayered by claystones of varying thickness, but the sealing of the fans is believed to be bad. Gas chimneys are commonly observed in the fan succession. This indicates the presence of an active petroleum system in the underlying Jurassic–Paleocene succession. Because of the very shallow burial, possible oil accumulations in the fan system may have been subject to biodegradation. Small amplitude anomalies are connected to the horizon, see e.g. Fig. 60 where a closure seems to be present at the northern part of the line. The fans occur only in the central part of the Judd Basin and may be related to the presence of sediment feeder channels related to rivers coming from the Shetland Platform and Scotland. The sequences are bounded downwards by the Top Balder Formation unconformity. The Lower Eocene fan succession is time equivalent to the Horda formation of the Central North Sea.

Figure 22. *Internal Lower Eocene Unconformity 2*

See caption for Fig. 21.

Figure 23. *Internal Lower Eocene Unconformity 1*

See caption for Fig. 21.

Figure 24. *Top Balder Formation*

The Balder Formation extends over the whole Faroes area. In the Judd Basin the Balder Formation is bounded upwards by an unconformity. Outside the area mapped here the Balder Formation is overlain by a mudstone succession with interlayered sands. This succession extends primarily in the middle and northern part of the Faroe-Shetland Trough where big fan complexes are present. The Balder Formation reflects increasing water depth in the UK area where the Formation has been drilled. At the base of the Formation, tuff layers occur together with lacustrine to shallow water deposits, including claystones with coal beds.

Figure 25. *Top Balder Tuff*

This map represents the anticipated Balder tuff deposited at the final phase of the volcanic activity of the upper basalt formation. The horizon cannot be mapped as a continuous horizon over greater areas but seems commonly to consist of downlapping reflections originating from intercalating tuff beds and probably also from coal beds in the lower part of the formation.

The sediments directly overly the basalts belonging to the T45 sequence of the Flett Formation. For mapping purposes the Base of the Balder formation can be interpreted at the base of the Tuffs. However the Balder Formation is defined as a sequence bounded up and downwards by surfaces of maximum condensation. The lower part of the Balder Formation contains prospective sand members in UK waters. The bad resolution of the succession on most of the Faroes area makes it difficult to map the Formation correctly.

9.2.2 Depth maps:

Figure 26. *Internal Middle Eocene Unconformity. 1*
See caption for Fig. 19.

Figure 27. *Base Middle Eocene Unconformity*
The Early Eocene constituted the final period of subsidence in the Judd Basin. The depositional centre for the Early Eocene is located to the SE around the boundary to the UK, where about 800 m of sediment was deposited. The Early Eocene sediments, interpreted to be a succession containing many basin slope fans, has been sourced by rivers coming from the S to SE. The very well-defined erosional boundaries between the fans indicate cyclic sedimentation related to small changes in uplift, erosion and sedimentation of the Faroe-Shetland area. Parts of the Lower Eocene sediments may originate from the highs such as e.g. the Judd High near by. During the Paleocene, sediment entry points shifted along the Shetland Platform margin, from central parts of the Flett basin in mid-Paleocene time to the south and southwest in the late Paleocene. The Lower Eocene of the Judd basin can be considered as the last phase of the sedimentary system that was strongly influenced (cooling phase) by the Icelandic plume. The Lower Eocene must be considered prospective. The greatest risk is the sealing properties of the claystones that interfinger the fans.

9.2.3 Isochore map :

Figure 28. *Lowest mid-Eocene Isochore (Base Middle Eocene Uncformity – Internal mid- Eocene Uncformity 1)*
The isochore map shows the lower part of the Lutetian transgressive wedge. The formation is restricted to a basin to the north of the Judd Inversion structure. The 3-D seismic inline 1900 (Fig. 68) that crosses the inversion on UK area shows the wedge, between the green mid-Eocene Uncformity and the light blue near top Lutetian reflection. See also Figs 60 – 63, the orange horizon is the interpreted intr. mid-Eocene unconformity..

9.3 Internal Basalt Fm. maps and other maps in the Faroe-Shetland Trough

9.3.1 TWT maps :

Figure 29. *Top lower basalt formation? (The A Horizon)*
The map presents an internal basalt reflection. The SW-NE trending low in the middle part of the mapped horizon constitutes the southwestern part of the depression (see also the Top Basalt map Fig. 5) formed to the south of the Fugloy Ridge in Late Oligocene or mid-Miocene time. At the southern edge of the map a northern rim of the dome-formed Top Basalt structure (Fig. 5) is seen. The horizon may represent the A horizon of the Faroese basalt formations, i.e. the coal bed. However, detailed studies and modelling of the structural setting and the internal layering of the basalt must be carried out to evaluate the validity of such a correlation of the interpreted horizon.

Figure 30. *Base Upper flood Basalts*
In this study the basalts of the Faroes shelf have been subdivided into three successions. An upper, sub-aerially deposited flood basalt sequence, underlain by a prograding marine sequence of hyaloclastites, and a transition layer at the sediment basalt interface. The figure shows that greater areas of the eastern shelf were subject to deposition of flood basalts (plateau basalts) during the late Paleocene and earliest Eocene. The horizon is interpreted at the top of the prograding basalt and is a pure facies interpretation. It is not possible to make a stratigraphic subdivision, but it is anticipated that the flood basalts belong to both the middle and upper Faroese basalt formation. The eastern limit is a boundary zone east of which no subdivision of the basalt succession can be made.

Figure 31. *Base prograding basalt series. (Hyaloclastites)*
The base of the Hyaloclastite serie can be interpreted only in the northeastern part of the Faroese area at the Fugloy Ridge and the East Faroe High. The succession seems to have been deposited from eruption centres in the Fugloy Ridge area, but intercalations with basalts coming from the Erlend centres cannot be excluded in the northeastern part of the area, where the hyaloclastites are underlain by a sequence with a more continuous reflection pattern that may be basalt beds originating from Erlend.

9.3.2 Depth maps:

Figure 32. *Top lower Faroes basalt formation? (A horz. / Coal bed ?)*
See caption for Fig. 30.

Figure 33. *Base Upper flood Basalts*
See caption for Fig. 31.

Figure 34. *Base prograding Basalt serie. (Hyaloclastites)*
See caption for Fig. 32.

9.3.3 Isochore maps :

Figure 35. *Upper flood Basalts*
See caption for Fig. 31.

Figure 36. *Prograding Basalt serie (hyaloclasitite serie)*
See caption for Fig. 32.

Figure 37. *Upper + middle Faroes basalt formations.*
The total thickness of the interpreted upper + middle basalt formation thins from about 2000 m where the basalts crops out at the seabed east of Suduroy to 1500 m further to the SE. The thickness of the probably corresponding formations on the Faroe Islands is about 1900 m. The formations extends outside the area where they have been mapped in this study, but interpretation of the base of the formations becomes more and more uncertain. See also caption for Fig. 30.

9.4 Other maps in The Faroe Bank Basin & Channel area :

9.4.1 TWT maps :

Figure 38. *Top Lower Miocene (mid-Miocene Uncformity)*
The earliest Neogene succession, anticipated to be of Lower Miocene age, was in the Faroe Bank Basin only deposited in the deepest southwestern basin. The succession is clearly bounded up- and downwards by unconformities. See also text-fig. L.

Figure. 39 *Near Top Miocene, (Internal Pliocene Unconformity, INU Equivalent)*
Upper Miocene sediments are present in both subbasins to the SW and NE in the Faroe Bank Basin. Lower Miocene sediments occur only in the southwestern basin. The sediments are regularly layered and only slightly disturbed by compression or sliding, Fig. 56. The two sequences are overlain by an undisturbed upper Neogene sequence, Fig. 56, downward bounded by an unconformity anticipated to be equivalent to the INU (Stoker 1999).

Figure 40. *Base Oligocene Unconformity.*
An unconformity interpreted to be of Oligocene age bounds the Eocene sequence upwards. The Eocene sediments in the Faroe Bank Basin are influenced by compression and thin against the basin flanks, Fig. 56. The Eocene sediments are anticipated to have covered the Wyville-Thomson Ridge

and the Faroe Bank. All younger sequences onlap the Top Eocene along the Wyville-Thomson Ridge. Therefore the Late Eocene–Early Oligocene compression phase is considered to be a main event in the geological development of the area. The Oligocene sediments may consist mainly of reworked Eocene. Later, after a new Late Oligocene compression phase and development of the main Top Palaeogene unconformity, the three Neogene sequences was deposited. The anticipated Oligocene sequence has been mapped in the Faroe Bank Basin and in the Munken Basin. No Oligocene sediments are present in most parts of the Judd Basin to the E, because of inversion of the basin in mid-Eocene.

Figure 41. *Basalt intra_1 member*
More internal basalt horizons can be mapped in the basalt succession of the Faroe Bank Basin. Also a reflection anticipated to be the Base Basalt can be interpreted here. The basalts in this area may differ in internal layering and composition from other parts of the Faroes basalt plateau. The better transmission of energy through the basalts in this area can probably be related to a lack of interlayered tuff beds between the basalt beds. The massive middle Faroese basalt formation may dominate at the southwestern part of the Faroes area, as the Faroe Bank Basin.

Figure 42. *Top Int. Paleocene Fan A*
The basalts in the Faroe Bank Basin are anticipated to be underlain by a Paleocene and a Cretaceous succession as in the Northern Rockall Trough to the south of the Wyville-Thomson Ridge, (Tate *et al.* 1999). In the Paleocene, some structures, interpreted to be slope fans, have been identified. Three fans have been mapped, the present one and the two shown on Fig. 43. The proposed fans are underlain by a succession with an apparently parallel layering, which may be a Cretaceous claystone sequence.

Figure 43. *Top Internal Palaocene Fans, B and C*
See caption for Fig. 42

Figure 44. *Top Cretaceous ?*
The map shows the horizon interpreted as the base of the succession containing the slope fans, Figs 42 and 43. It may be Top Cretaceous.

Figure 45. *Internal Cretaceous 2*
This and the following fig. presents internal horizons in the anticipated Cretaceous sedimentary succession.

Figure 46. *Internal Cretaceous 1*
See caption for Fig. 45.

9.4.2 Depth maps :

Figure 47. *Top Int. Paleocene Fan A*

See caption for Fig. 42

Figure 48. *Top Cretaceous ?*
See caption for Fig. 44

9.4.3 Isochore maps :

Figure 49. *Internal Paleocene Fan A, Isochore*
See caption for Fig. 42

Figure 50. *Paleocene, Isochore*
Thickness map of the interpreted Paleocene succession. The Paleocene of the Faroe Bank Basin may constitute part of an undocumented western shallow extension of the Judd Basin, bounded southwards by the Wyville-Thomson Ridge. Another interpretation is that it constitutes a new subbasin which may extend further west or southwards below the basalt covered Faroe Bank.

9.4.4 Further maps :

Figure 51. *Shotpoint map, all lines in project*

Figure 52. *Location of seismic lines (Figs 55–67) attached to this report*
The NE-SW trending seismic lines Figs 68 and 69, crossing the Judd inversion structure on UK sector has not been plotted on this map for technical reasons, see Fig 70 for location of these lines.

Figure 53. *Paleocene amplitude anomalies or possible Leads in the Judd and Corona basin area.*
Amplitude anomalies observed by the interpretation was marked on the two S.P.-maps Figs 53 and 54. The anomalies can represent soft kicks generated by the presence of reservoired oil or gas, or occur from hard basalt beds, tuffs or volcaniclastic sandstones.

Figure 54. *Eocene amplitude anomalies or possible Leads*
Amplitude anomalies in the Lower Eocene succession of the Judd Basin, and in the probable Flett or Balder Formation overlying the Basalt formation.

9.4.5 Regional seismic lines and location map:

Figure 55. *OF95-135.*
NW-SE line along the flank of the Munkagrunnar Ridge in the Faroe Bank Basin.

The basalts are underlain by an about 600 m thick anticipated Paleocene sequence (light blue to red interval) with amplitude anomalies in the basal part. The top basalt reflection (dark blue) is very rough which presumably reflects the short distance to the eruption centre SW of Suduroy. The Base Basalt (light blue) is interpreted as an unconformity which correlates in depth with the base of the basalt south of the Wyville-Thomson Ridge. The dark green reflection represents the top of the interval with the interpreted Paleocene fans. The red line is the presumed Top Cretaceous.

Figure 56. *OF95-105.*
N-S line crossing the Wyville-Thomson Ridge and Faeroe Bank Basin, showing probable sub-basalt reflections (Cretaceous–Lower Paleocene) and Neogene formations.

The N-S profile through the western part of the Faroe Bank Basin shows the basalt formation underlain by a suggested Paleocene–Cretaceous succession. The overlying Eocene–Oligocene succession shows internal unconformities that reflect uplift and compression phases in Middle Eocene–Oligocene time. Oligocene sediments are anticipated to occur only in the central part of the basin. The Neogene is split into three sequences by unconformities, where the upper one constitutes a downlap surface for the prograding Pliocene deposits to the NE in the Basin. The middle sequence was deposited during relative lowstand conditions. The underlying sequence of proposed Early Miocene age has a greater horizontal extension, which indicates deposition before the anticipated uplift and up-faulting phase of the Faroe Bank and the Wyville-Thomson Ridge during mid-Miocene.

Figure 57. *OF95-127.*
NW–SE line in the Munken Basin showing a Paleocene and Cretaceous sediment succession below the basalt. The succession can be tied to wells in the Judd Basin. The line is located along the north flank of the Knoll volcanoe and shows the characteristic dome formed structure of the volcano (Top Basalt reflection). The Base Basalt may be shallower to the SE than the interpretation shows. Base Oligocene and Top Palaeogene (see the erosion scar) is also interpreted.

Figure 58. *OF94-22A.*
Seismic line crossing the Munkagrunnar Ridge. Dipping basalt beds can be seen at the seabed at the NE flank of the Ridge. a set of transverse and reverse faults is present on both sides of the Ridge. The green interpreted line is the probable reflection from the transition between the lower and middle Faroese basalt formation; (the coal horizon).

Figure 59. *DGH95-07.*
SW-NE line through the the Munken Basin and the Judd Basin. The line shows the inverted Eocene basin bounded upwards by the Mid-Eocene unconformity.

The Eocene–Oligocene Munken Basin constitutes a shallow basin underlain with basalt and a Cretaceous–Paleocene succession. The mid-Eocene sediments, bounded downwards by a unconformity, pinch out against the Lower Eocene sequence in the Judd Basin, which was inverted about 700 m early in mid-Eocene time. A condensed Neogene succession overlies the Oligocene sequence in the Munken Basin. The basalt formation pinches out near to the Paleocene–Eocene boundary at the SW flank of the Judd Basin. The Top Balder reflection is a pronounced unconformity. The tuff layer in the upper part of the T36 sequence is marked in the Paleocene succession

Figure 60. *OF94-21A.*
NW–SE line through the southern part of Judd basin showing probable leads in Lower Eocene and in Paleocene T32, T36 and T40 sandstones.

The Lower Eocene succession in the NW part of the Judd Basin is underlain by a basalt sequence, which pinches out against the SE (see also Fig. 4). The Paleocene succession has a braided stream pattern at the top. Below are the T38–T40 sequences that downlap onto the Top T36 sequence, which contains a pronounced tuff layer below the upper claystone subsequence. A thin Danian (T10) sequence drapes the Mesozoic fault blocks at the base of the Paleocene. Two horizons with amplitude anomalies originating from volcanics or gas-sands are seen internally in the Paleocene. The prograding mid–late Pliocene sequence (see also Fig. L, sequence D2) can be seen to the NW

Figure 61. *DGSF97-100.*
The NW–SE trending line shows how the Lower and Middle Eocene Formations of the Judd Basin thin against the Munkagrunnar ridge. Strong erosion is seen in the area with the inverted Paleocene–Lower Eocene Judd Basin. A prograding Pliocene fan, downlapping onto the Early Pliocene unconformity (INU), (not interpreted), is seen in the upper part of the section. The (un)conformity on top of the prograding fan is the Glacial Unconformity.

Figure 62. *OF96-232*
W–E line in the Judd Basin showing inverted Eocene sequences and unconformities including the Base Mid-Eocene unconformity. A prograding Pliocene fan (same fan as in Fig. 61) downlap the Early Pliocene unconformity is present in the upper part of the section. Note also the Lower Eocene unconformities, e.g. the pink top Balder Fm. The Base Basalt reflection is hardly interpretable. The Paleocene deposits is present below the basalts

Figure 63. *OF95-124A.*
SW–NE line showing the Eocene section and its thinning to the NE against the proposed limit of the Judd Basin at the Westray transfer zone.

Profile showing the NE flank of the Judd Basin at the transition to the Corona basin. The base mid-Eocene Unconformity, the Top Lower Eocene, grades into a conformity outside the inverted Judd basin, where it often forms a very discontinuous reflection like other internal Eocene reflections in the mid–late Eocene succession. Many dykes are present in the subbasalt section in the Corona basin, which makes interpretation of the Base Basalt reflection uncertain. The Westray transfer zone separating the Judd and Corona Basins is developed as a small ridge further to the NW of the present location. No reflection representing the Eocene–Oligocene boundary can be interpreted on this section.

Figure 64. *OF95-122.*

SW–NE Line showing the Westray Splay transfer/inversion zone in the northern part of the Judd Basin. The visible stratification in the Lower Eocene disappears and strongly disturbed Eocene continues to the North. The inversion is very late, Neogene to present time, and the Neogene sediments can be seen to onlap the Eocene Ridge. The Top Paleogene reflection is masked by reflections from layers enriched with precipitated opal. Interpretation of the Top Palaeogene is therefore uncertain in the northeastern part of the profile. At the Base Basalt level more reflections originating from different dykes are present, which makes exact interpretation of the basalt to sediment interface difficult.

Figure 65. *OF95-153.*

NW–SE line over the East Faroe High complex showing the compressed basalt formation with probable lead locations below the basalts.

The profile crosses the northern part of the East Faroe High. The Paleogene sequence is overlain by a complex Neogene succession to the SE, which may include both early and late Neogene sequences. A late Neogene sequence idownlap onto the early Pliocene unconformity (INU) to the NW, where they are underlain by one or two other Oligocene–Neogene sequences.

Figure 66. *GSF97-009.*

SW–NE line showing the Basalt Escarpment and a gas anomaly in Early Eocene Flett or Balder Fm. The gas trap may be charged along faults through in the basalt.

The Faroe-Shetland Escarpment was formed as a coastline and later deformed by normal faulting and compression in Late Palaeogene and Neogene time. The upper flood basalt series are seen to overlay a prograding hyaloclastite sequence internally in the basalt succession. A layer with discontinuous reflections originating from basalt flows, sills or tuff layers are interpreted between the hyaloclastites and the anticipated underlying Paleocene – Cretaceous succession. A typical Eocene–Oligocene succession, characterised by discontinuous reflections, is overlain by a Neogene succession that is subdivided into three sequences by the mid-Miocene and early Pliocene unconformities. A reflection, thaught to originate from an opal–quartz precipitation/transition zone, is seen strongly to mask the real Top Paleogene reflection at Top Oligocene level. Disturbance of the two Miocene sequences indicates late Miocene to Pliocene faulting and inversion movements.

Figure 67. *WZ96-117.*

NW–SE line over Fugloy Ridge and down into the deep Tertiary basin with proposed Oligocene beds.

The Fugloy Ridge was up-faulted in Late Oligocene–Miocene time, where extensive erosion of the Eocene succession also took place. The most complete post basalt succession on the Faroes area was deposited to the SE of the ridge. An Eocene–Oligocene succession characterised by a discontinuous reflection pattern is overlain by three Neogene sequences. A reflection from the assumed opal precipitation horizon is also seen. The mid-Neogene sequence (D1a+b) of presumed late Miocene–early Pliocene age is deposited under regressive conditions after up-faulting of the Fugloy Ridge. The overlying transgressive sequence (D2) is tentatively correlated to the prograding mid-late Pliocene sequence present in the basins east and west of Suduroy. The underlying sequence (C) is documented to be of Early Miocene age by tie to 214/4-1. Only one reflection, which via jump correlation is interpreted to represent the mid-Miocene unconformity, has been interpreted on the north flank of the Fugloy Ridge. Small bright spots are identified at Balder Formation level. The basalts can be subdivided into an upper flood basalt succession underlain by a hyaloclastite succession. A proposed transition layer consisting of sills, tuffs, and different basalt flows is present at the base.

Figure 68. *BP-3D Reproc1999, inline 1900.*
SW–NE line crossing the inverted Paleocene Judd Basin. The basalts are overlain by a variable succession of claystones, sands, tuff and limnic organic–rich sediments including coal beds, belonging to the Flett and Balder formations. A sequence of Ypressian age, equivalent to the Frigg formation is deposited between the Top Balder and the mid-Eocene unconformities. It is overlain by a strongly transgressive mid-Eocene succession bounded upwards by a new unconformity (light blue) which may represent the top Middle Eocene. A big slump that may be of late Eocene age rests on the unconformity. A thin sequence, thaught to be of Oligocene age, can be interpreted in the upper part of the Palaeogene succession.

Figure 69. *Tie line from well no. 204/28-1 into the BP-3D reproc. 1999 survey.*
The tie line shows the thick Paleocene succession overlain by the Balder Formation (no basalts are present) and the Ypresian succession; the latter is bounded upwards by the mid-Eocene unconformity (yellow). The red reflection represents the Top Palaeogene, dated to be Top Oligocene in the well 204/28-1. Consequently only a thin Oligocene sequence overlies the slump (between the two blue reflections). A Neogene succession, Miocene–Recent, constitutes the upper layers in the wells.

Figure 70. Line location map for Figs. 68 and 69.

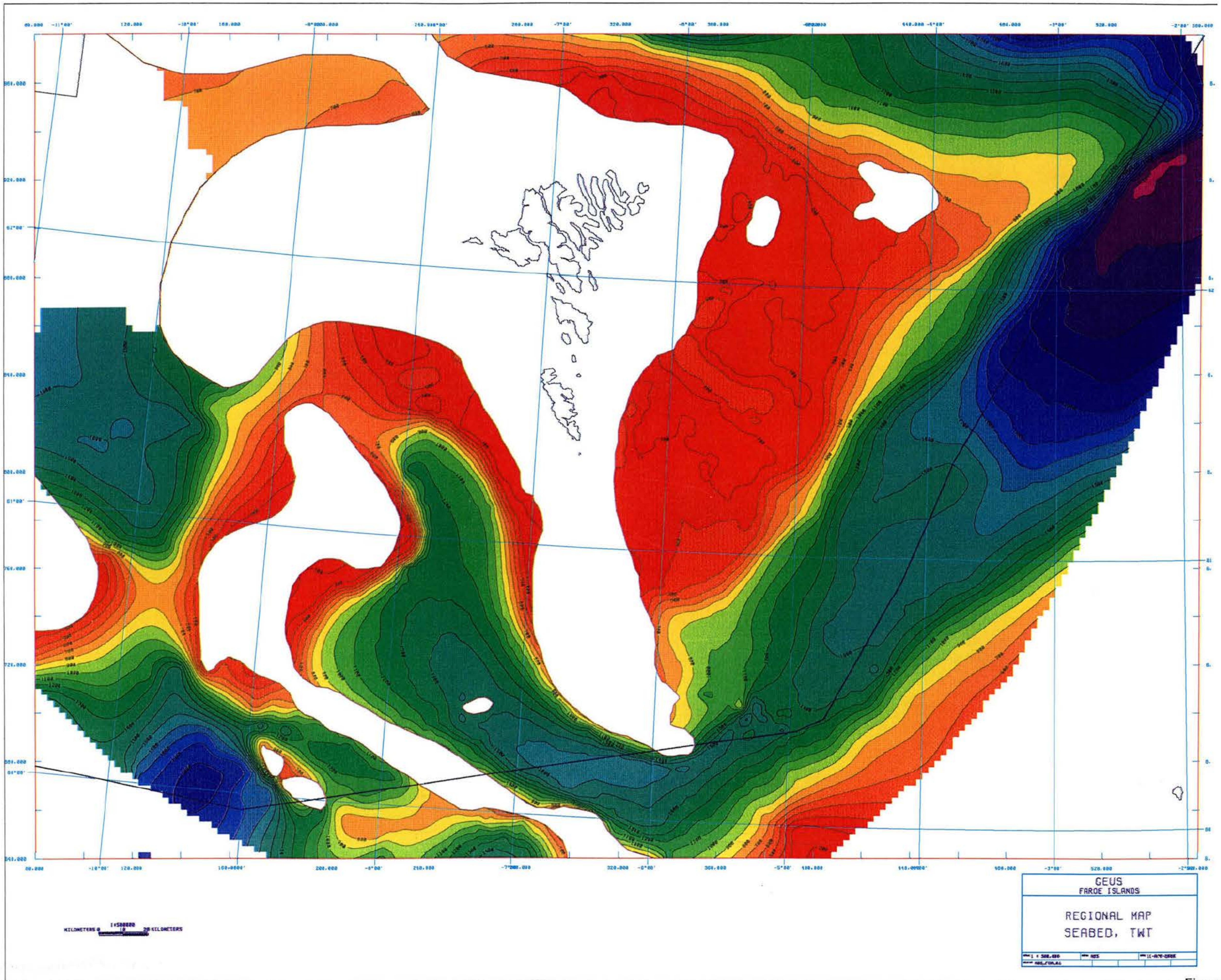


Figure 1

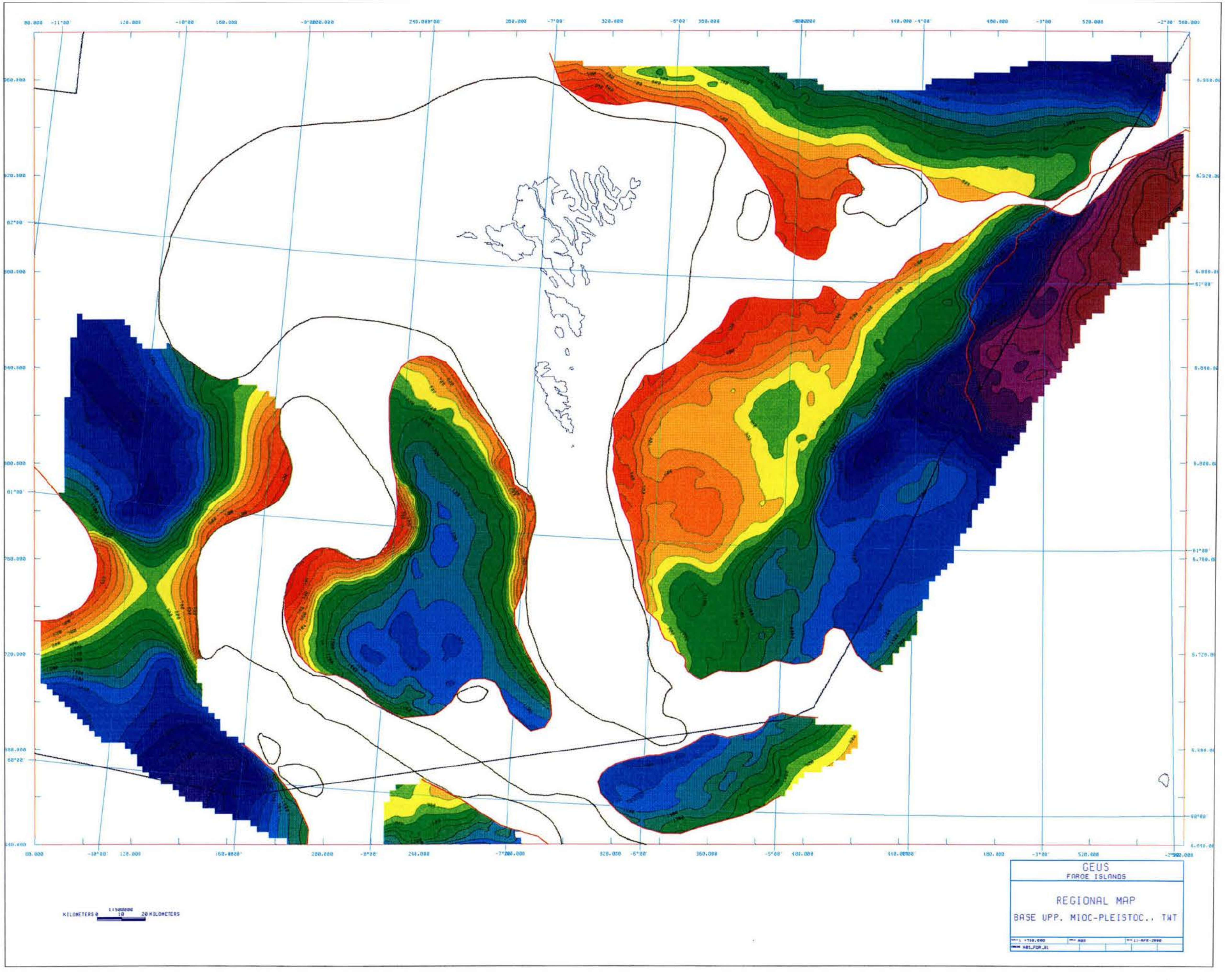

GEUS
FAROE ISLANDS
REGIONAL MAP
BASE UPP. MIOC-PLEISTOC.. TWT
KILOMETERS 0 10 20 KILOMETERS

Figure 2

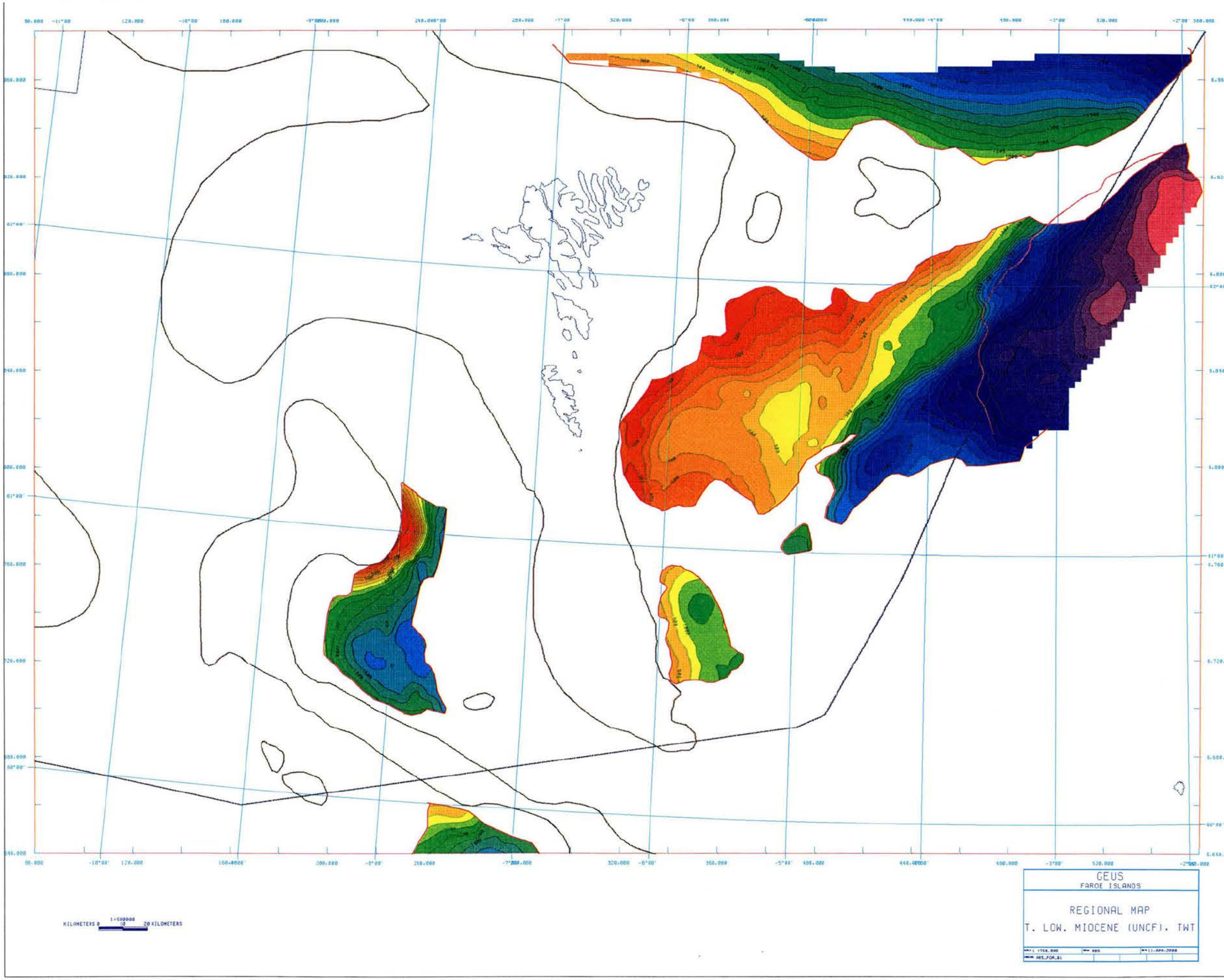
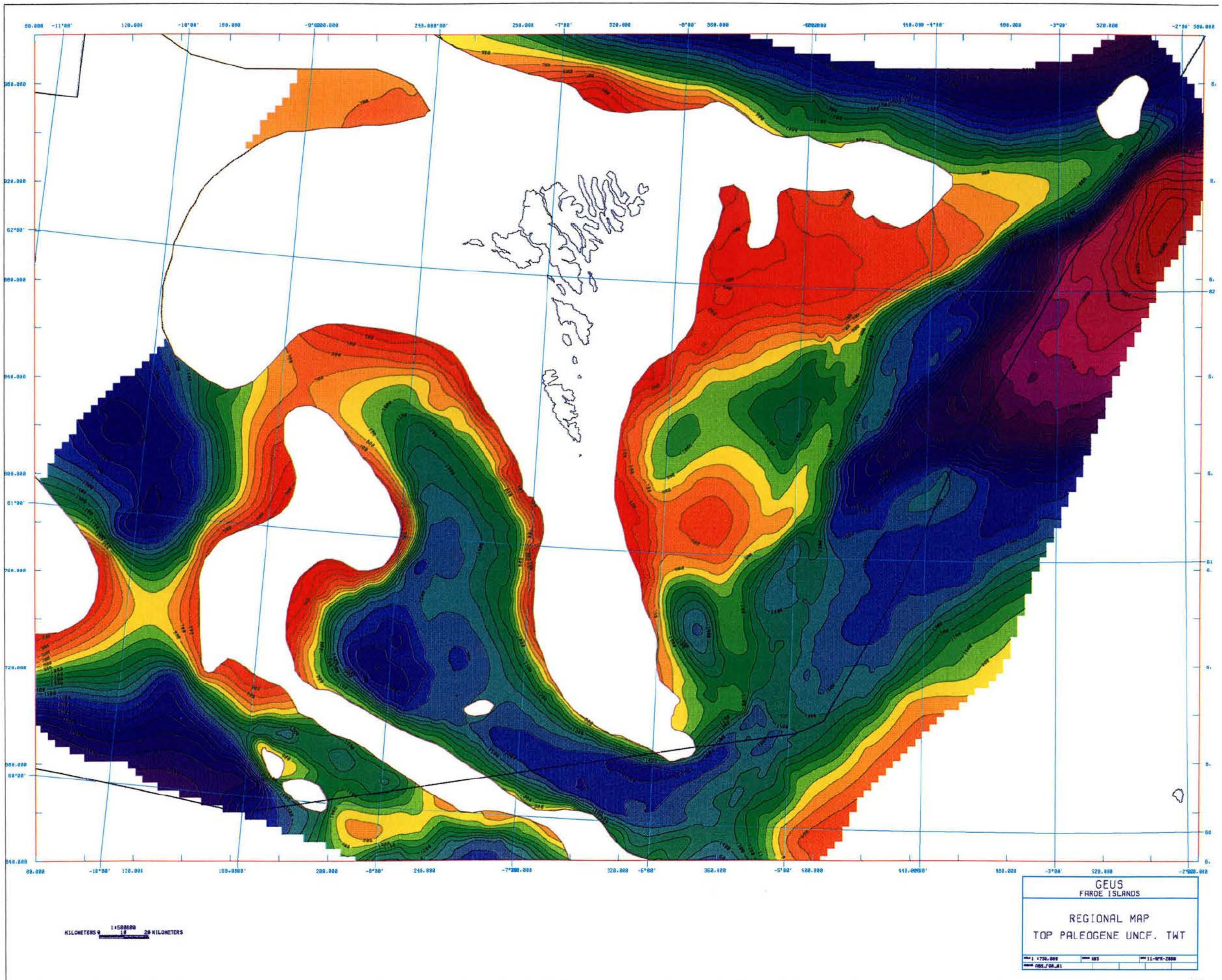


Figure 3



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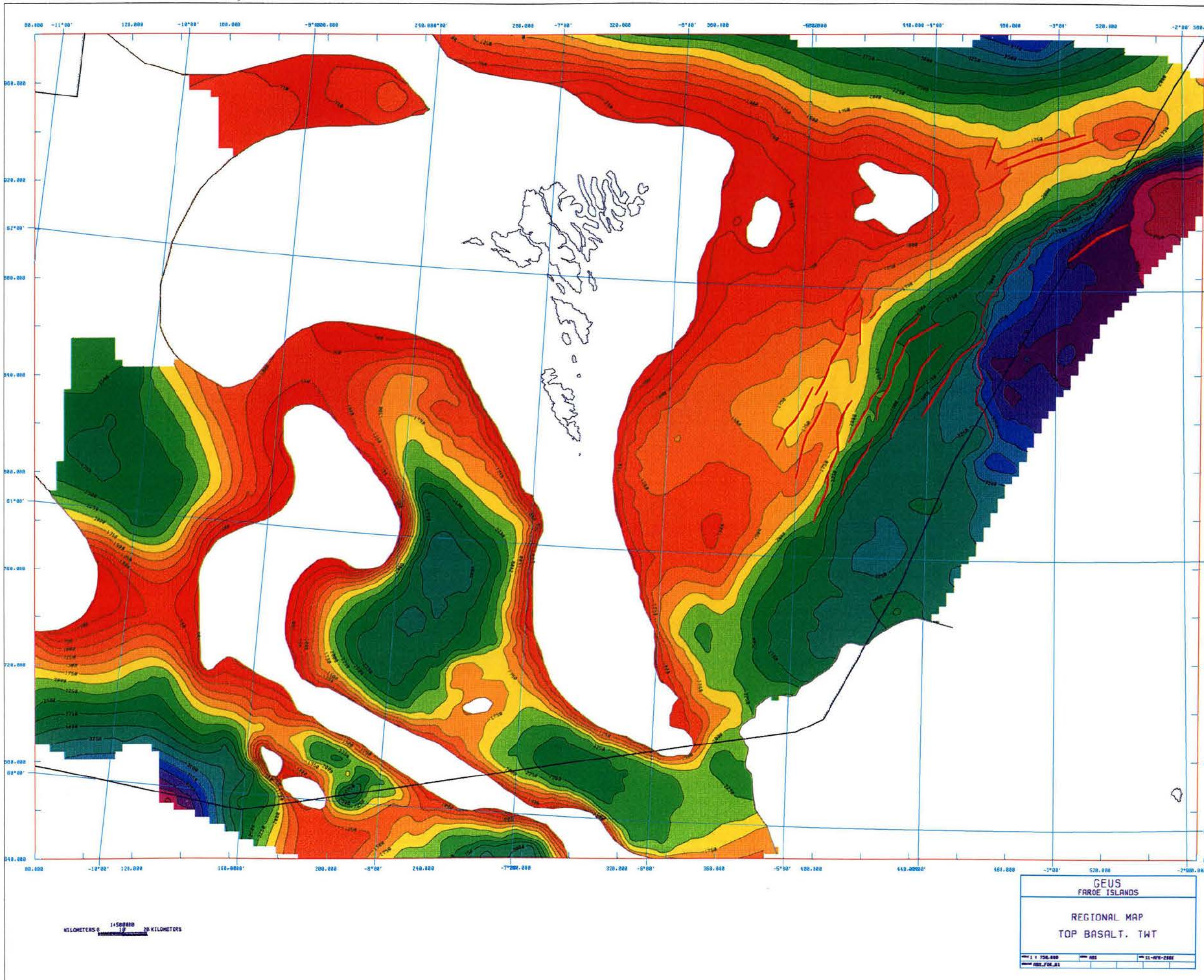


Figure 5

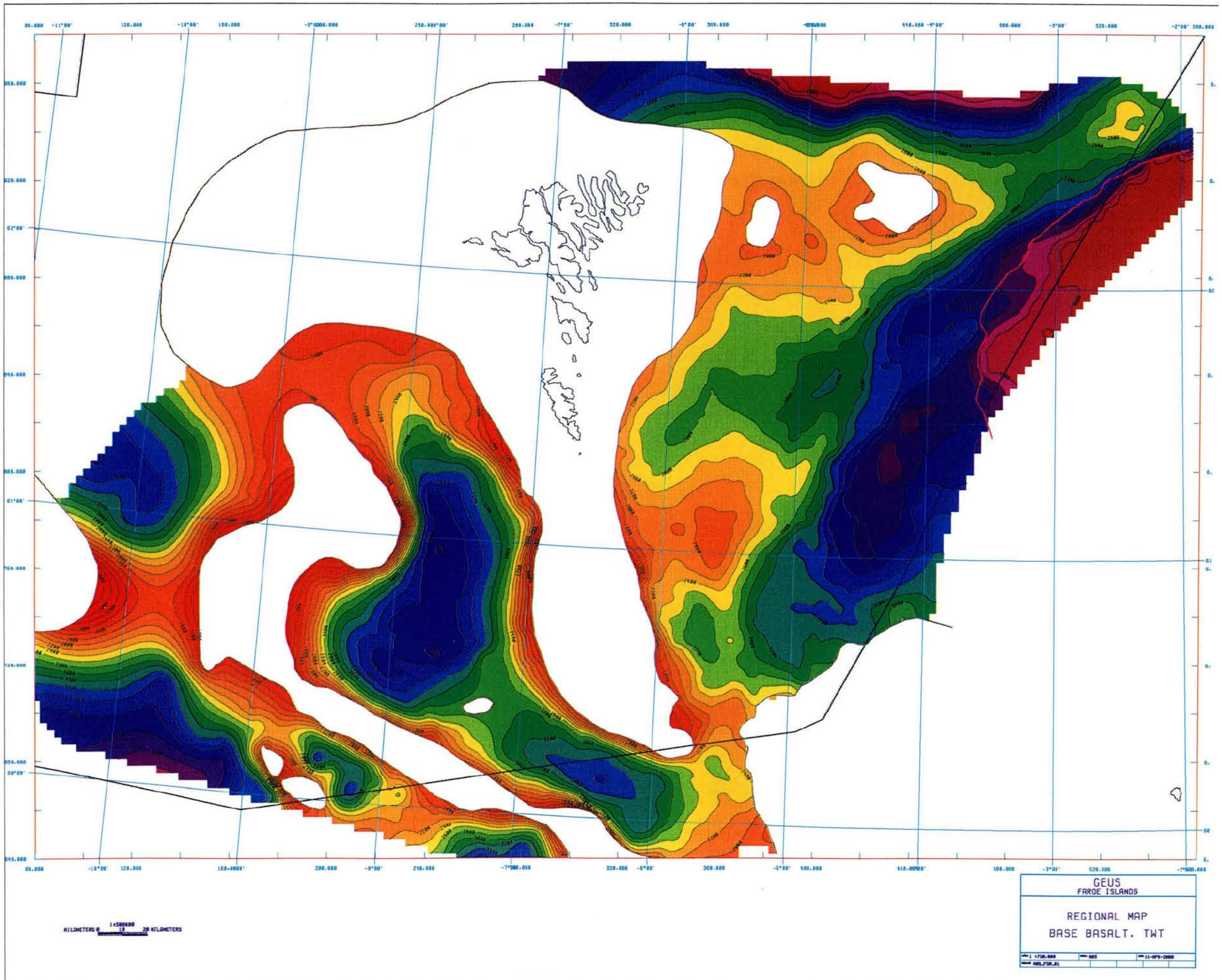
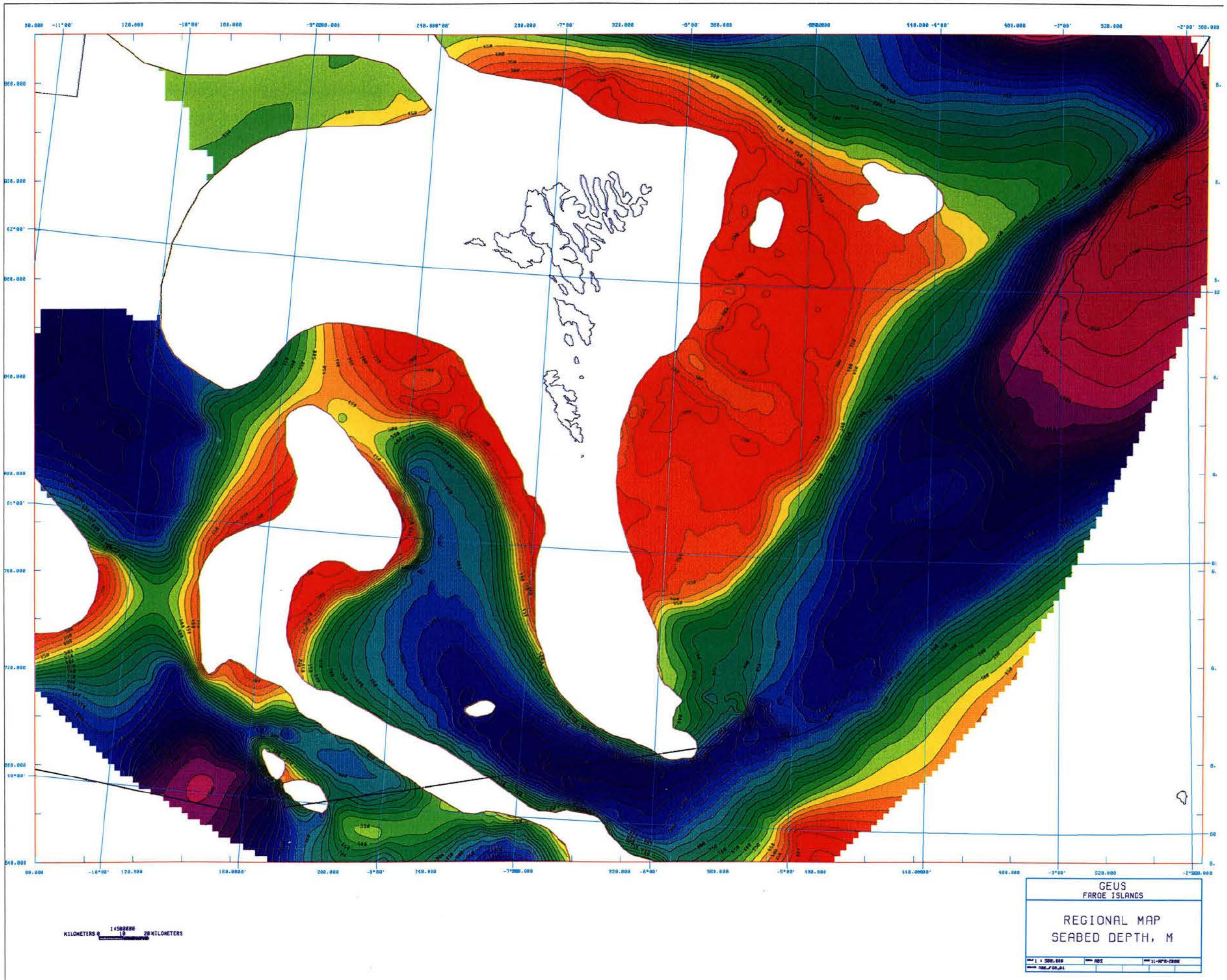


Figure 6



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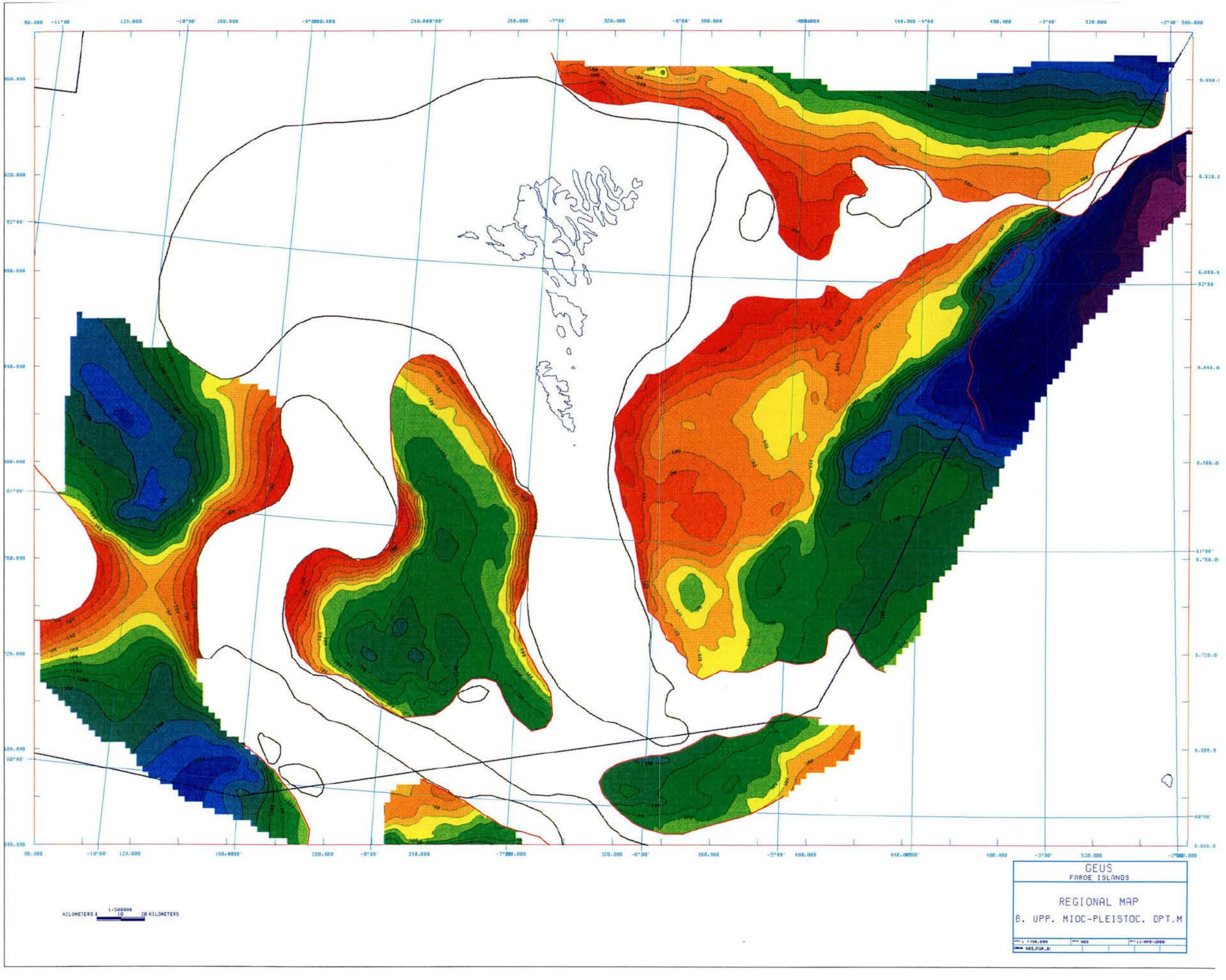

GEUS
FAROE ISLANDS
REGIONAL MAP
B. UPP. MIOC-PLEISTOC. DPT.M
KILOMETERS 0 10 20 KILOMETERS

Figure 8

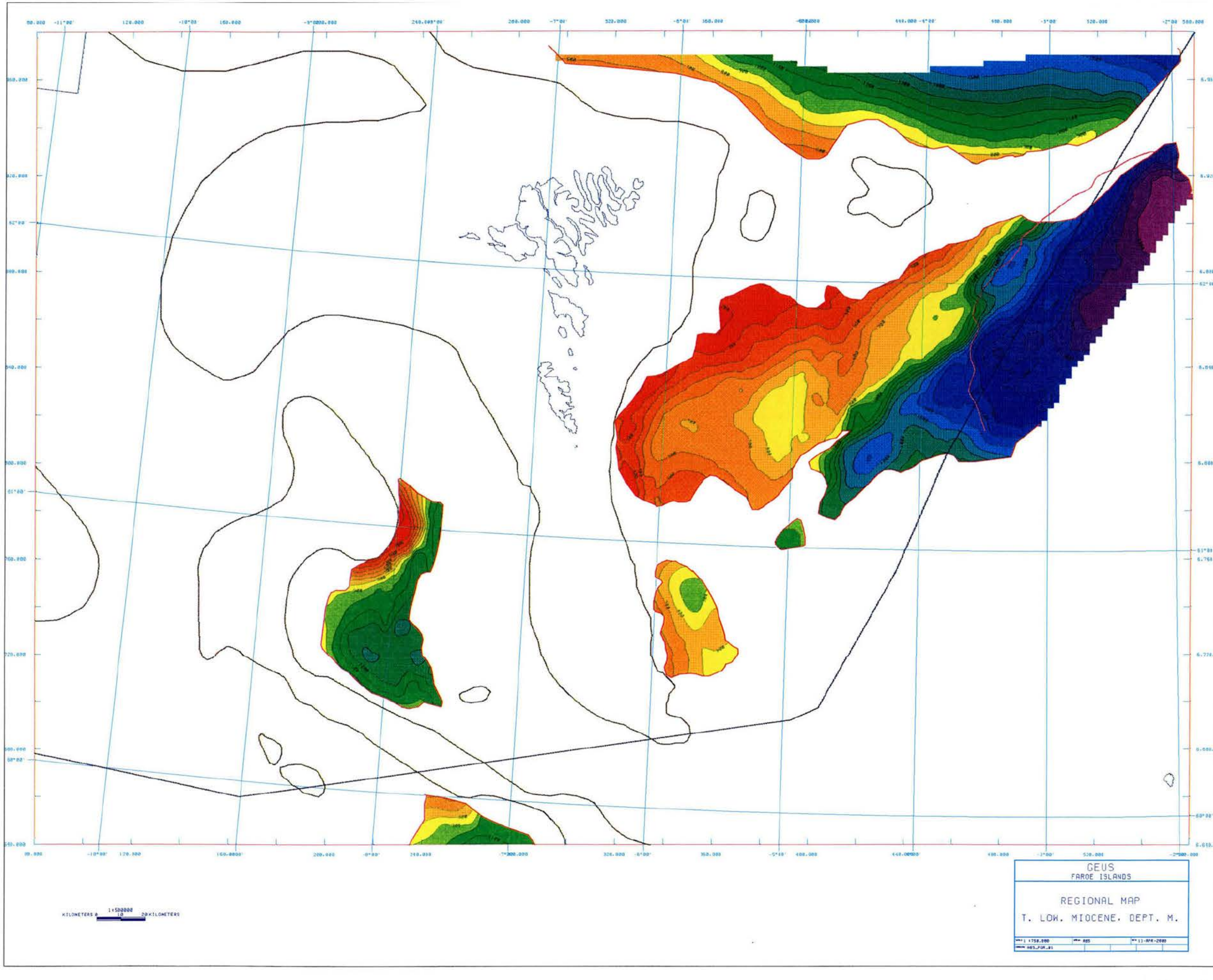
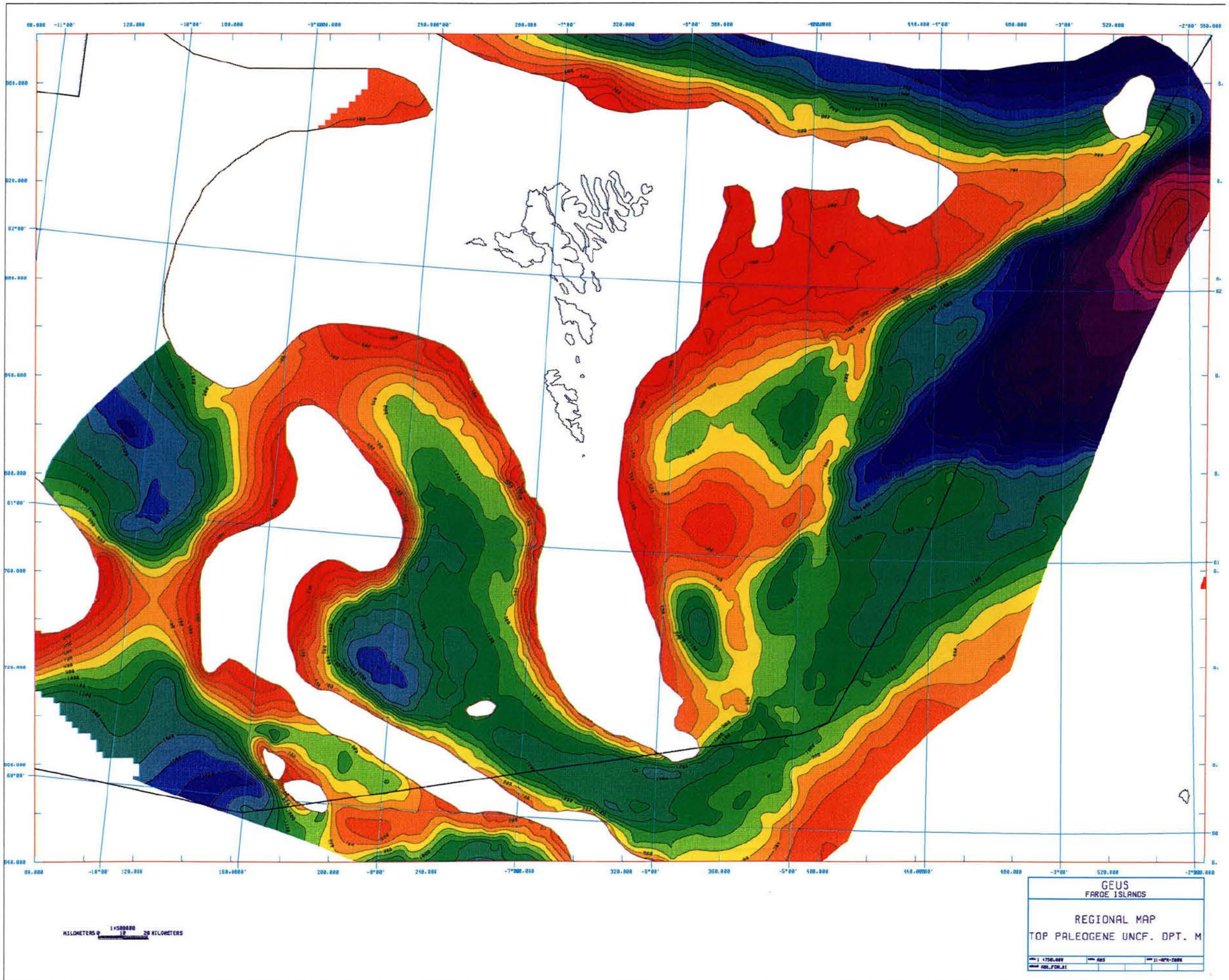


Figure 9



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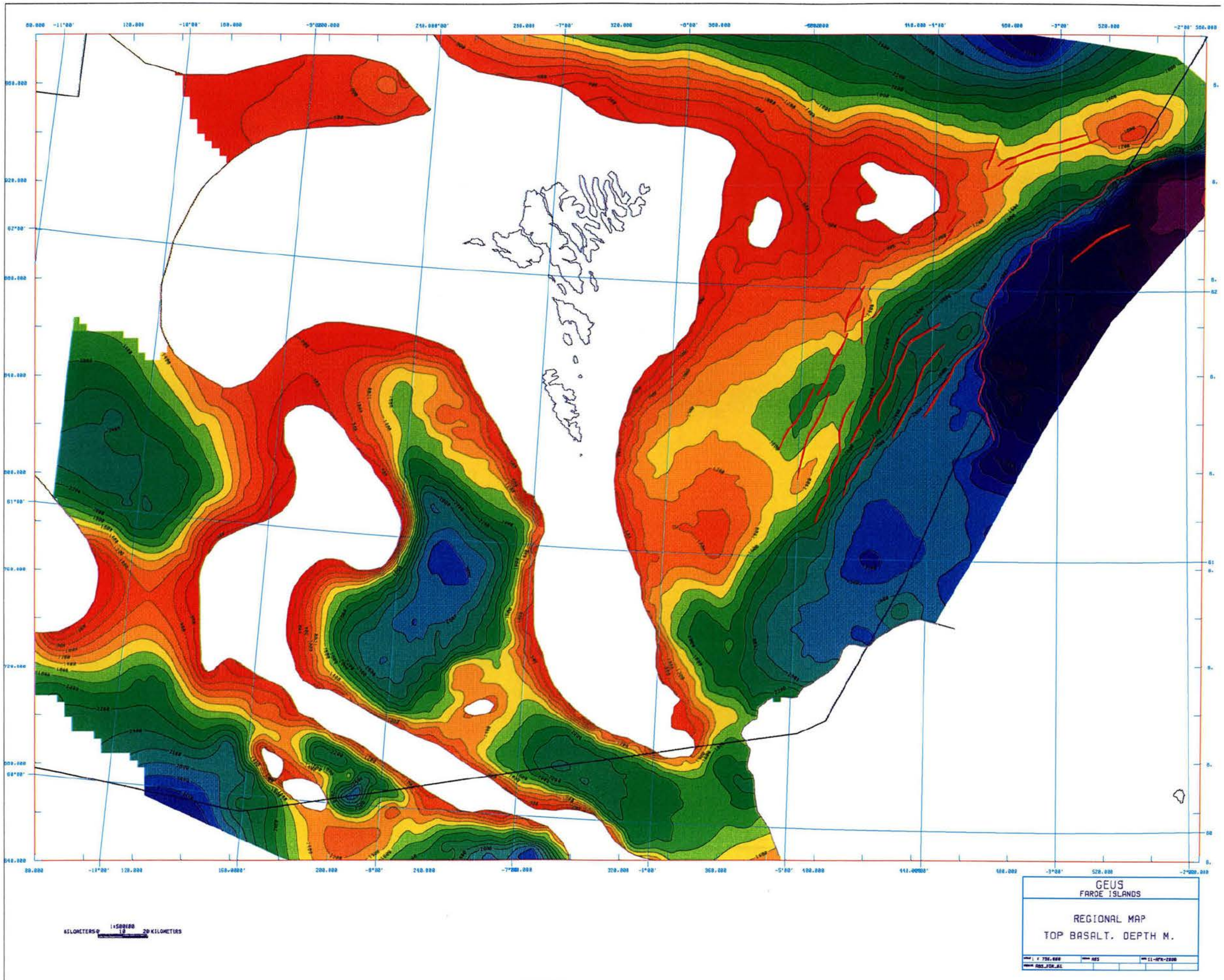
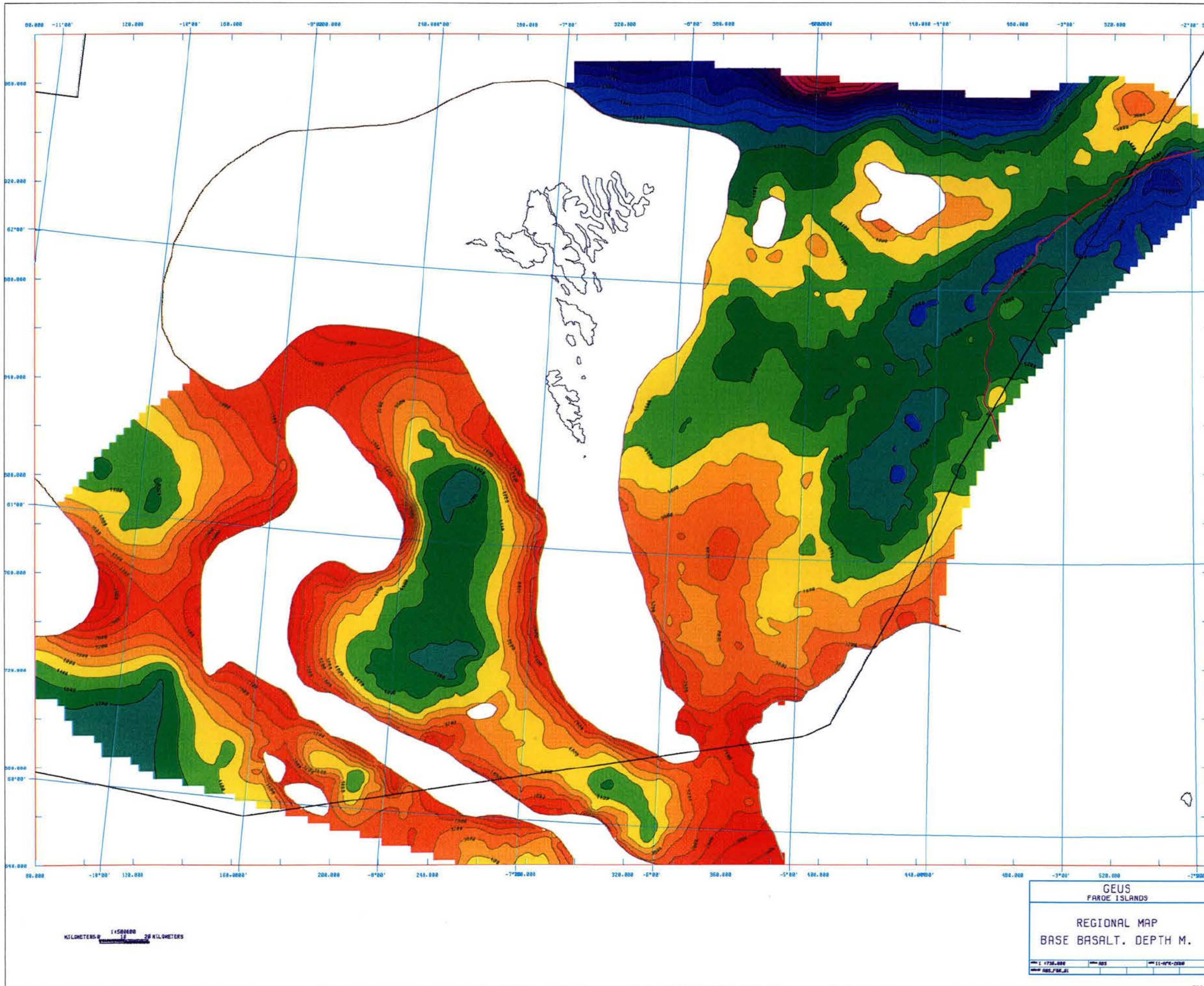

GEUS
FAROE ISLANDS
REGIONAL MAP
TOP BASALT. DEPTH M.
KILOMETERS 0 10 20 KILOMETERS

Figure 11



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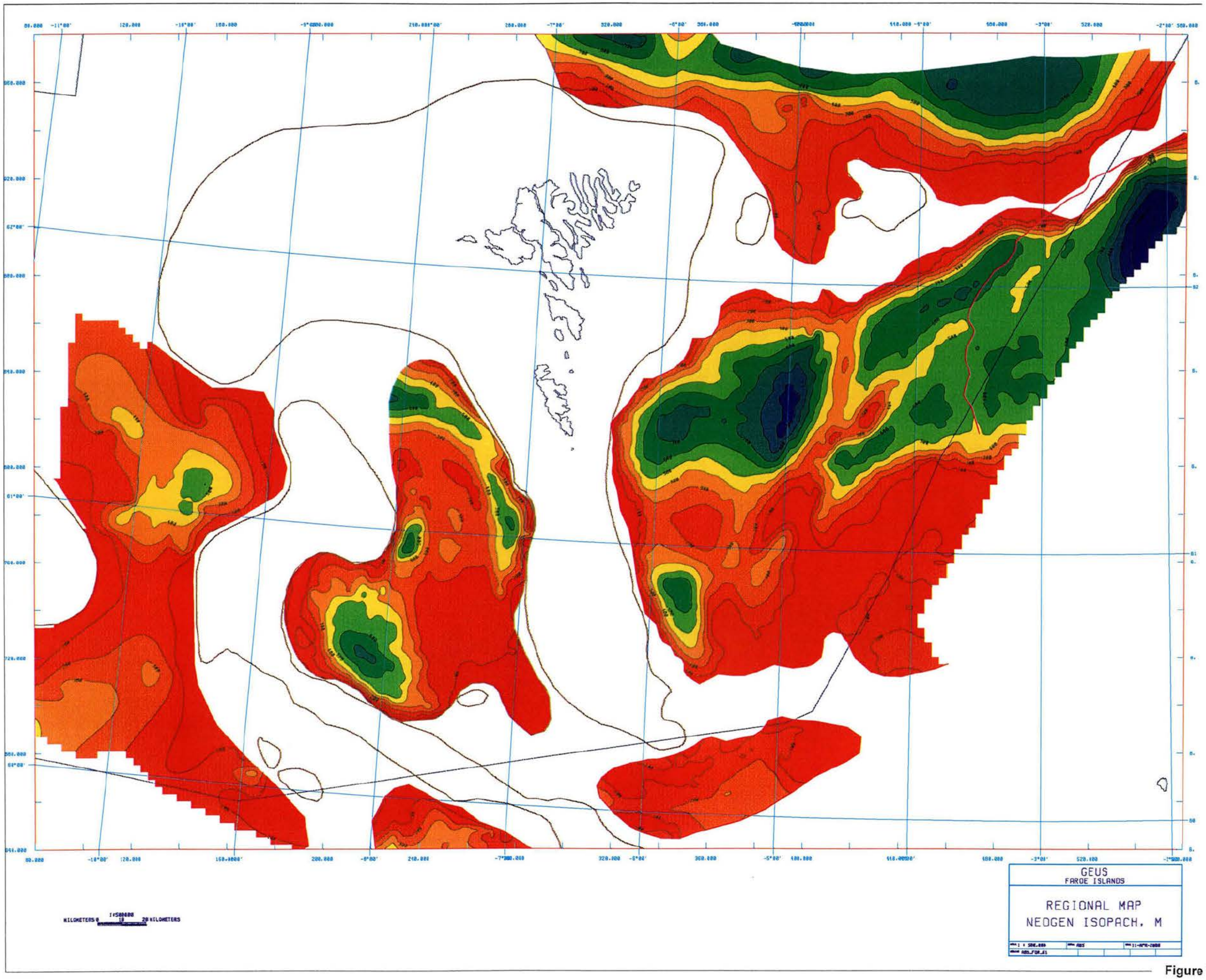
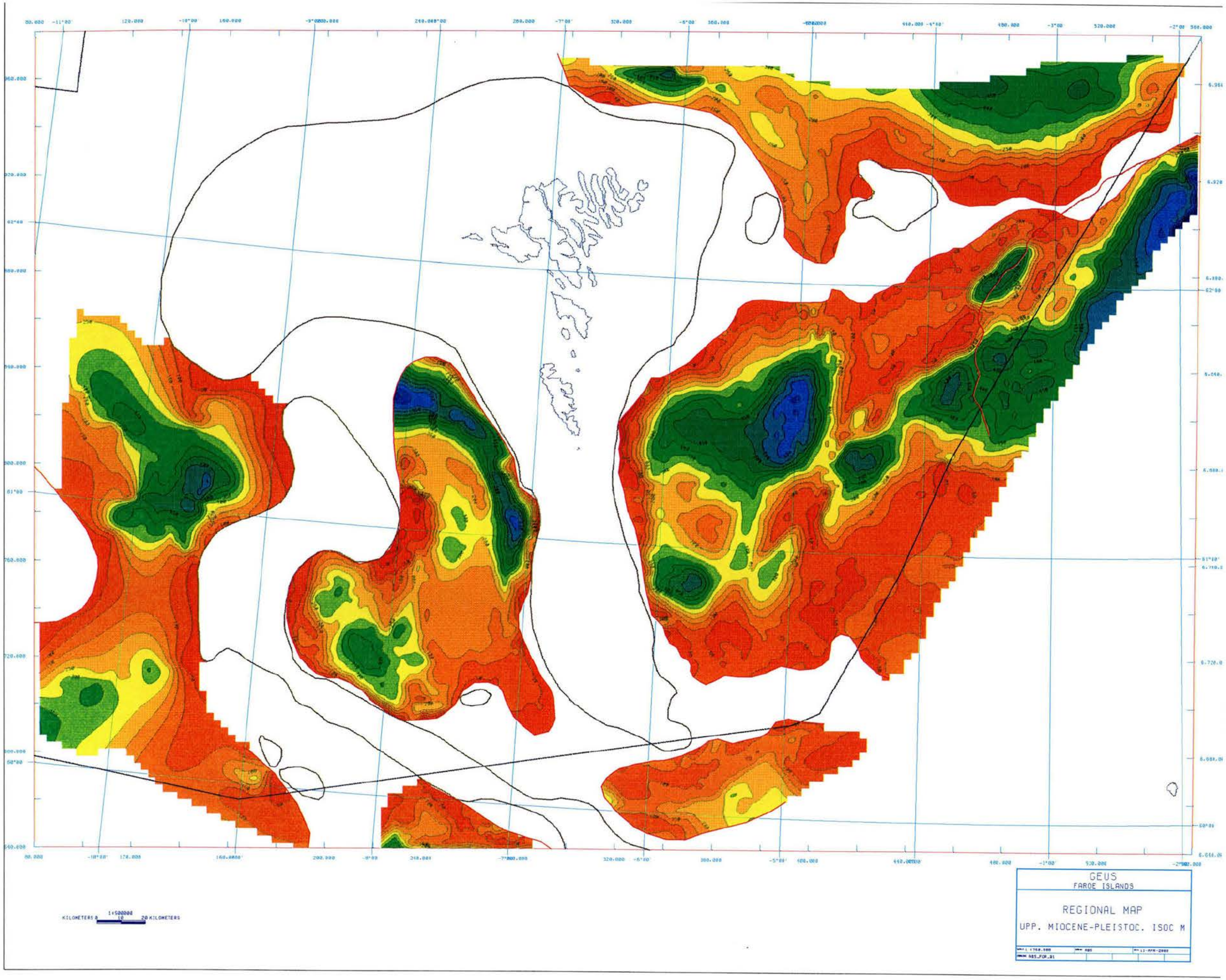


Figure 13



GEUS
FAROE ISLANDS
REGIONAL MAP
UPP. MIOCENE-PLEISTOC. ISOC M
KILOMETERS 0 10 20 KILOMETERS

Figure 14

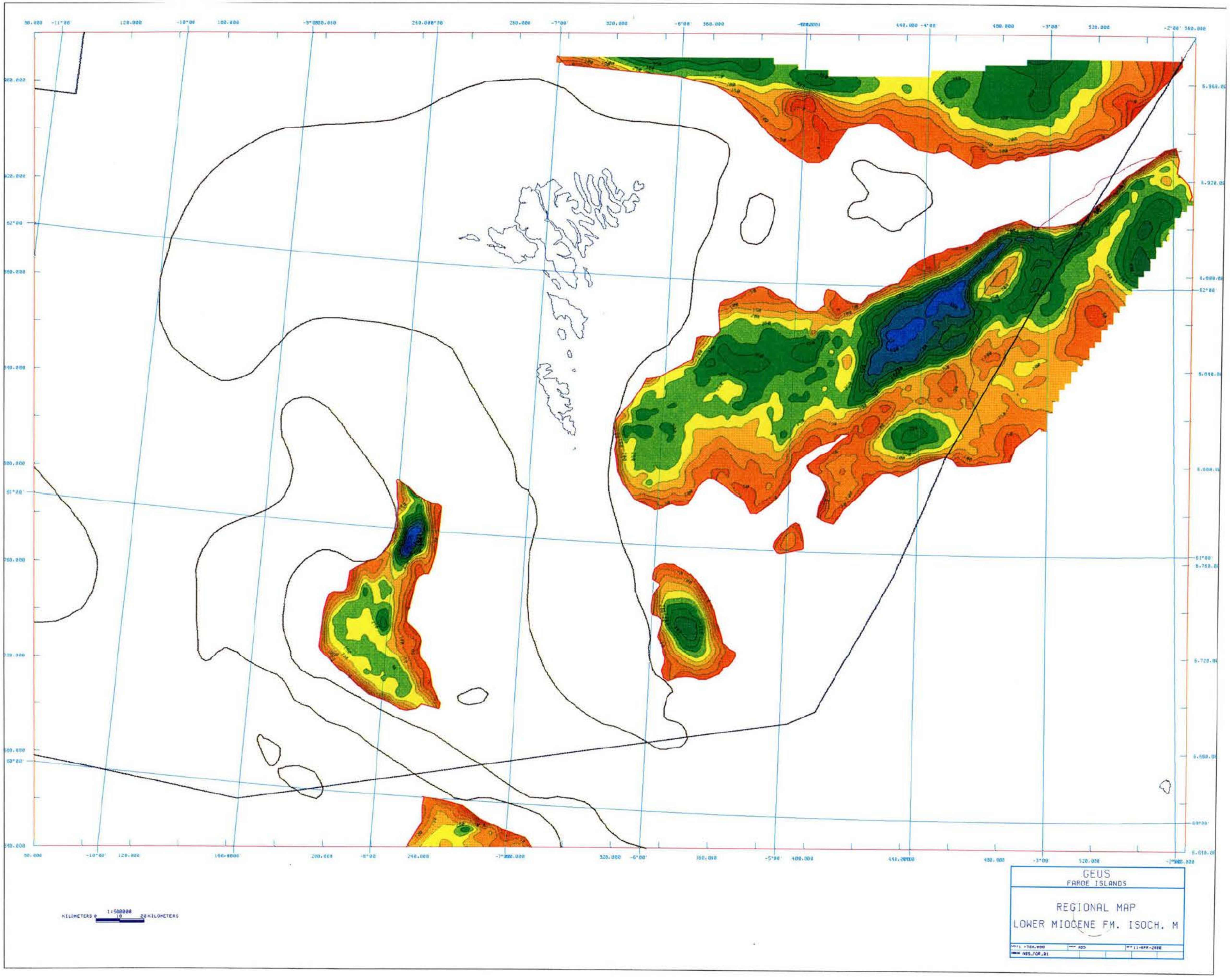

GEUS
FAROE ISLANDS
REGIONAL MAP
LOWER MIOCENE FM. ISOCH. M
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Figure 15

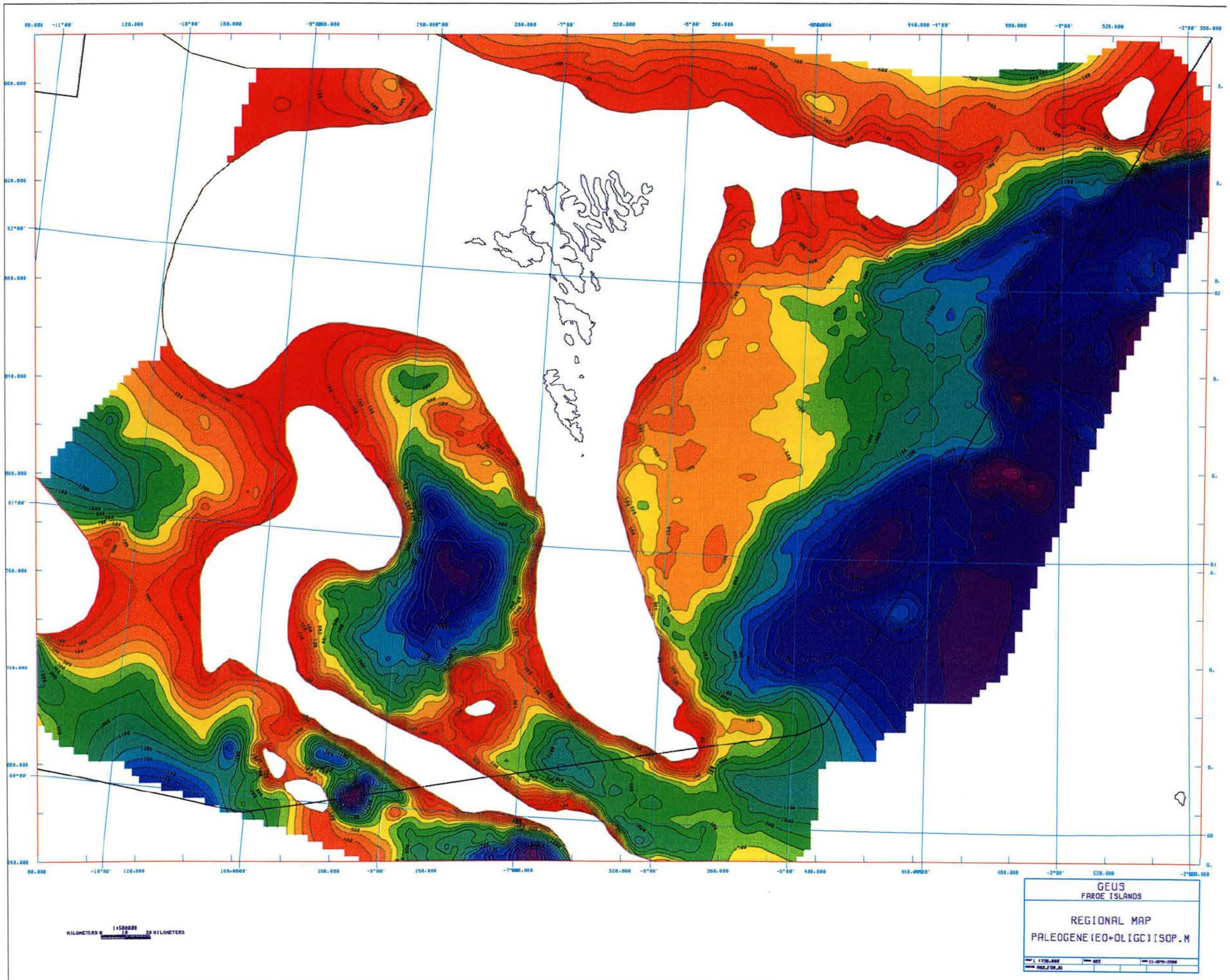


Figure 16

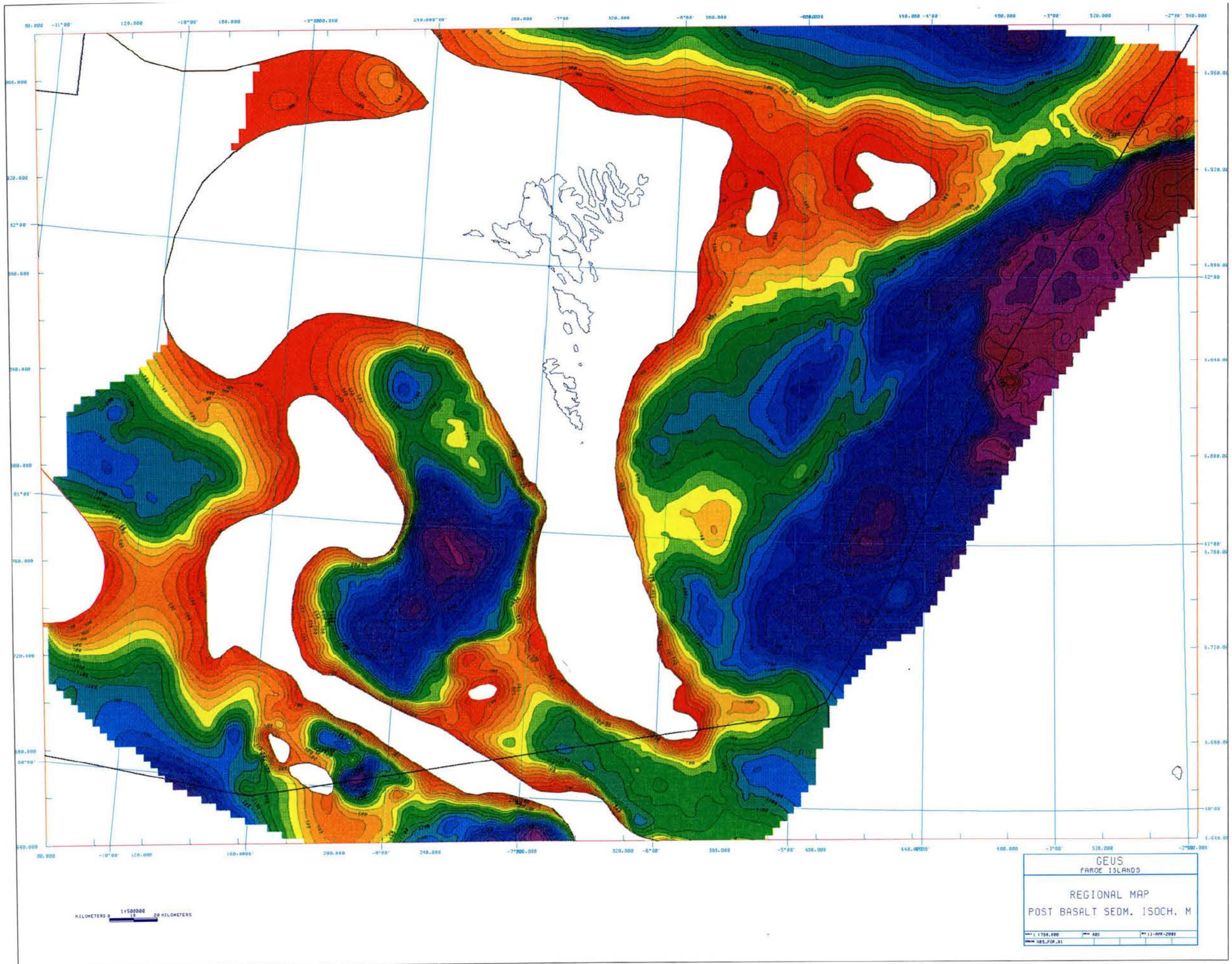


Figure 17

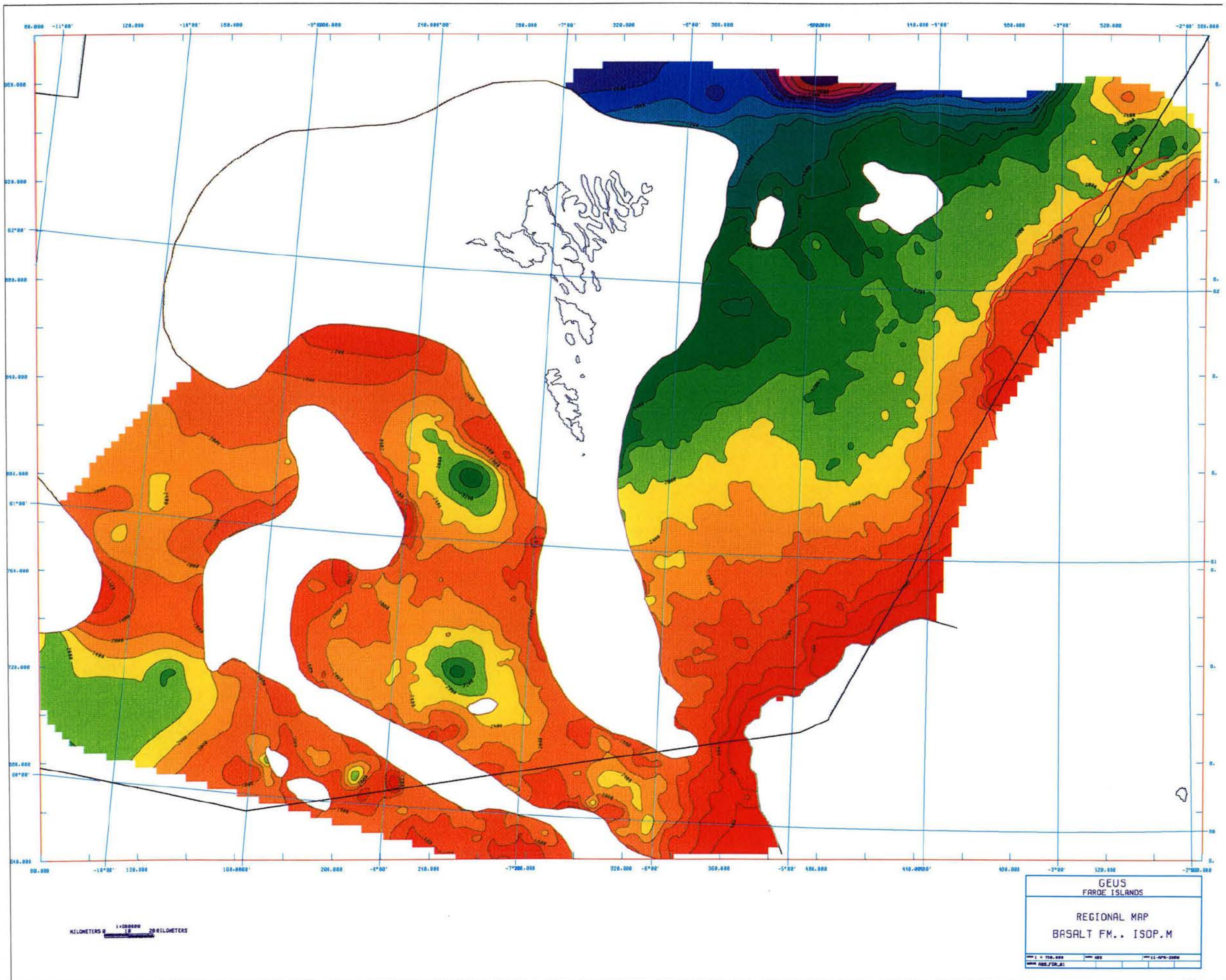
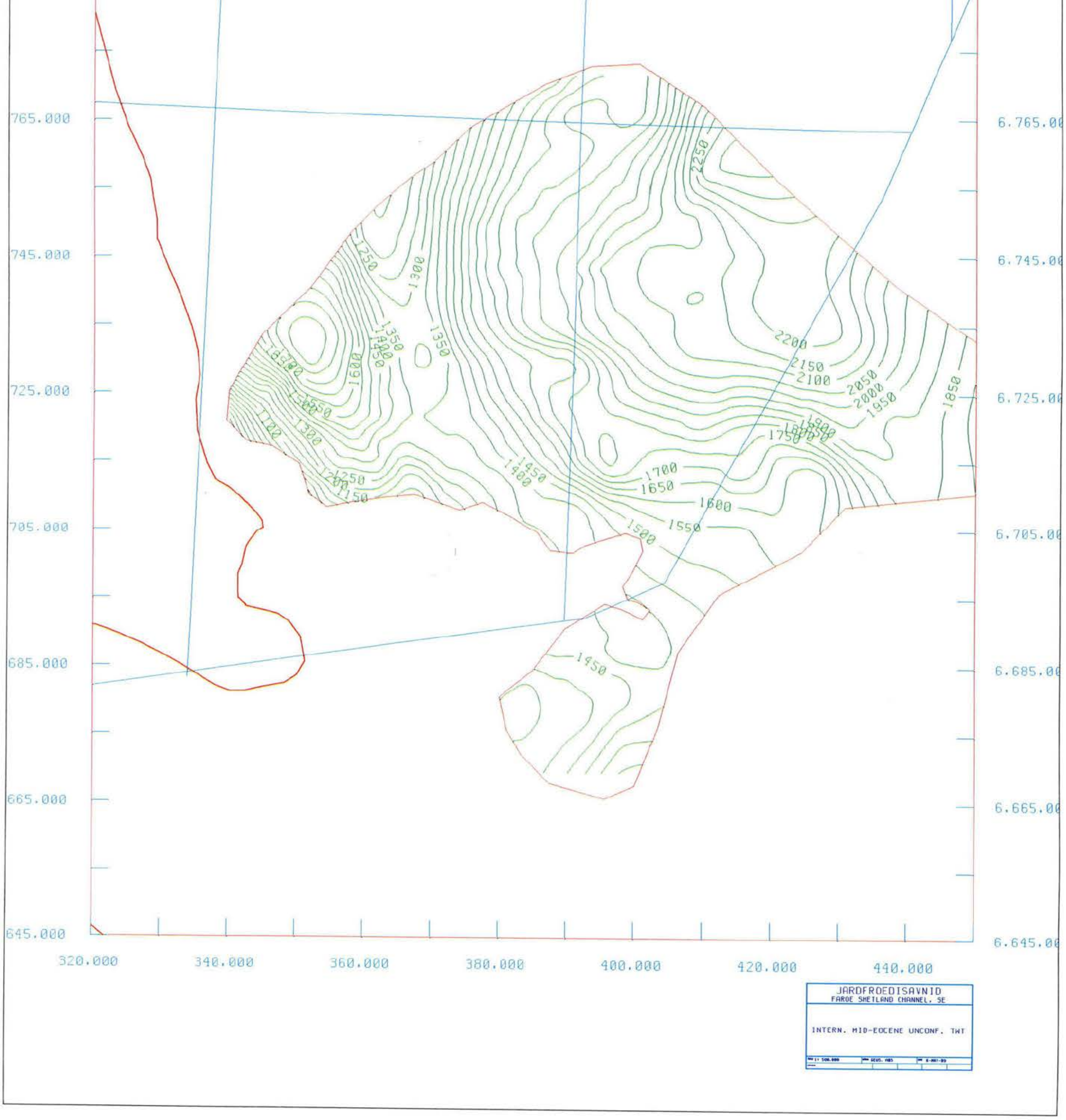


Figure 18



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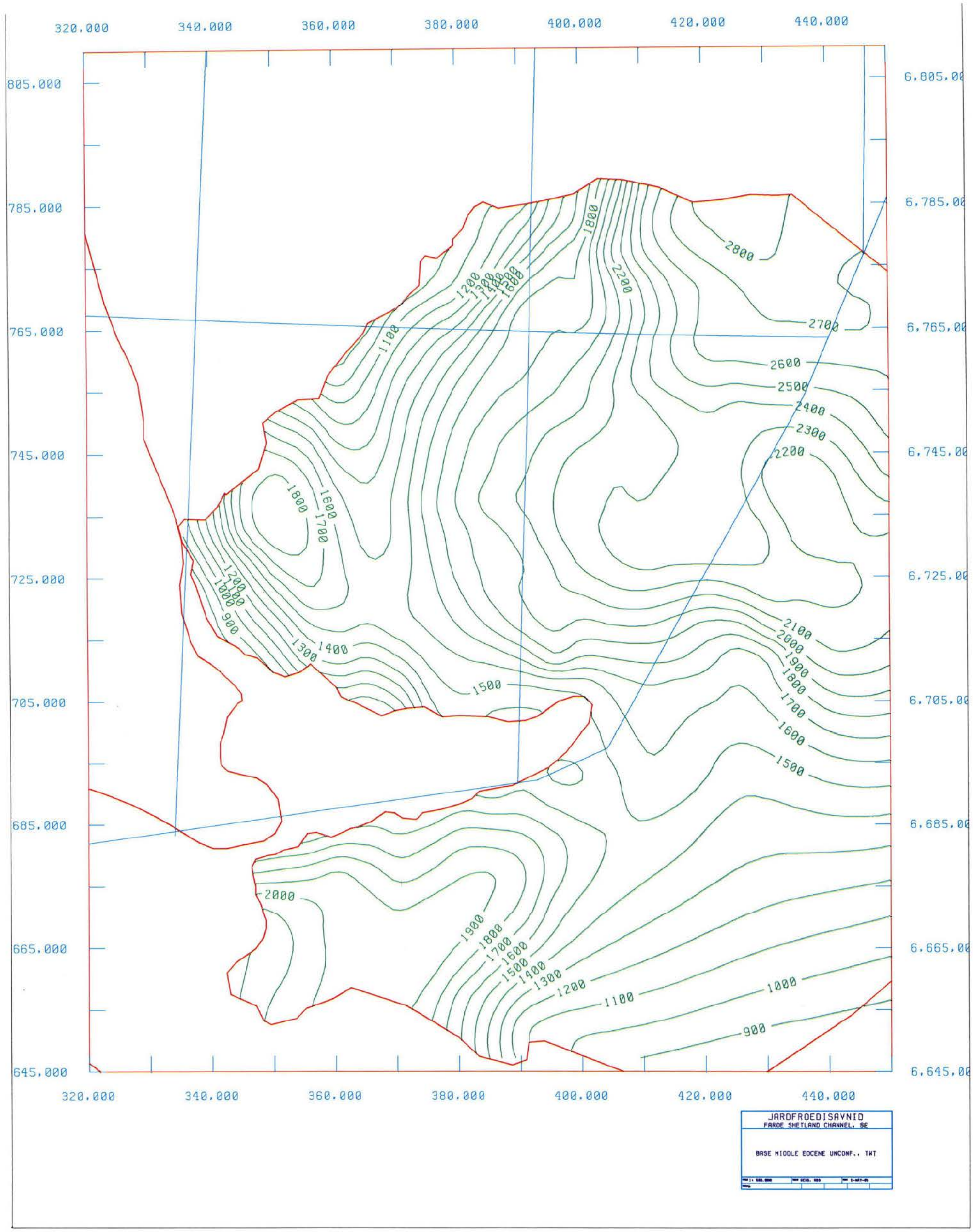
JARDFROEDISAVNID
FAROE SHETLAND CHANNEL, SE
INTERN. MID-EOCENE UNCONF. TWT

Figure 19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6,645.00
JARDFROEDISAVNID
FAROE SHETLAND CHANNEL, SE
BASE MIDDLE EOCENE UNCONF., TWT

Figure 20

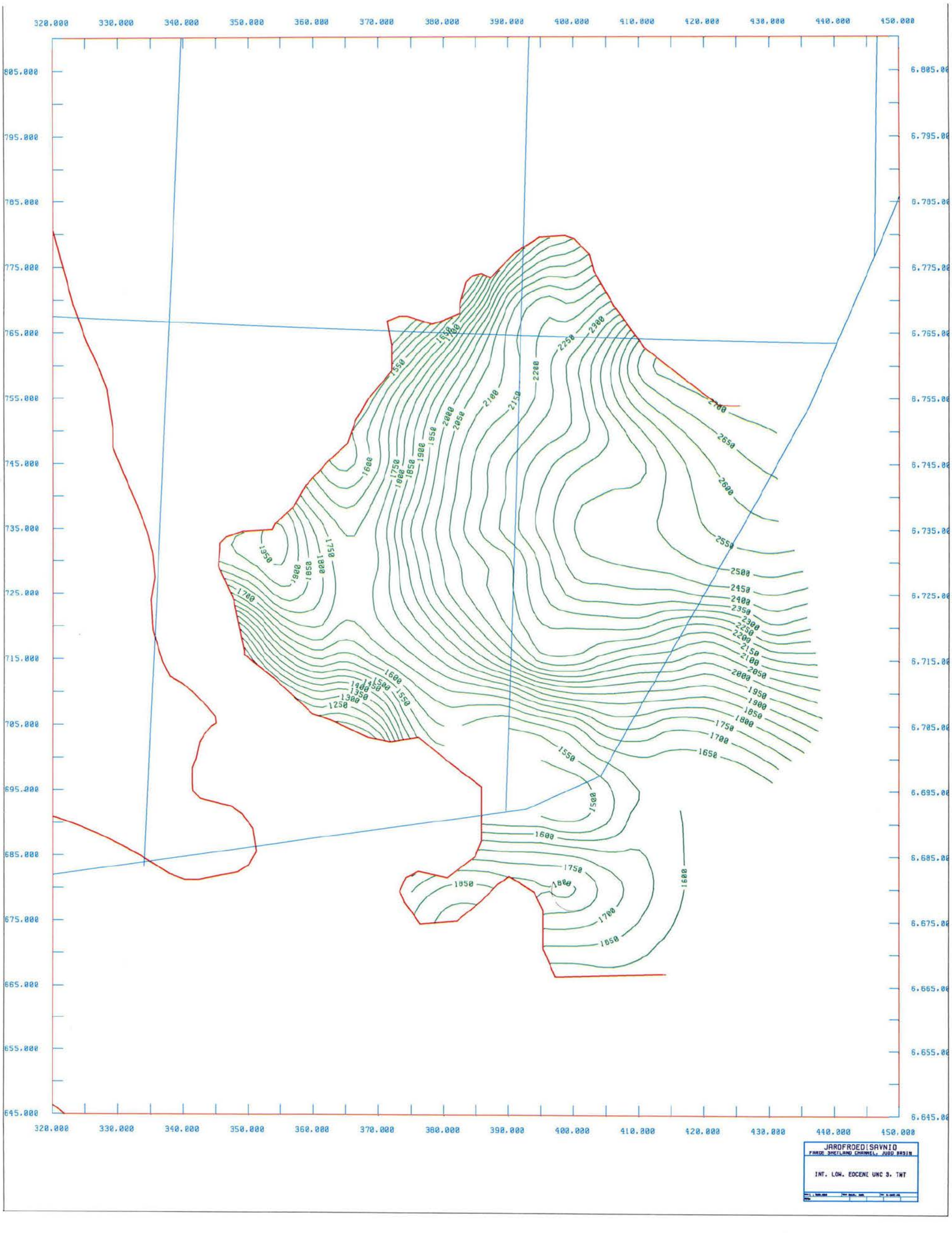

JARDFROEDISAVNID
FAROE SHETLAND CHANNEL, JUDD BASIN
INT. LOW. EOCENE UNC 3. TWT

Figure 21

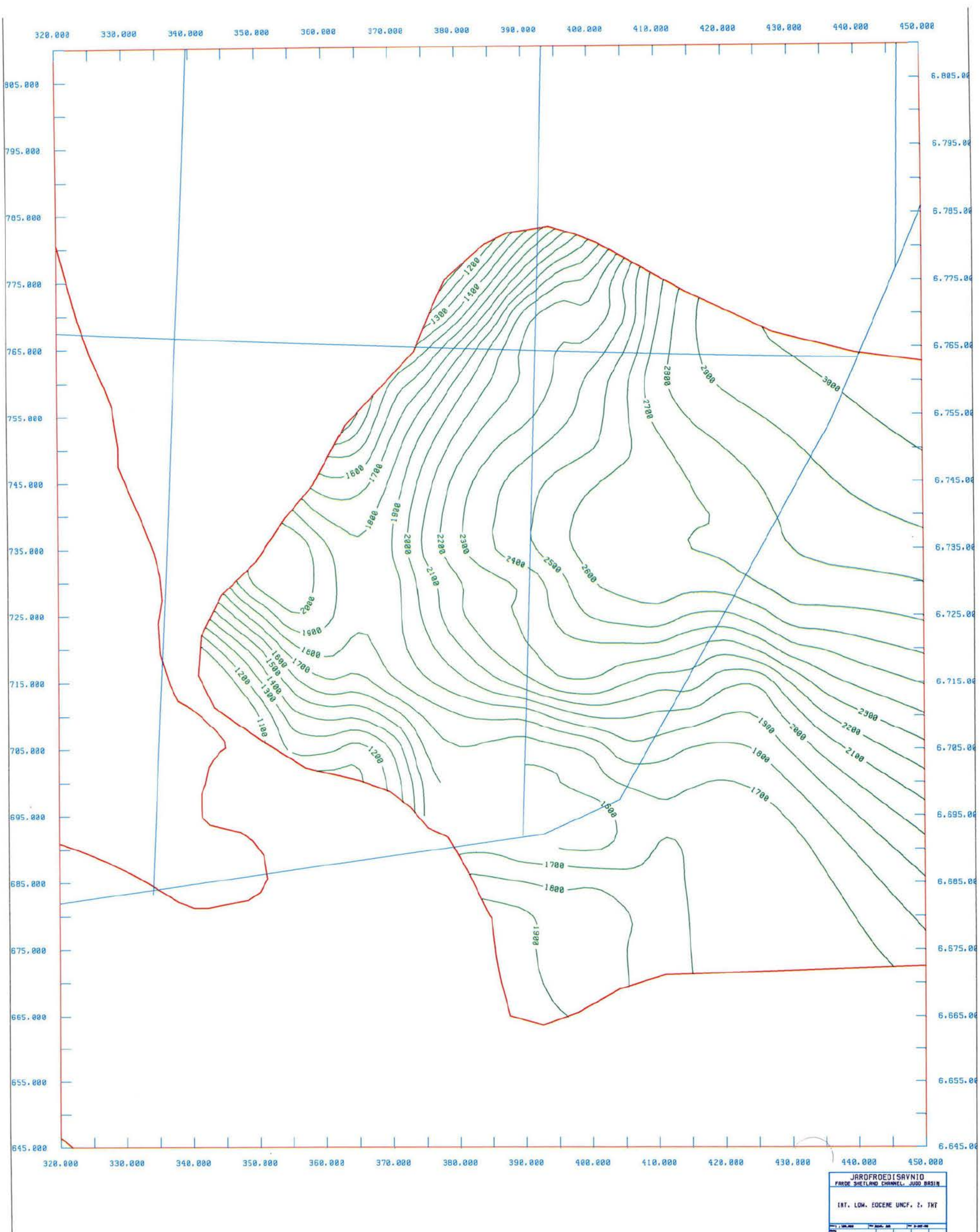

JAROFROEDISAVNID
FAROE SHETLAND CHANNEL, JUDD BASIN
INT. LOW. EOCENE UNCF. 2. TWT

Figure 22

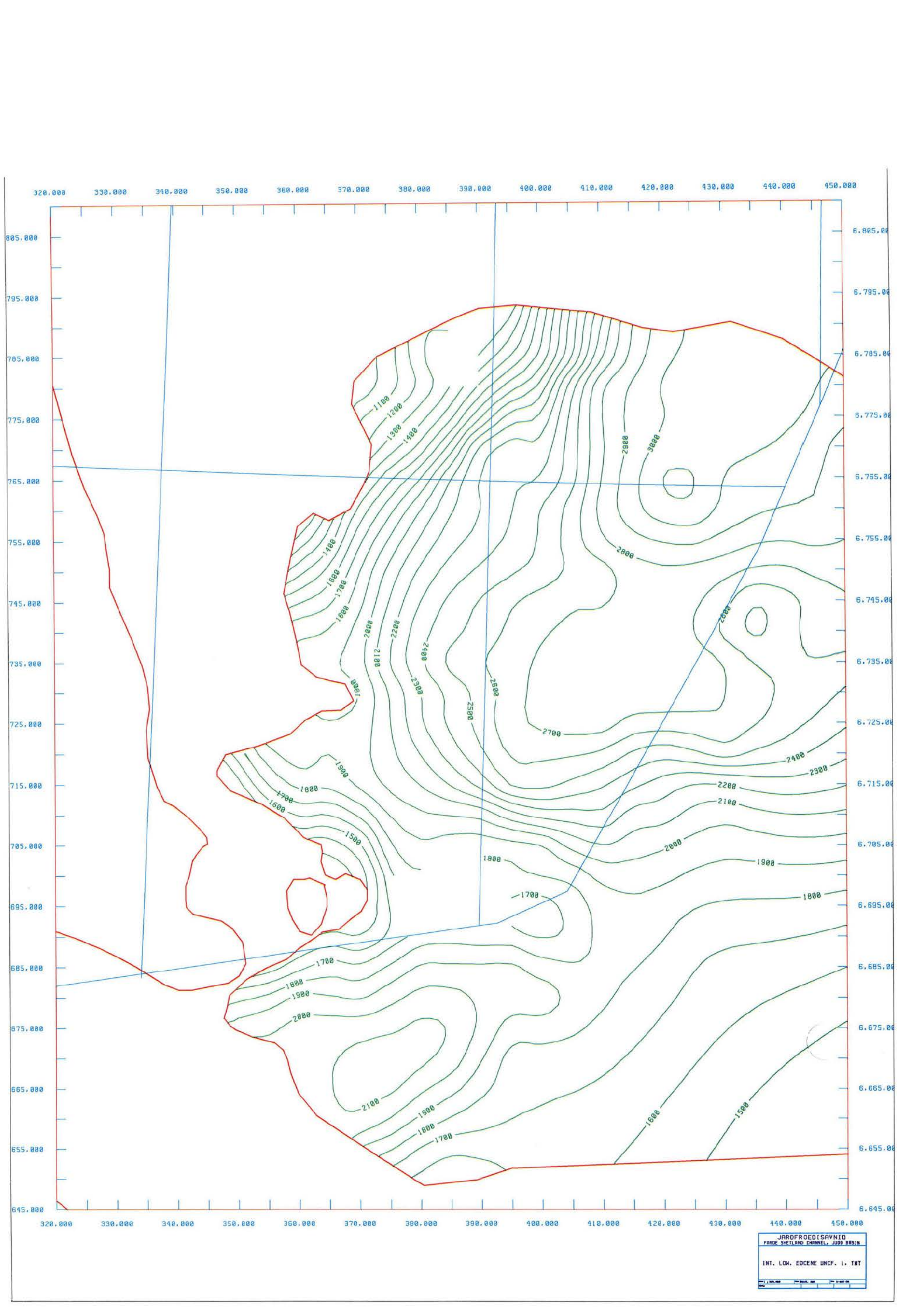

JAROFROEDISAVNID
FAROE SHETLAND CHANNEL, JUDD BASIN
INT. LOW. EOCENE UNCF. 1. TXT

Figure 23

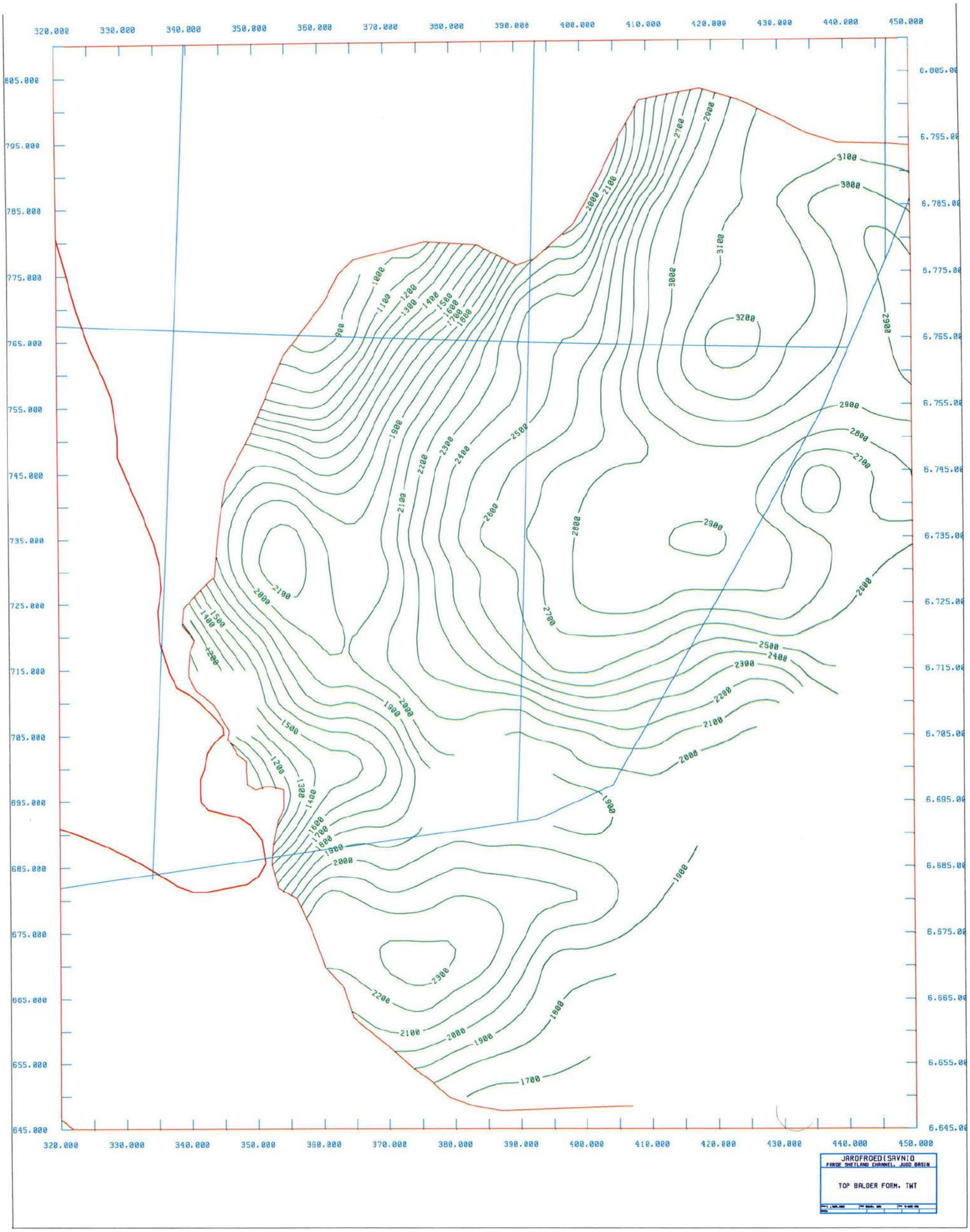
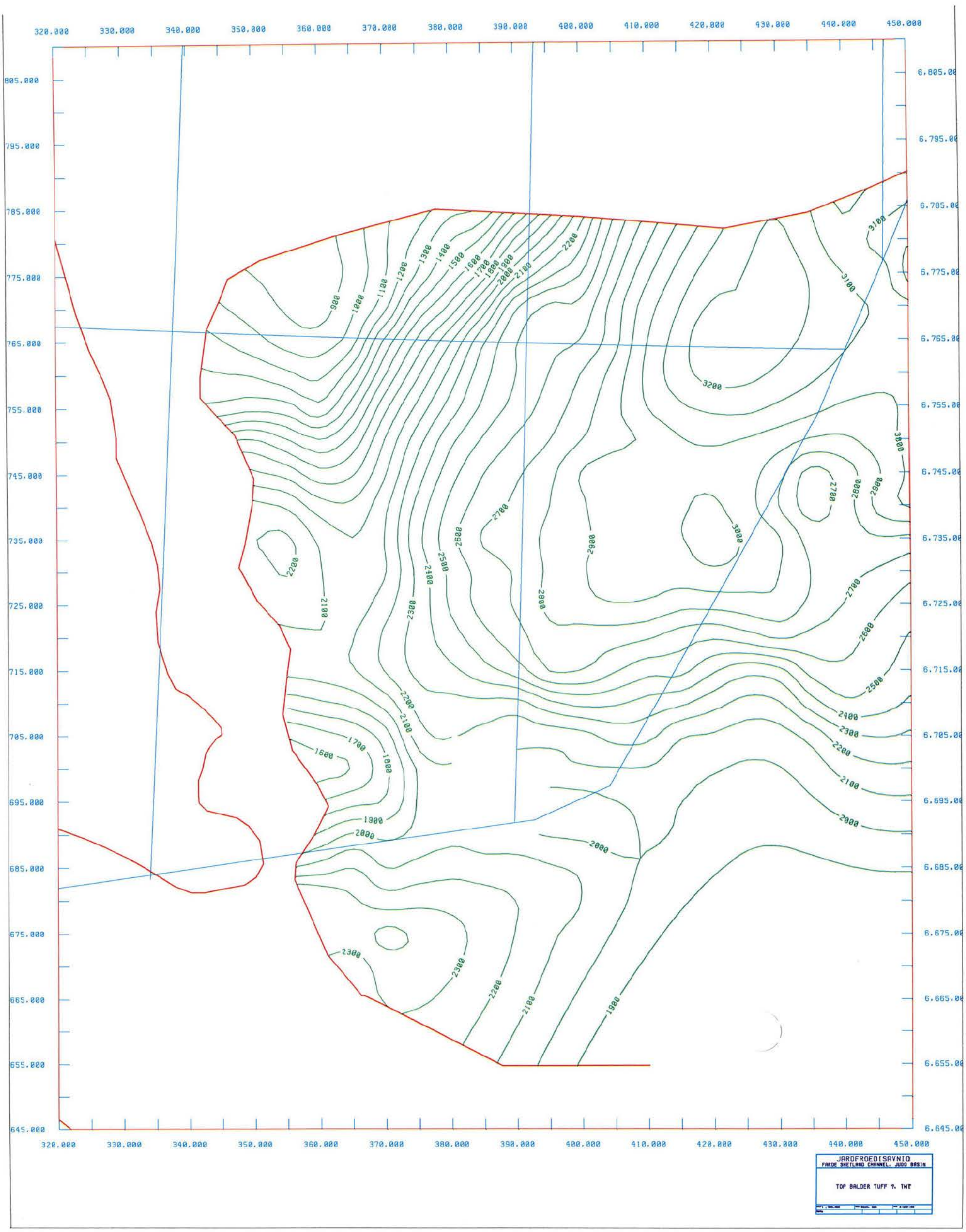

JARDFROEDISAVNID
FAROE SHETLAND CHANNEL, JUDD BASIN
TOP BALDER FORM. TWT

Figure 24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FAROE SHETLAND CHANNEL. JUDD BASIN
TOP BALDER TUFF ?. TWT
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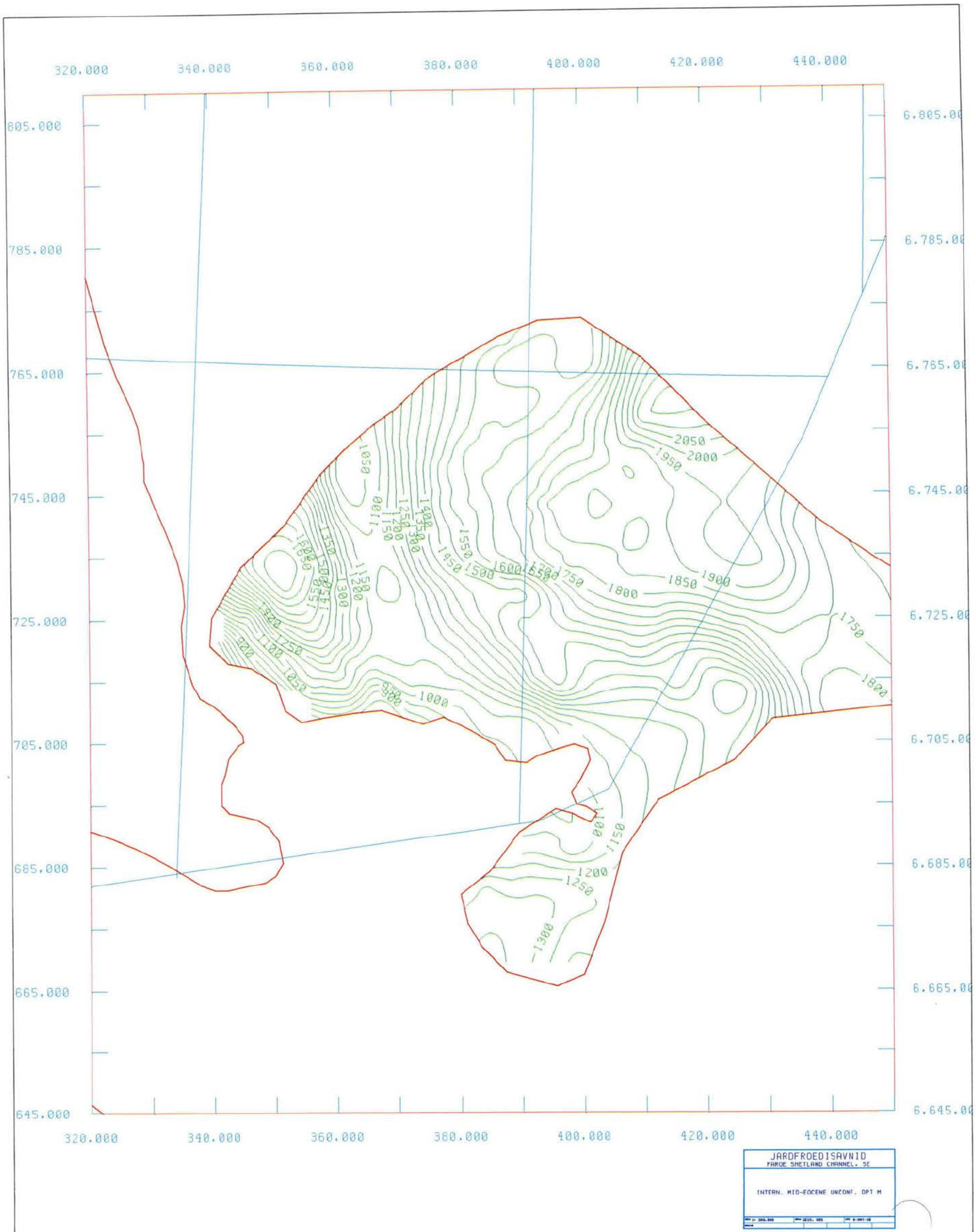
Figure 25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1800
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1600
1550
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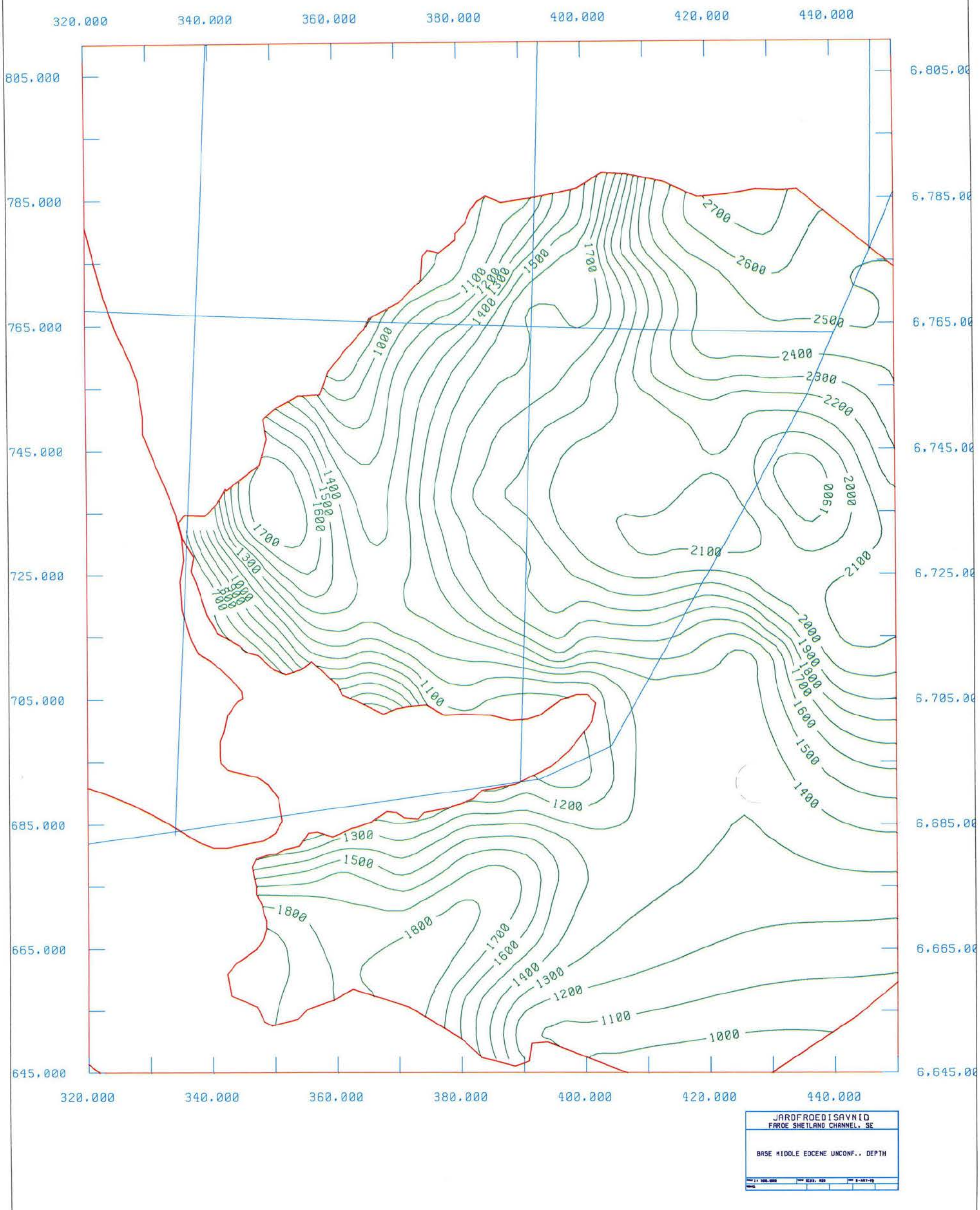
JARDFROEDISAVNID
FAROE SHETLAND CHANNEL. SE
INTERN. MID-EOCENE UNCONF. DPT M

Figure 26



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2400
2300
2200
2100
2000
1900
1800
1700
1600
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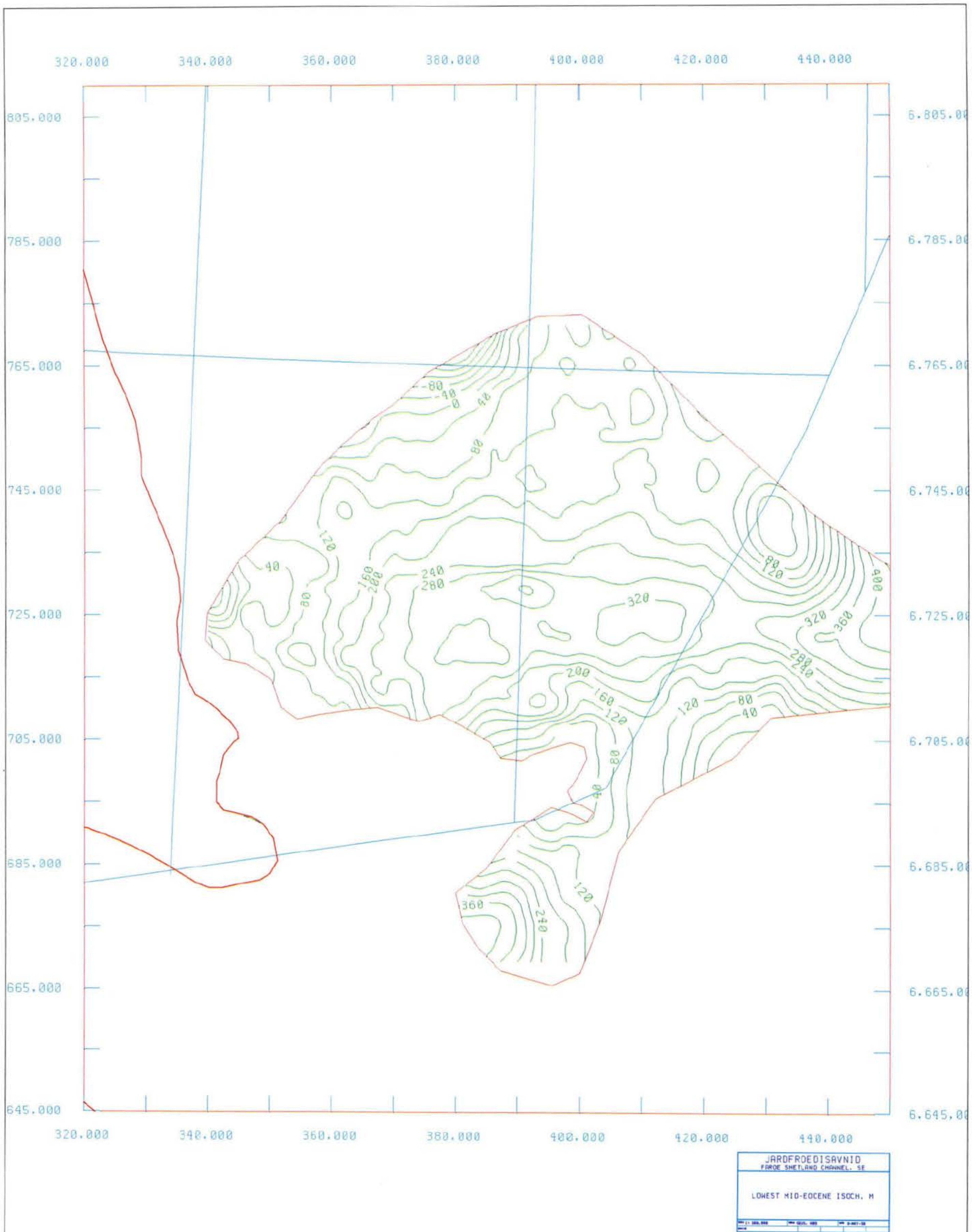
1100
1000
JARDFROEDISAVNID
FAROE SHETLAND CHANNEL, SE
BASE MIDDLE EOCENE UNCONF., DEPTH

Figure 27



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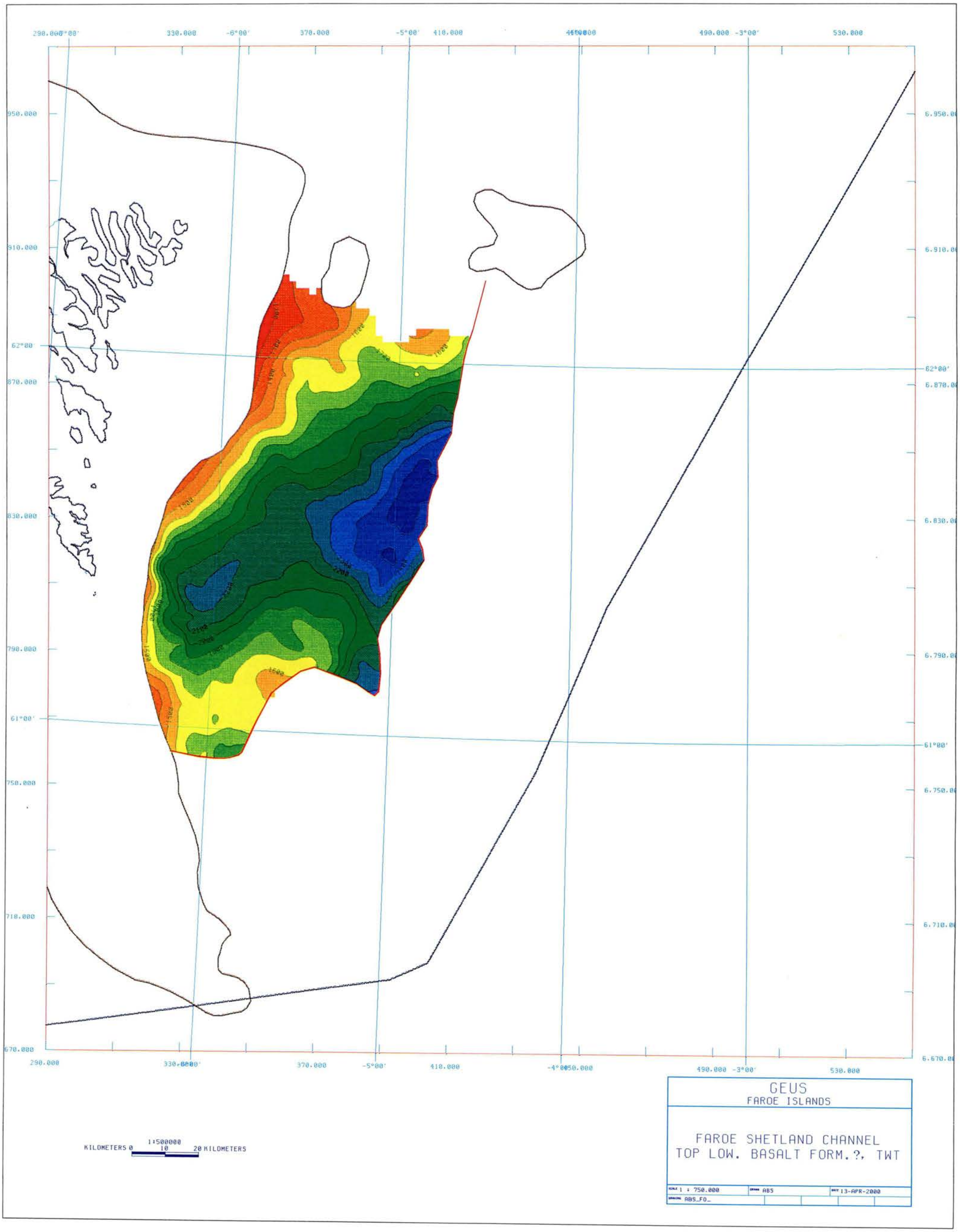
6.645.00
JARDFROEDISAVNID
FAROE SHETLAND CHANNEL. SE
LOWEST MID-EOCENE ISOCH. M

Figure 28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FAROE SHETLAND CHANNEL
TOP LOW. BASALT FORM.?, TWT
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13-APR-2000
ABS_FO_
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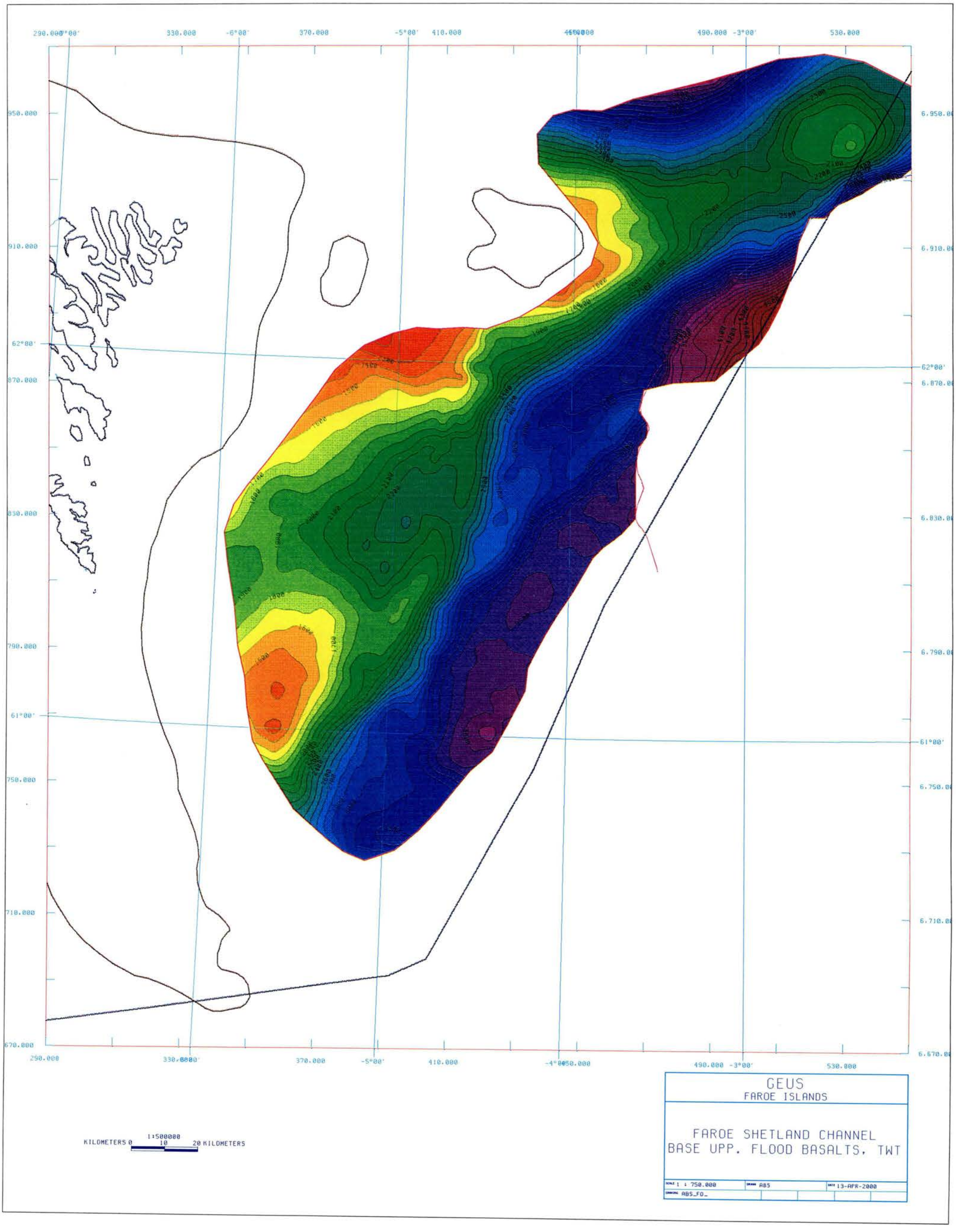
Figure 29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FAROE SHETLAND CHANNEL
BASE UPP. FLOOD BASALTS, TWT
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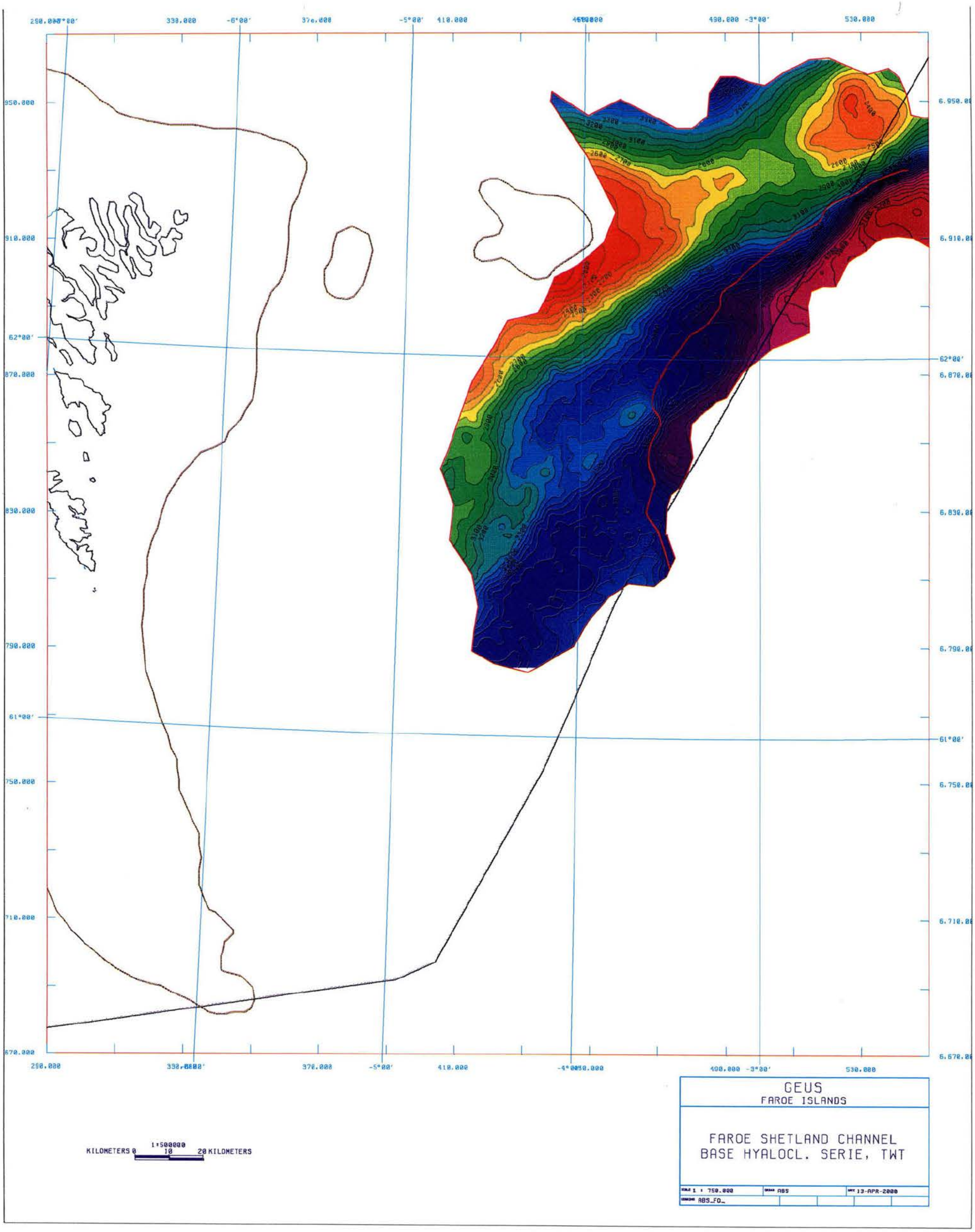
Figure 30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FAROE SHETLAND CHANNEL
BASE HYALOCL. SERIE, TWT
SCALE 1 : 750.000
ABS
13-APR-2000
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KILOMETERS 0 10 20 KILOMETERS
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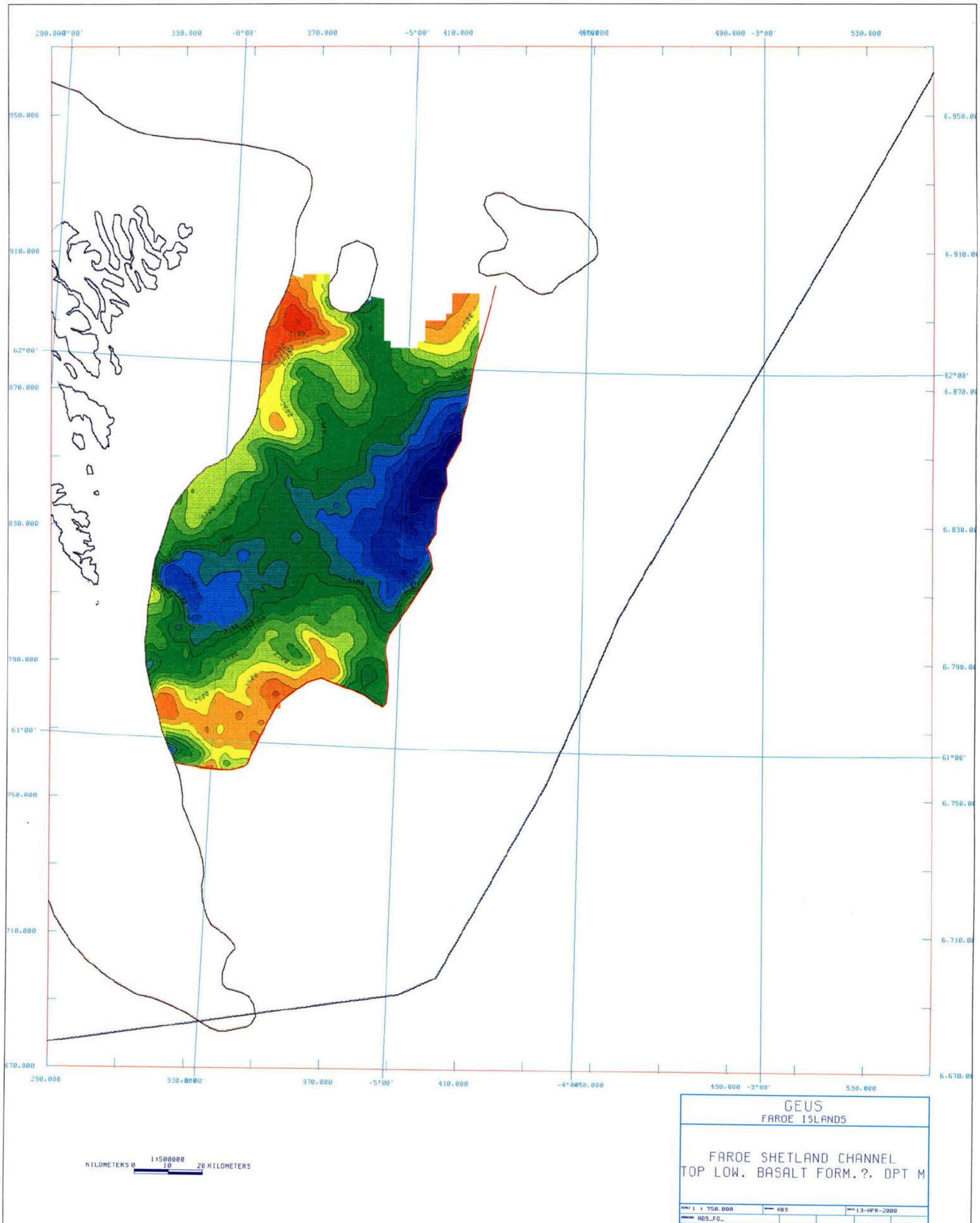
61°00'
-5°00'
-3°00'

Figure 31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FAROE ISLANDS
FAROE SHETLAND CHANNEL
TOP LOW. BASALT FORM.?. DPT M
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KILOMETERS 0 10 20 KILOMETERS
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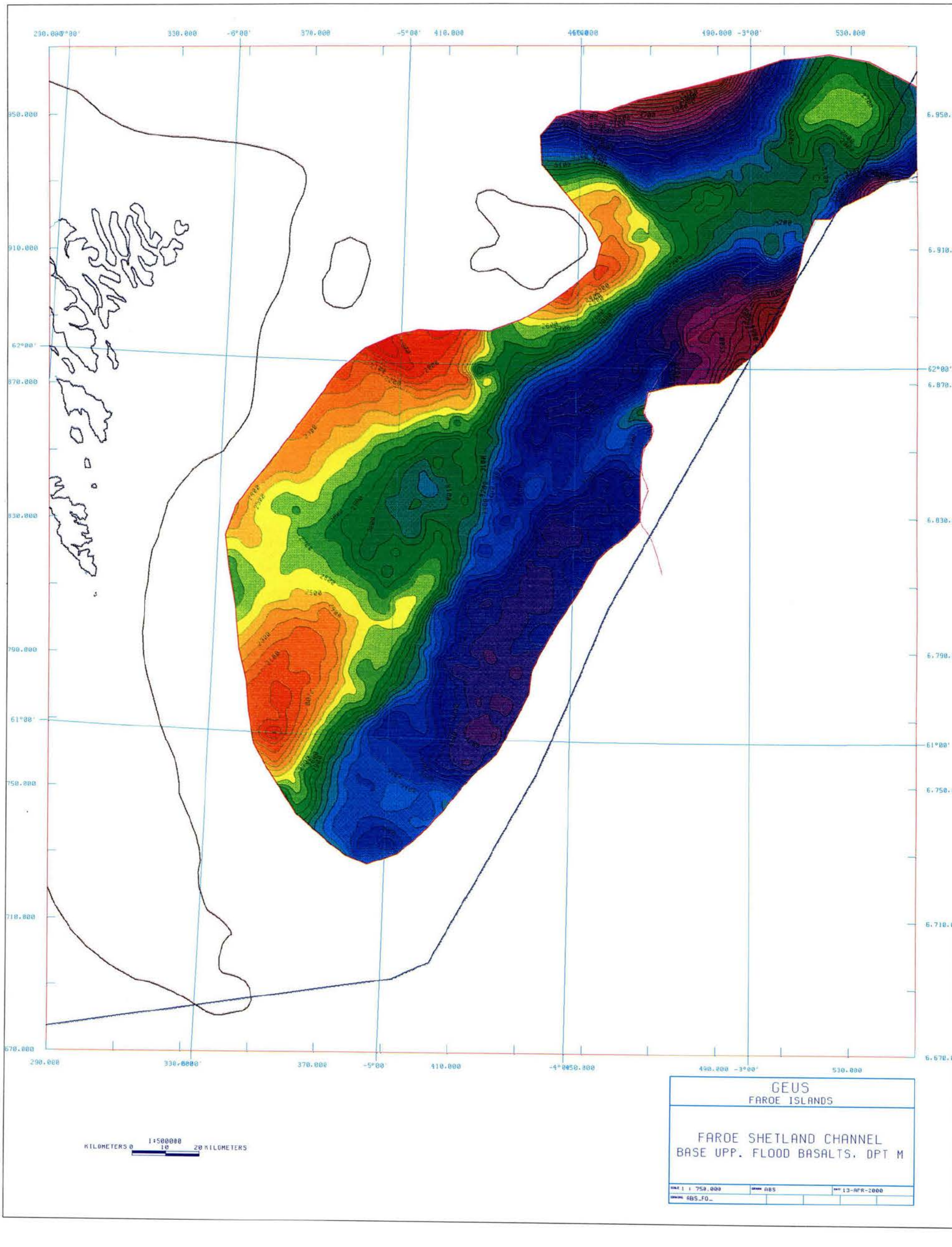
Figure 32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BASE UPP. FLOOD BASALTS. DPT M
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KILOMETERS 0 10 20 KILOMETERS
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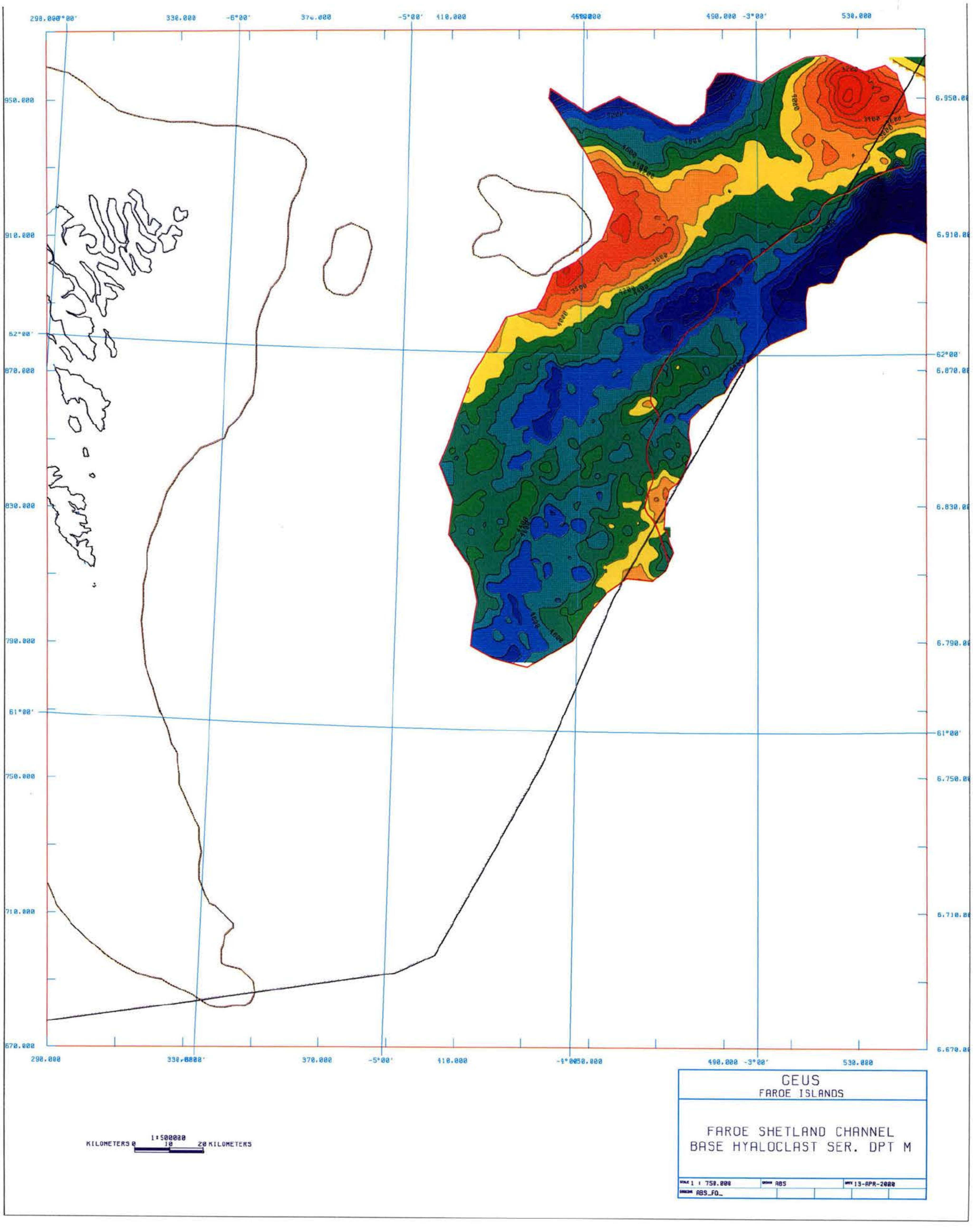
Figure 33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FAROE ISLANDS
FAROE SHETLAND CHANNEL
BASE HYALOCLAST SER. DPT M
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ABS_FO_
KILOMETERS 0 10 20 KILOMETERS
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61°00'
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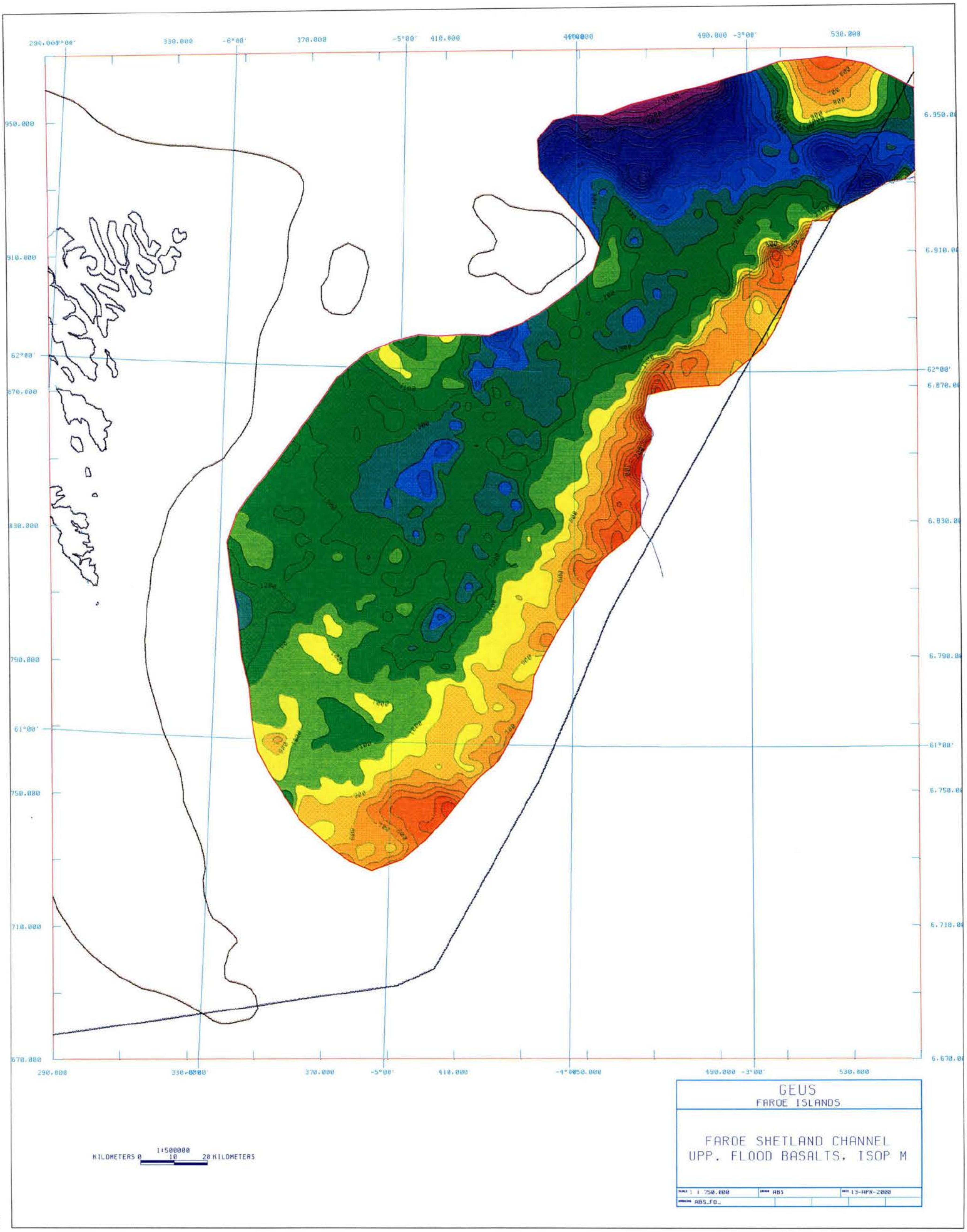
Figure 34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FAROE ISLANDS
FAROE SHETLAND CHANNEL
UPP. FLOOD BASALTS. ISOP M
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13-APR-2000
ABS_FO_
KILOMETERS 0 10 20 KILOMETERS
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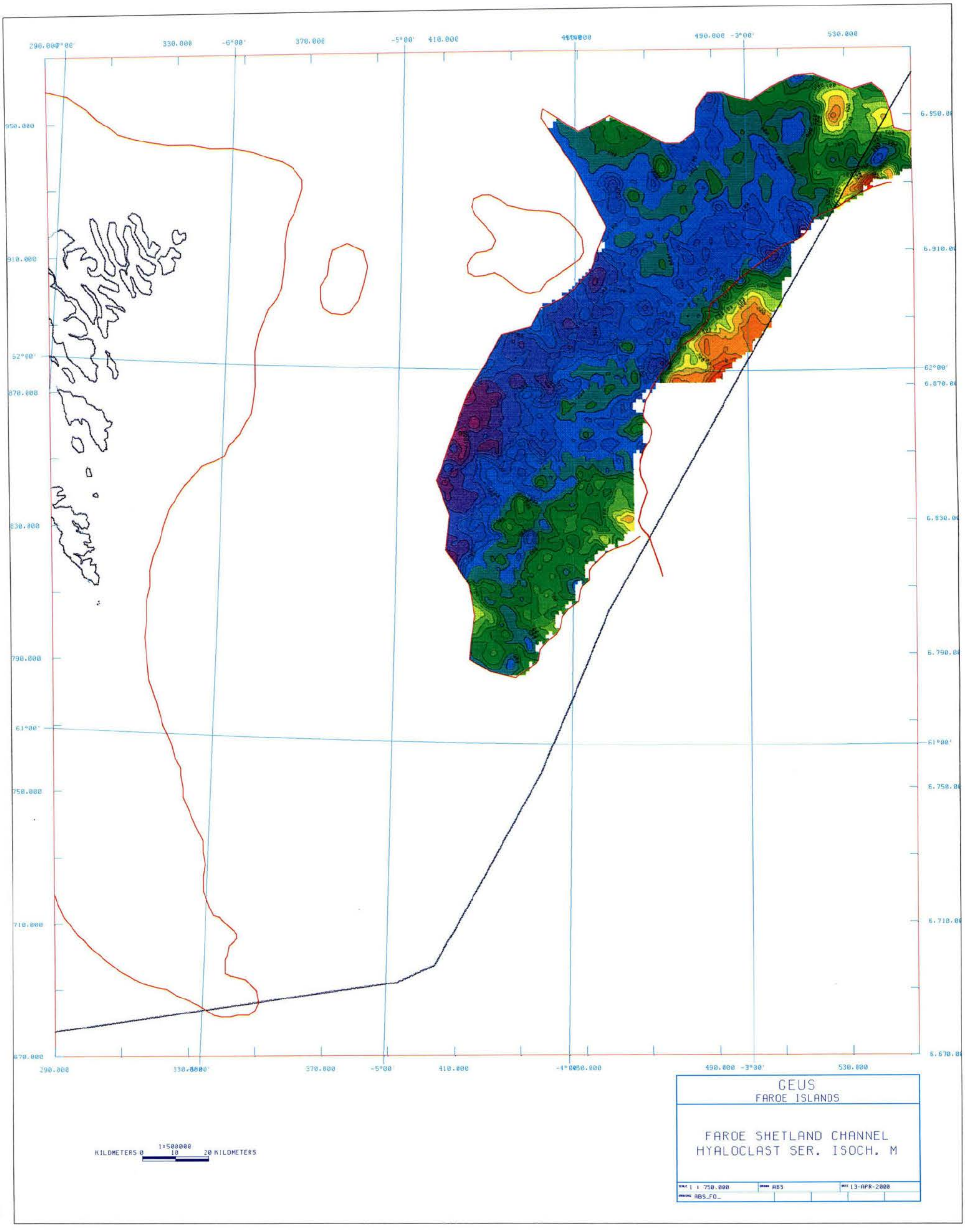
6.670.000

Figure 35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FAROE ISLANDS
FAROE SHETLAND CHANNEL
HYALOCLAST SER. ISOCH. M
1 : 750.000
ABS
13-APR-2000
ABS_FO_
KILOMETERS 0 10 20 KILOMETERS
1:500000
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61°00'
-5°00'
-3°00'
-6°00'

Figure 36

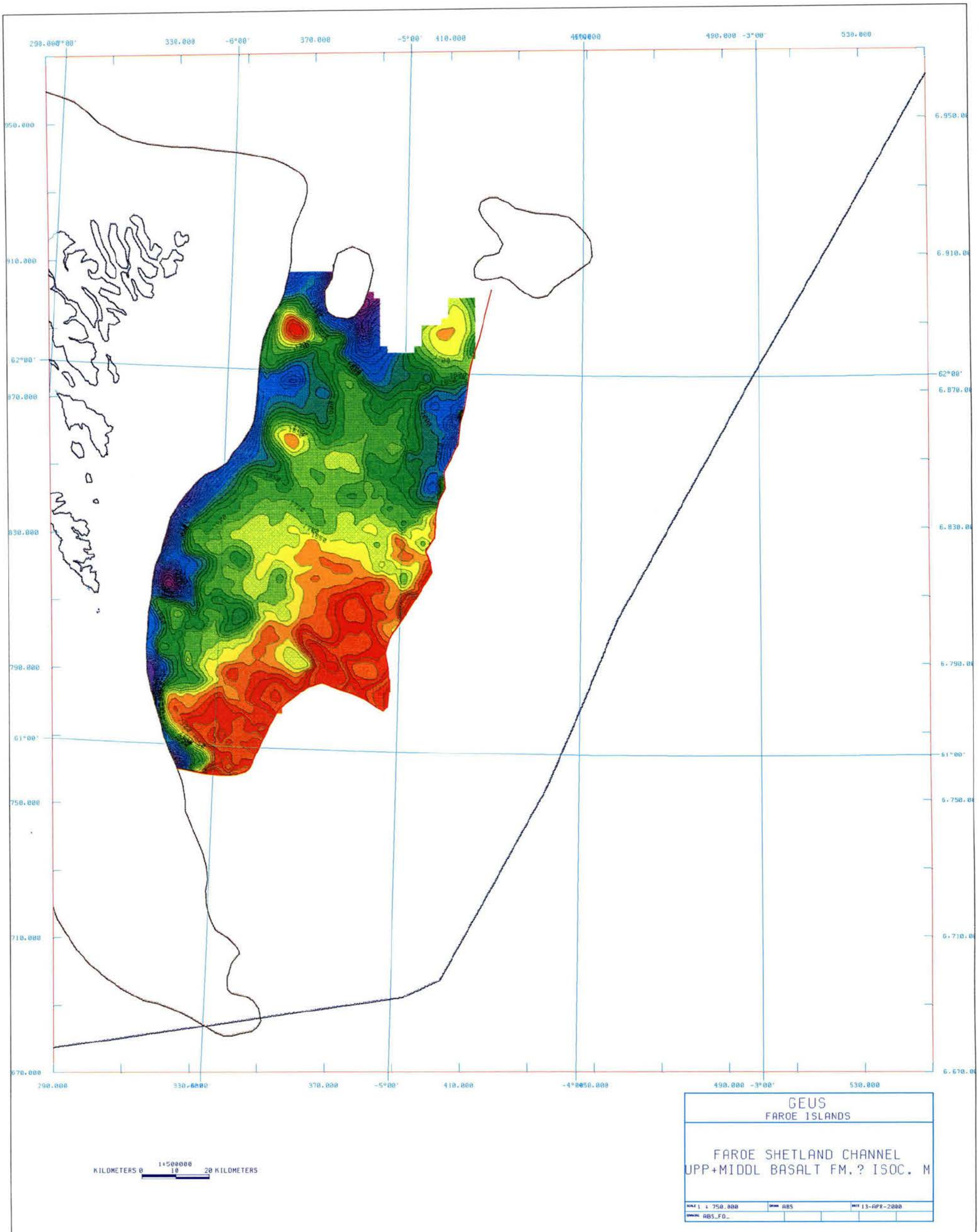
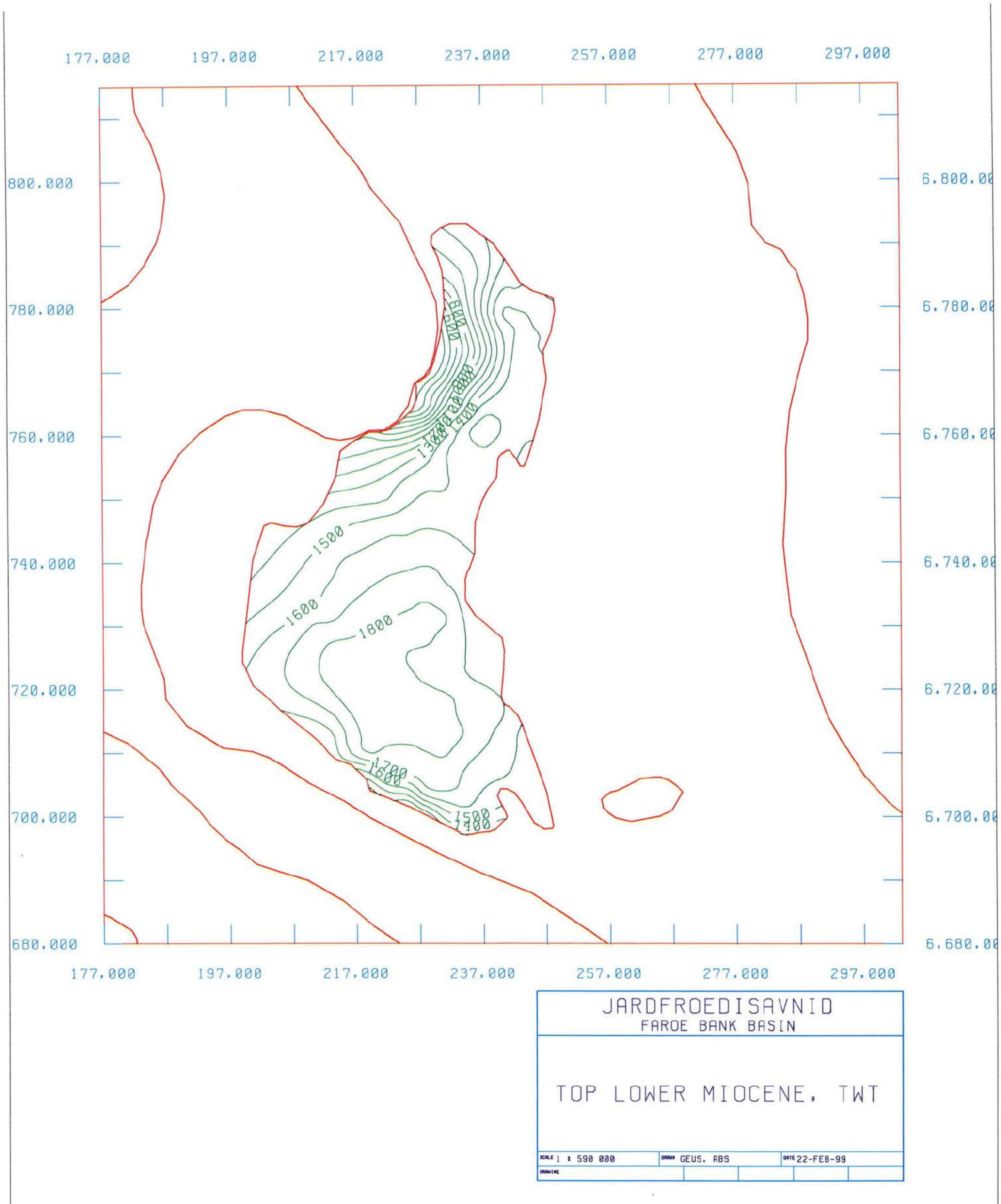

GEUS
FAROE ISLANDS
FAROE SHETLAND CHANNEL
UPP+MIDDL BASALT FM.? ISOC. M
KILOMETERS 0 10 20 KILOMETERS

Figure 37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JARDFROEDISAVNID
FAROE BANK BASIN
TOP LOWER MIOCENE, TWT
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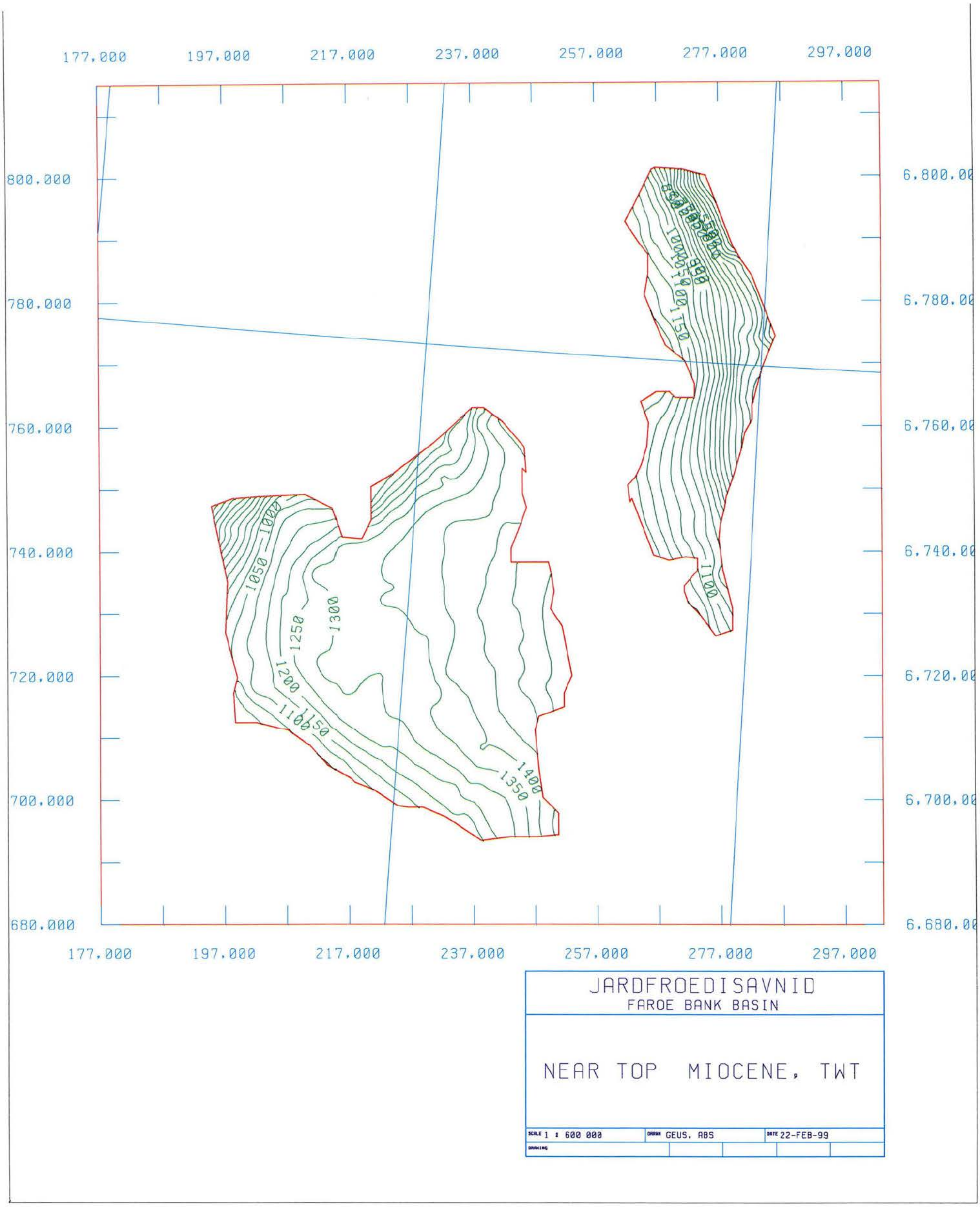
DRAWN GEUS. ABS
DATE 22-FEB-99
DRAWING

Figure 38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JARDFROEDISAVNID
FAROE BANK BASIN
NEAR TOP MIOCENE, TWT
SCALE 1 : 600 000
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DATE 22-FEB-99
DRAWING

Figure 39

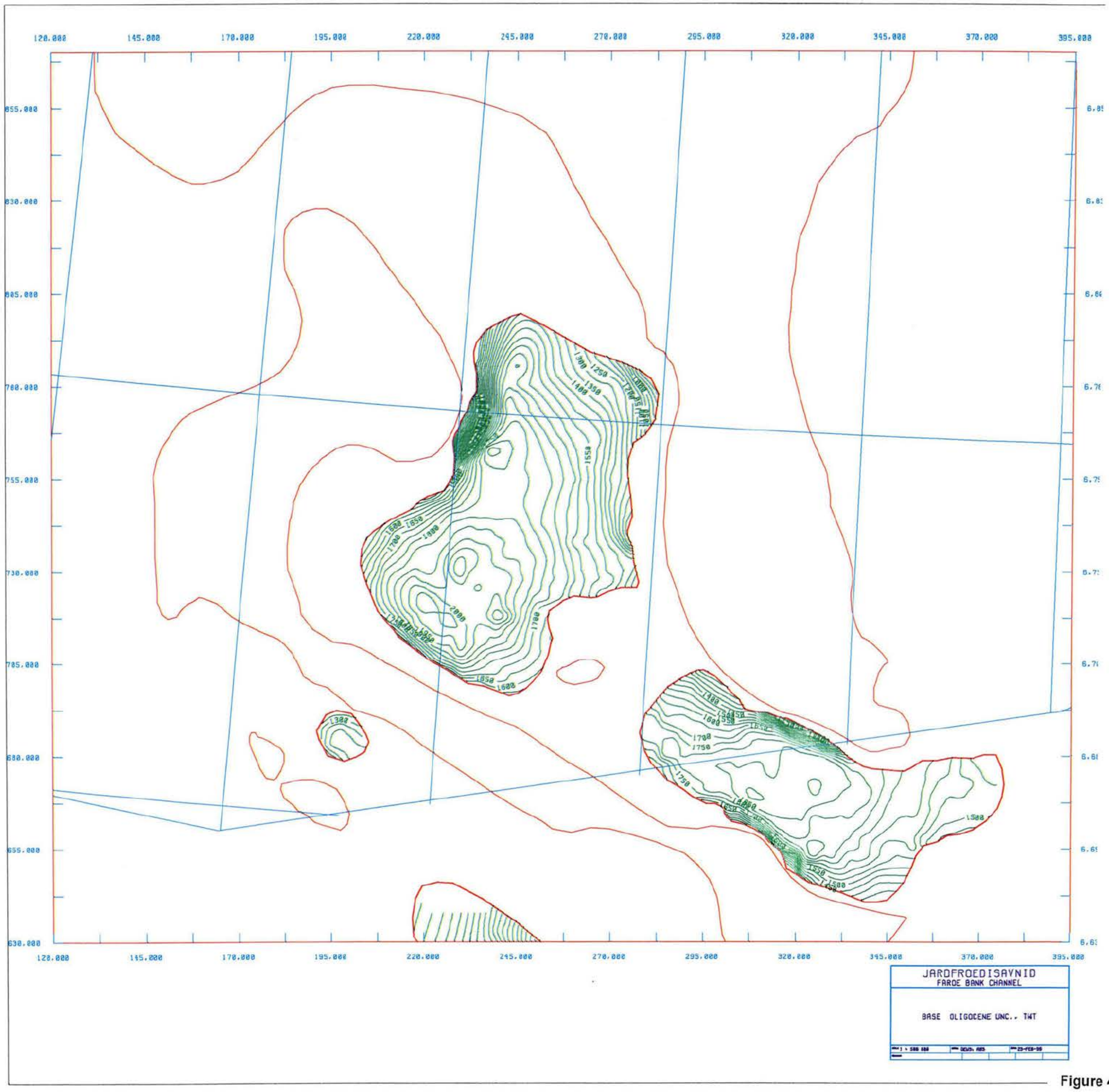
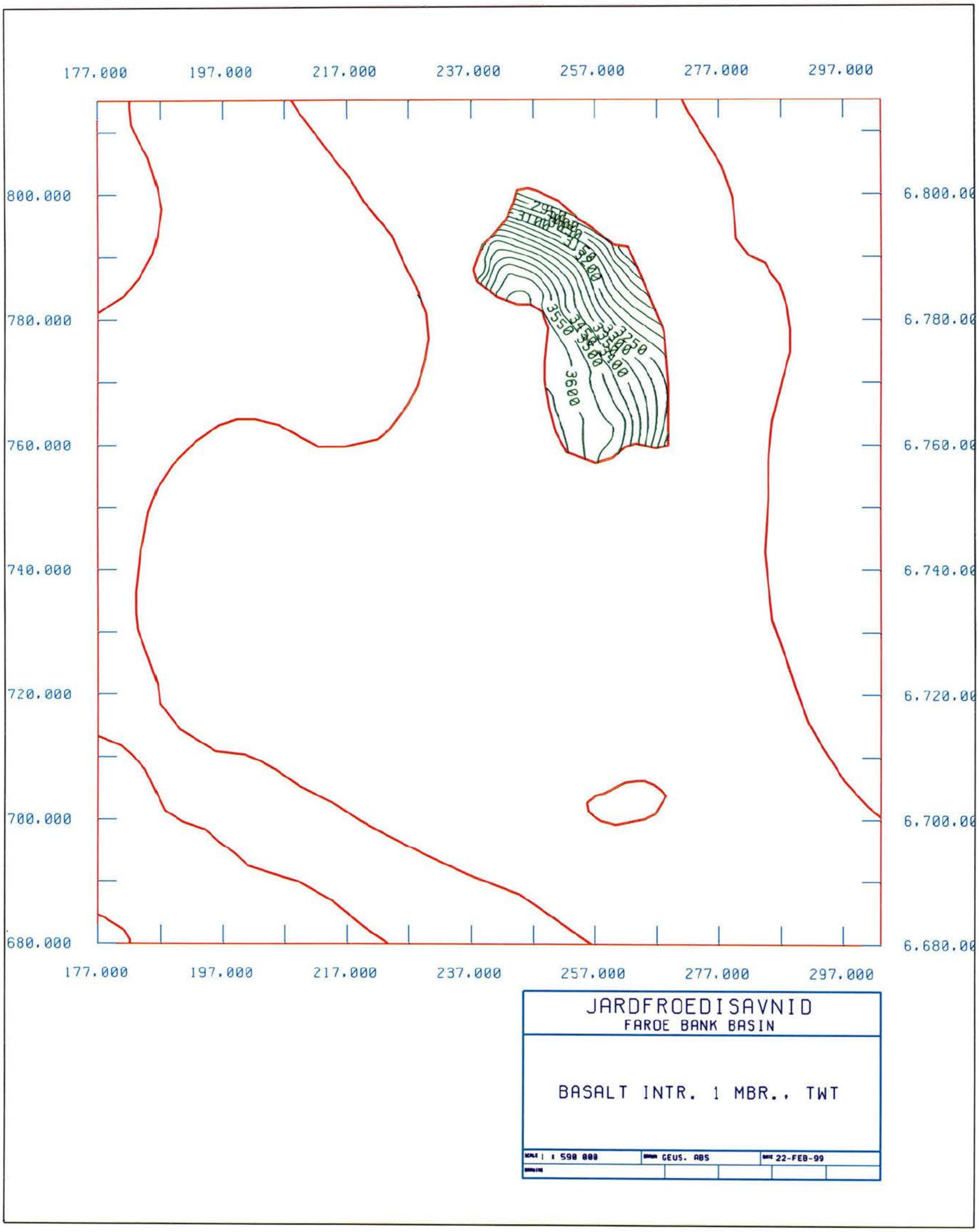

JARDFROEDISAVNID
FAROE BANK CHANNEL
BASE OLIGOCENE UNC., TWT

Figure 40



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3600
3550
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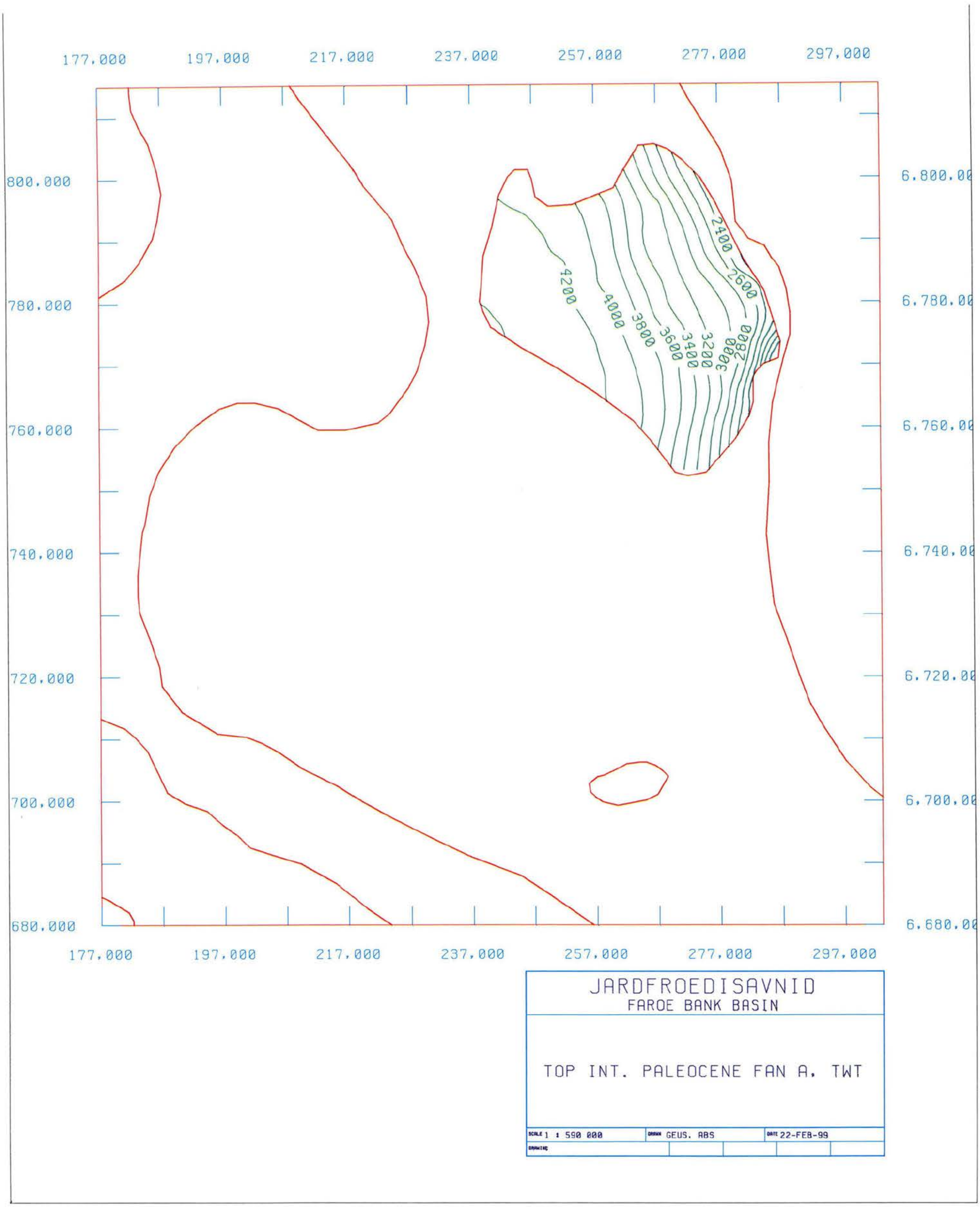
FAROE BANK BASIN
BASALT INTR. 1 MBR., TWT
GEUS. ABS
22-FEB-99

Figure 41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JARDFROEDISAVNID
FAROE BANK BASIN
TOP INT. PALEOCENE FAN A. TWT
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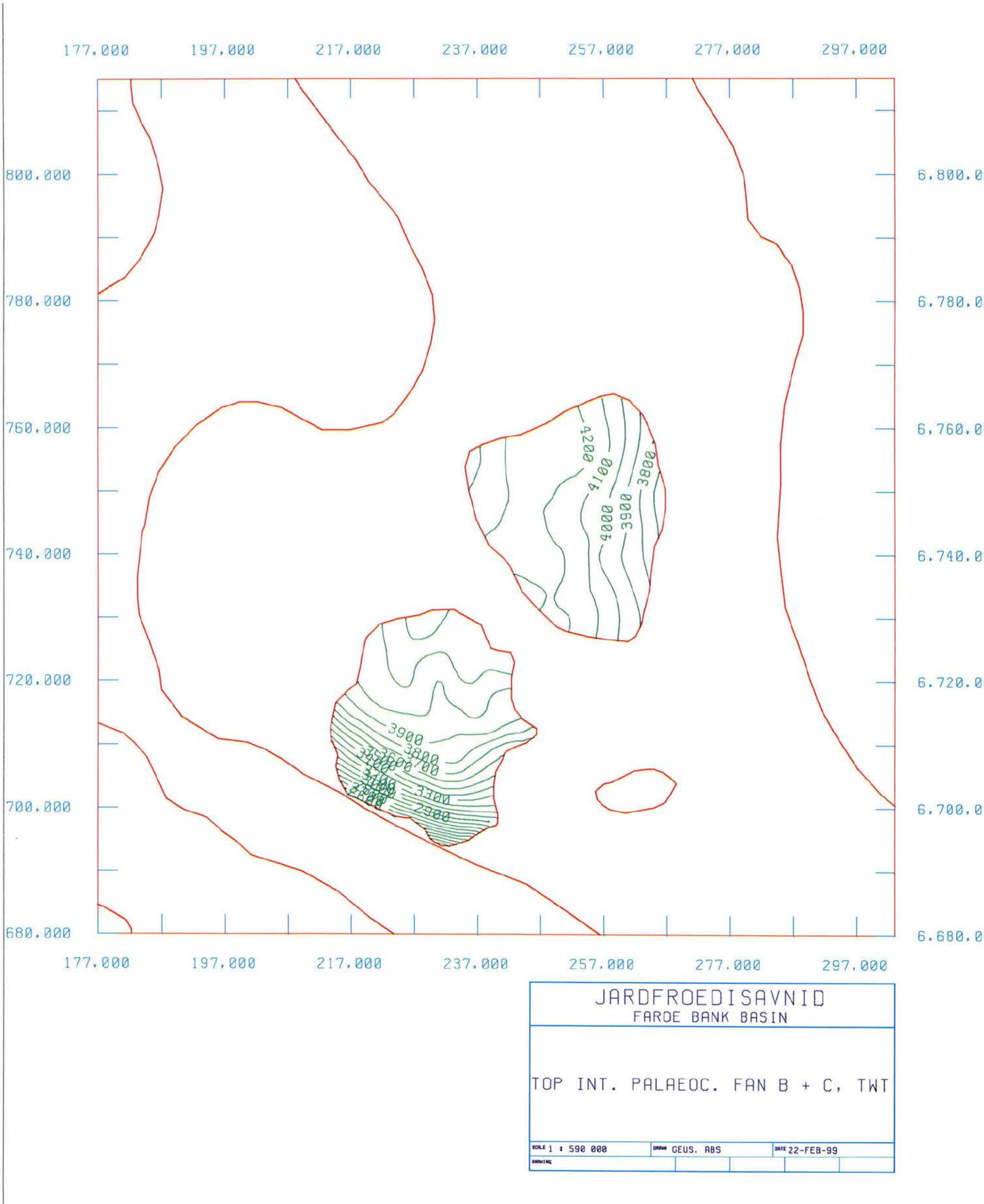
DATE 22-FEB-99
DRAWING

Figure 42



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JARDFROEDISAVNID
FAROE BANK BASIN
TOP INT. PALAEOC. FAN B + C, TWT
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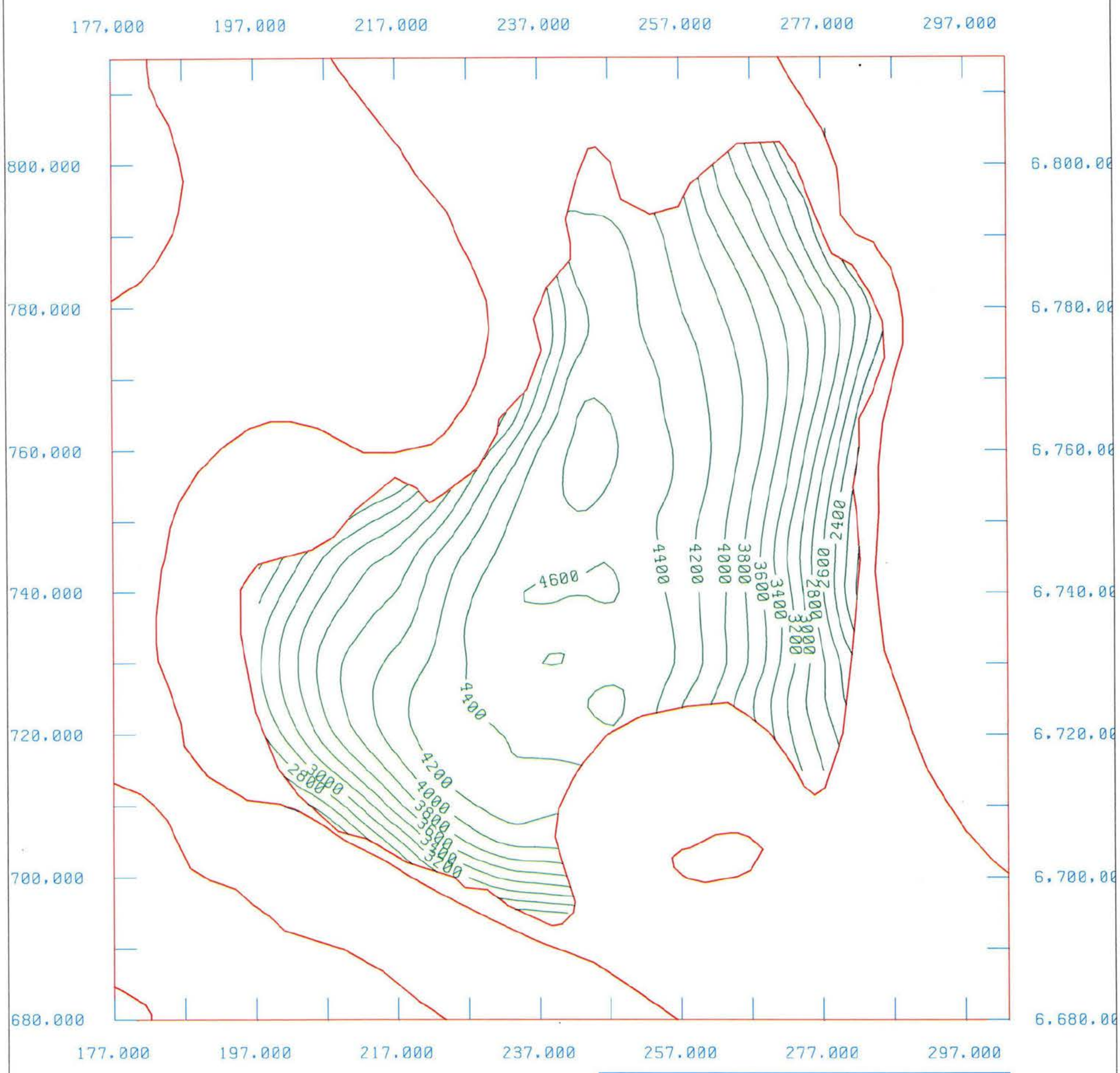
DATE 22-FEB-99
DRAWING

Figure 43



JARDFROEDISAVNID
FAROE BANK BASIN

TOP CRETACEOUS, TWT

SCALE 1 : 590 000	DRAWN GEUS, ABS	DATE 22-FEB-99
DRAWING		

Figure 44

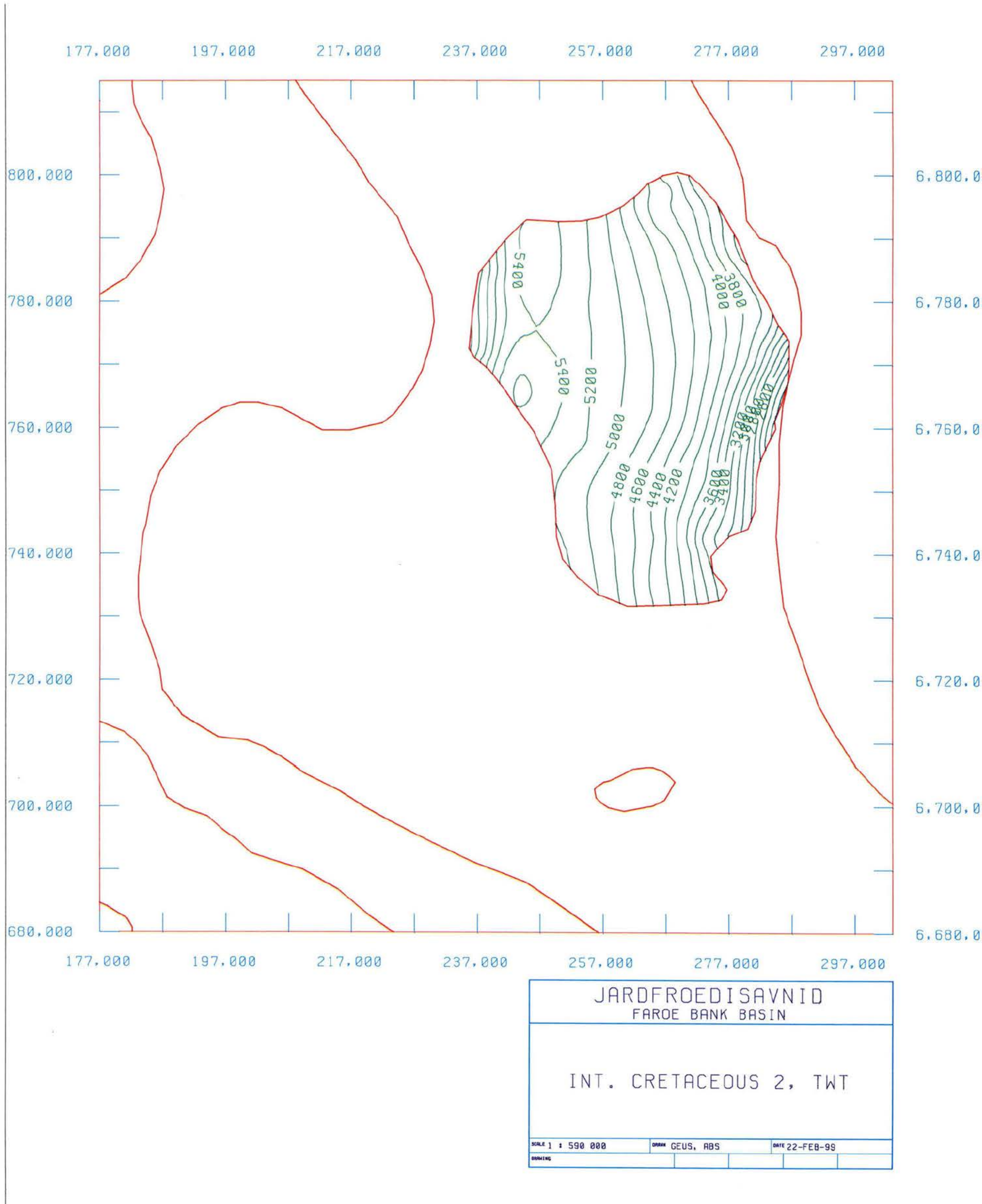
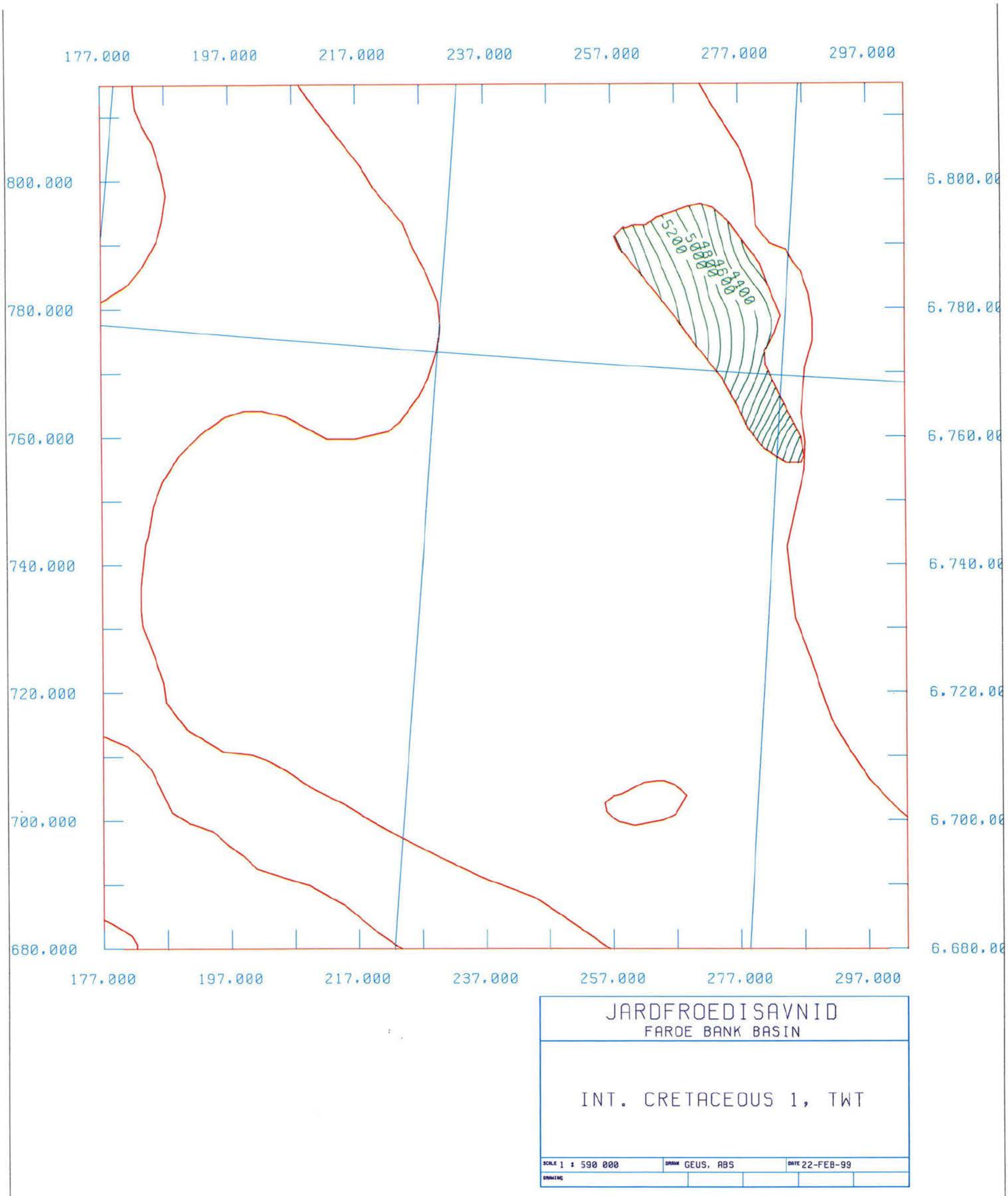

177.000
197.000
217.000
237.000
257.000
277.000
297.000
800.000
780.000
760.000
740.000
720.000
700.000
680.000
6.800.00
6.780.00
6.760.00
6.740.00
6.720.00
6.700.00
6.680.00
5400
5200
5000
4800
4600
4400
4200
4000
3800
3600
3400
3200
JARDFROEDISAVNID
FAROE BANK BASIN
INT. CRETACEOUS 2, TWT
SCALE 1 : 590 000
DRAWN GEUS, ABS
DATE 22-FEB-99
DRAWING

Figure 45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197.000
217.000
237.000
257.000
277.000
297.000
800.000
780.000
760.000
740.000
720.000
700.000
680.000
6.800.00
6.780.00
6.760.00
6.740.00
6.720.00
6.700.00
6.680.00
5200
JARDFROEDISAVNID
FAROE BANK BASIN
INT. CRETACEOUS 1, TWT
SCALE 1 : 590 000
DRAWN GEUS, ABS
DATE 22-FEB-99
DRAWING

Figure 46

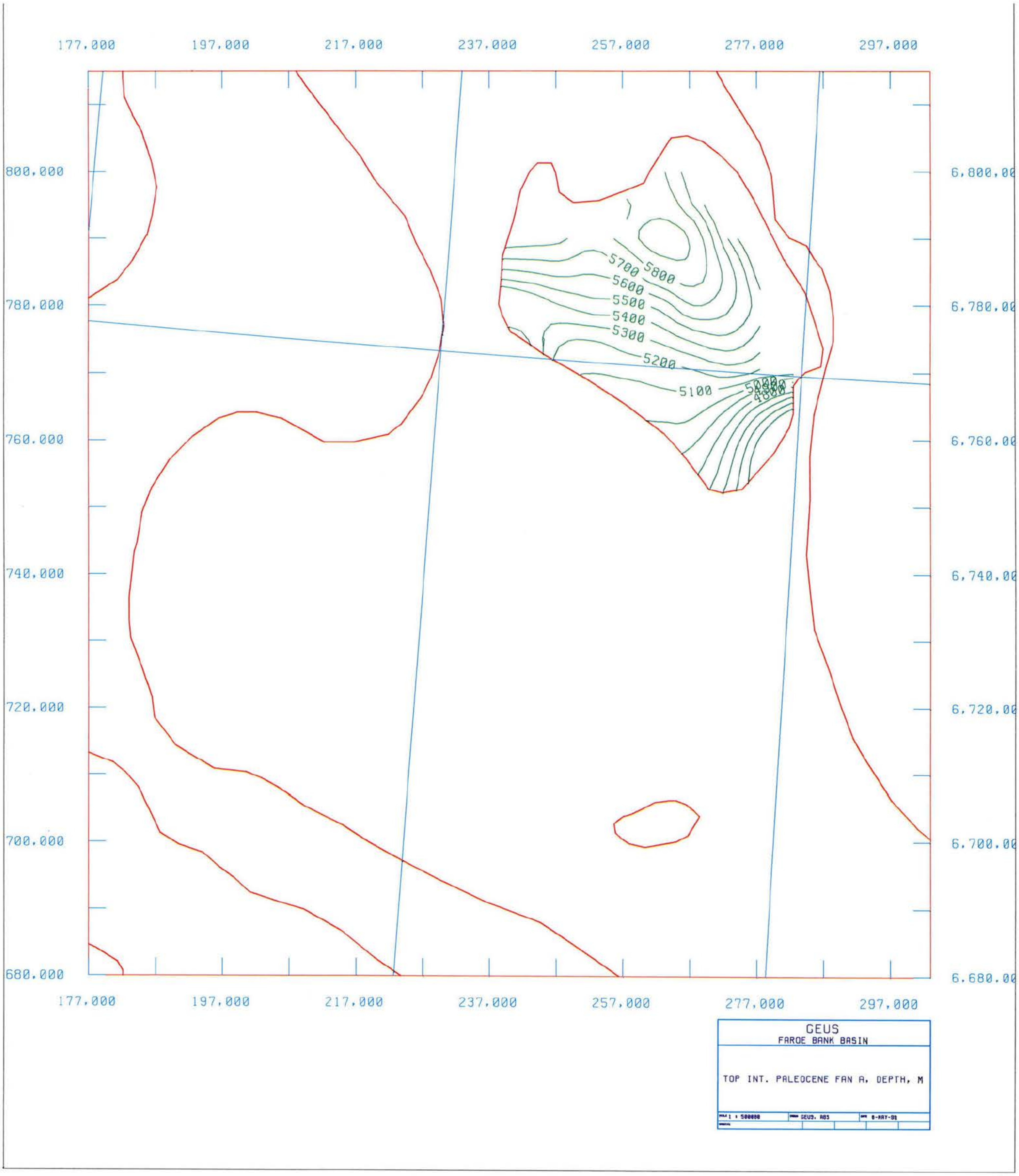
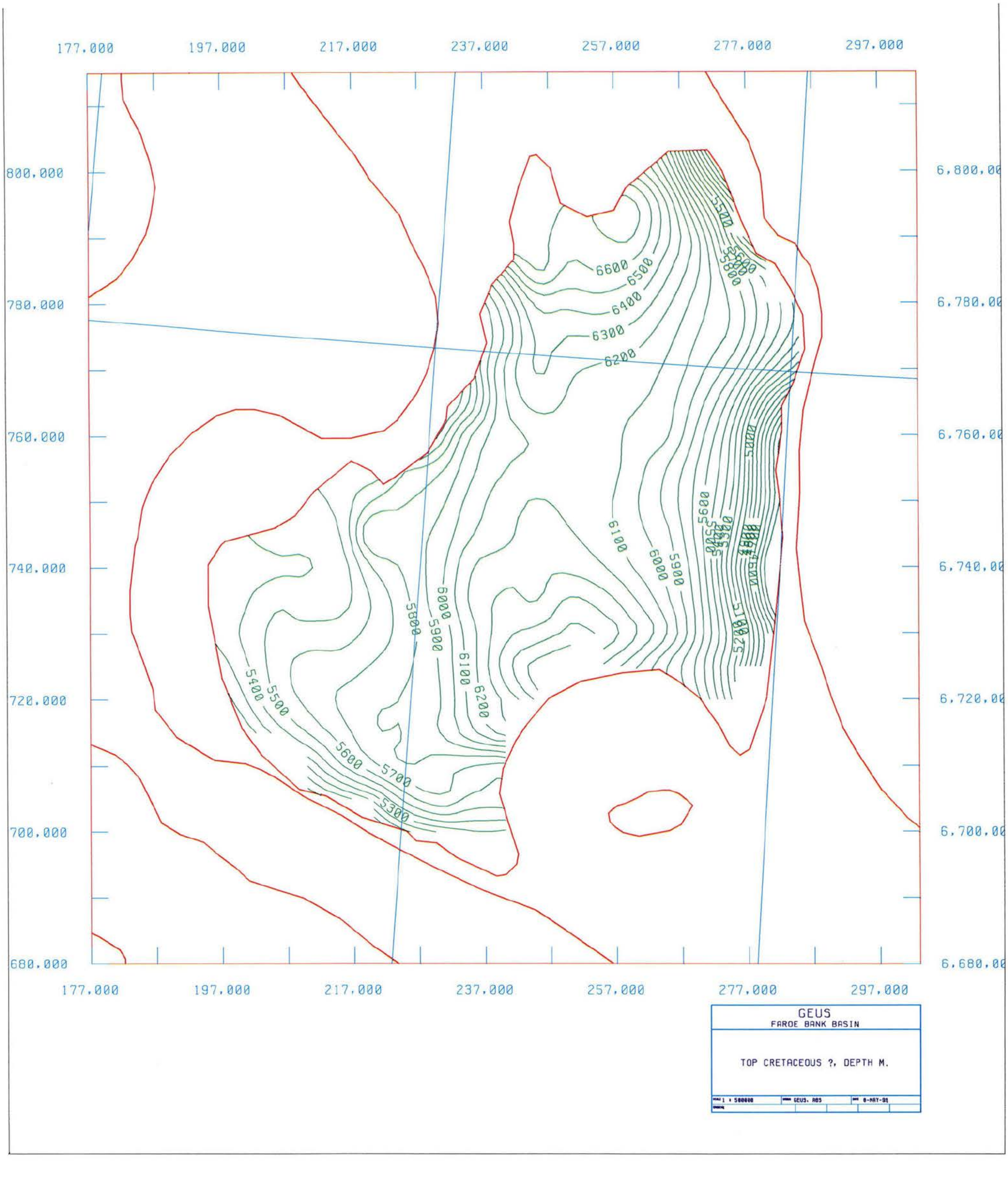
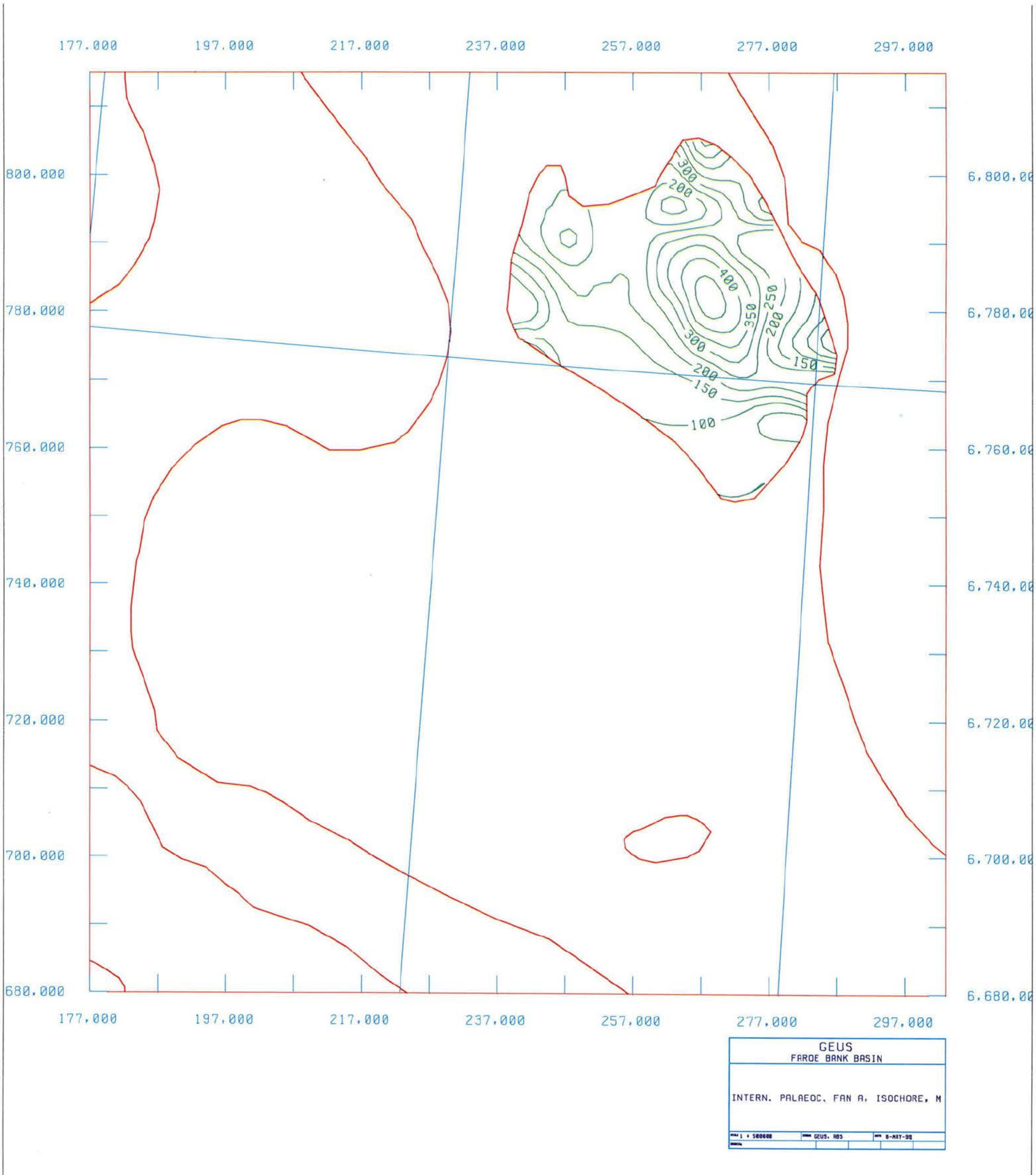

177,000
197,000
217,000
237,000
257,000
277,000
297,000
800,000
780,000
760,000
740,000
720,000
700,000
680,000
6,800,00
6,780,00
6,760,00
6,740,00
6,720,00
6,700,00
6,680,00
5800
5700
5600
5500
5400
5300
5200
5100
GEUS
FAROE BANK BASIN
TOP INT. PALEOCENE FAN A, DEPTH, M
1 : 500000
GEUS, ABS

Figure 47



177.000
197.000
217.000
237.000
257.000
277.000
297.000
800.000
780.000
760.000
740.000
720.000
700.000
680.000
6,800.00
6,780.00
6,760.00
6,740.00
6,720.00
6,700.00
6,680.00
6600
6500
6400
6300
6200
5500
5800
6100
6000
5900
5600
5400
5300
5700
6200
5200
5100
GEUS
FAROE BANK BASIN
TOP CRETACEOUS ?, DEPTH M.

Figure 48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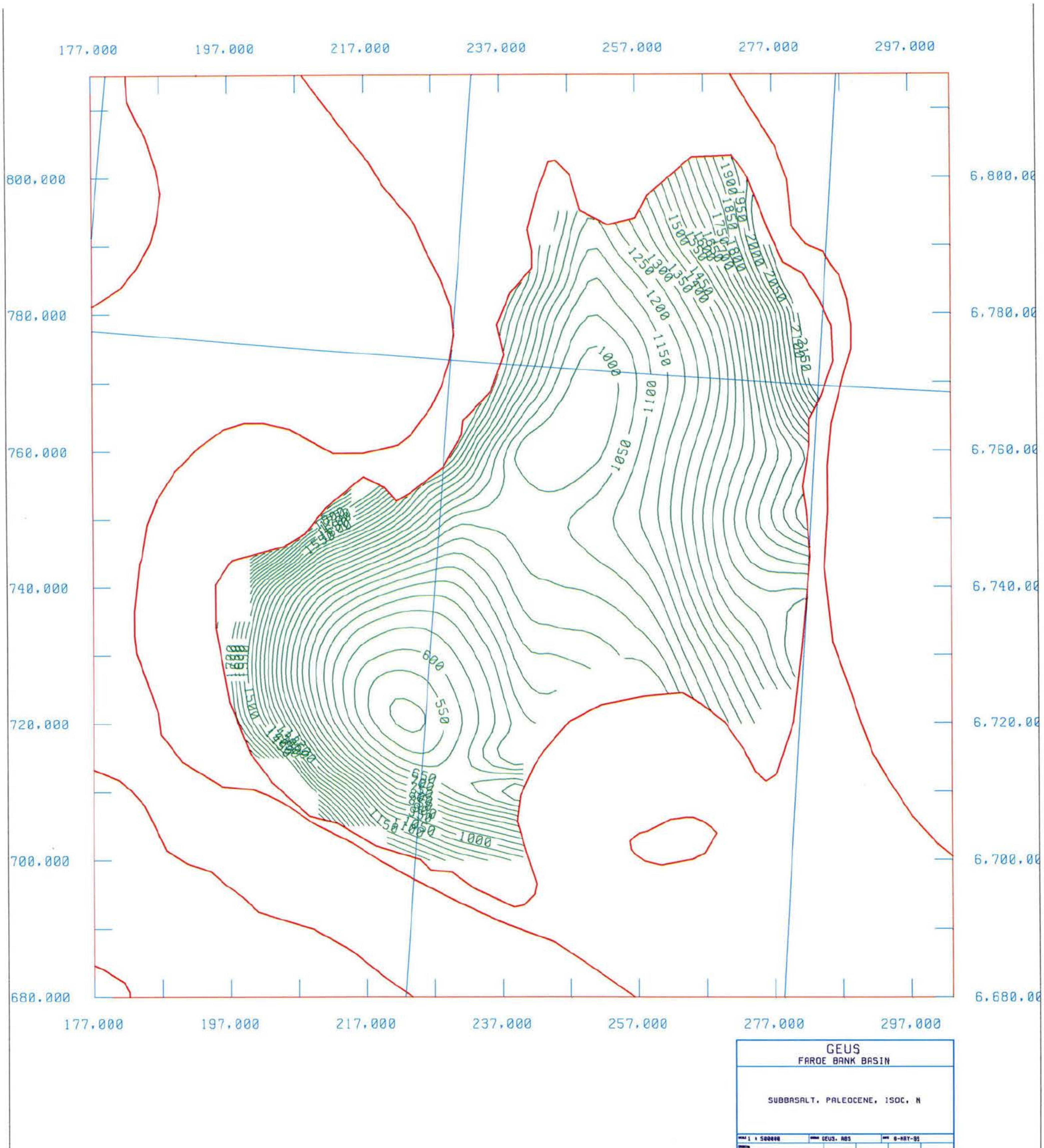
217.000
237.000
257.000
277.000
297.000
800.000
780.000
760.000
740.000
720.000
700.000
680.000
6,800.00
6,780.00
6,760.00
6,740.00
6,720.00
6,700.00
6,680.00
300
200
400
350
250
150
100
GEUS
FAROE BANK BASIN
INTERN. PALAEOC. FAN A, ISOCHORE, M
1 : 500000
GEUS, ABS
8-MAY-98

Figure 49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237.000
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277.000
297.000
800.000
780.000
760.000
740.000
720.000
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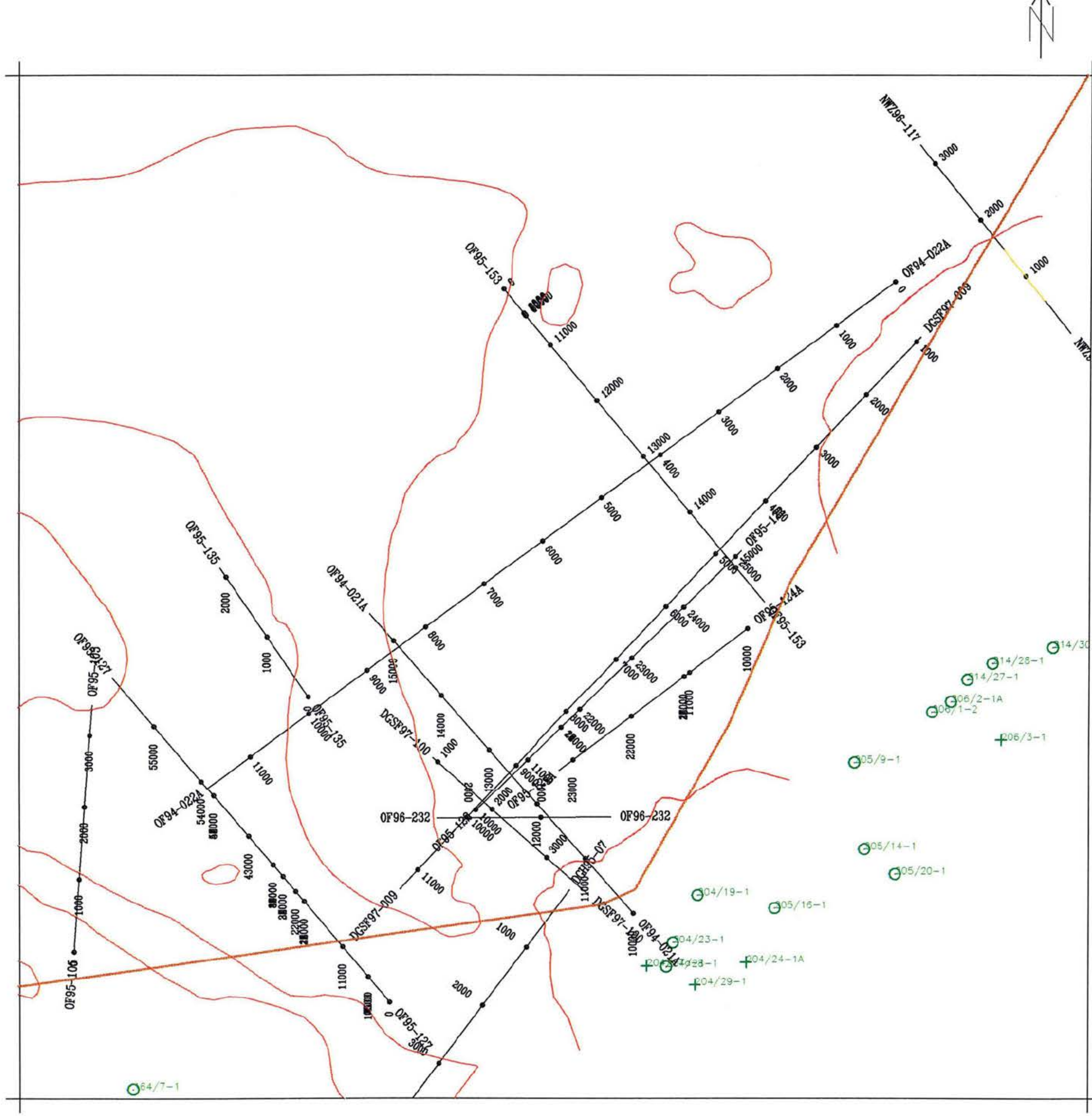
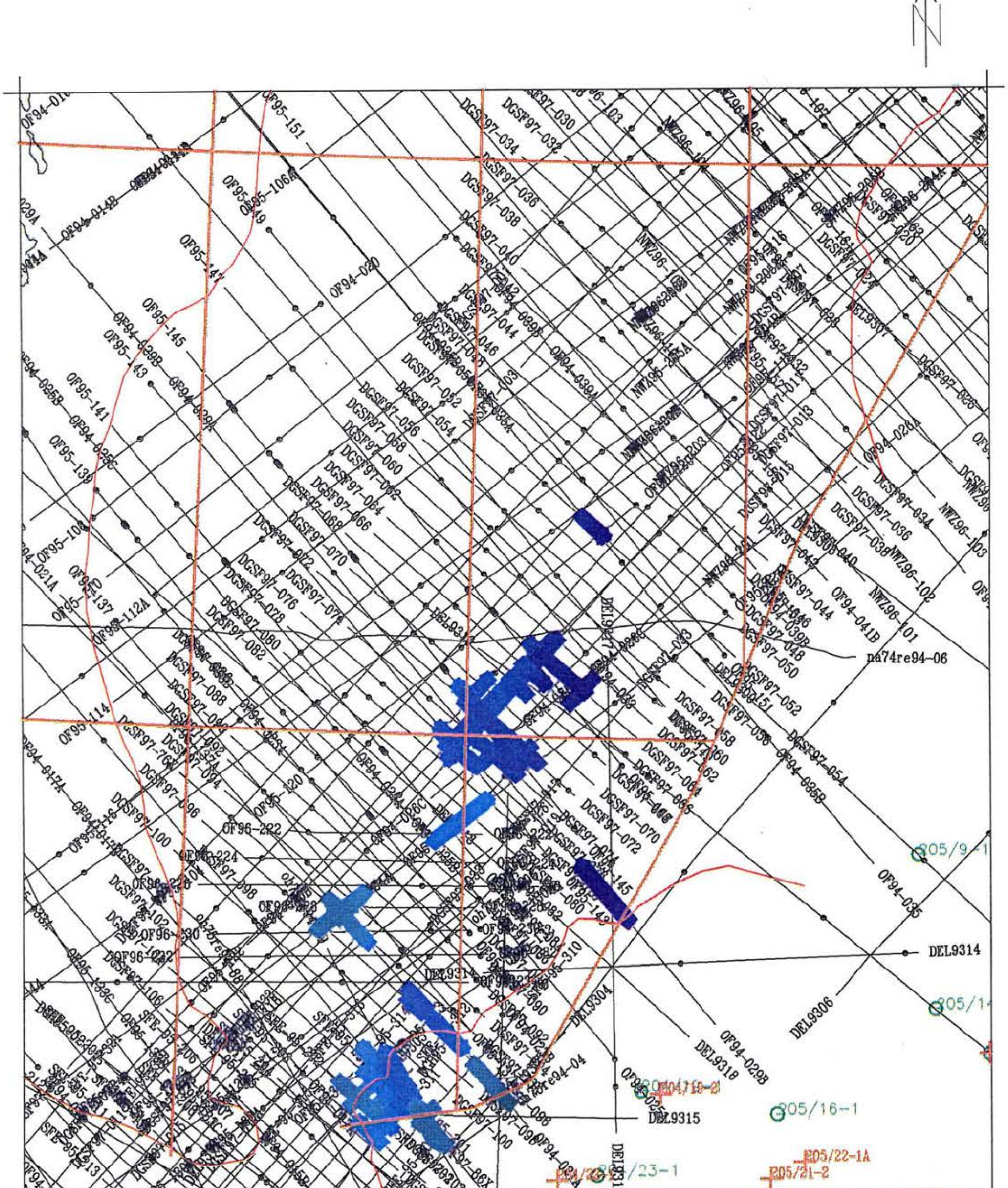
680.000
6,800.00
6,780.00
6,760.00
6,740.00
6,720.00
6,700.00
6,680.00
600
550
1000
1050
1100
1150
1200
GEUS
FAROE BANK BASIN
SUBBASALT. PALEOCENE. ISOC. M

Figure 50



NWZ96-117
OF94-022A
DGSF97-009
OF95-153
OF95-135
OF94-021A
OF95-127
OF95-106
OF96-232
DGSF97-100
204/19-1
204/23-1
204/24-1A
204/29-1
205/9-1
205/14-1
205/20-1
205/16-1
206/2-1A
206/1-2
206/3-1
214/28-1
214/27-1
164/7-1

Figure 52



HRZ:(1896.00,4004.00) Prospect_1

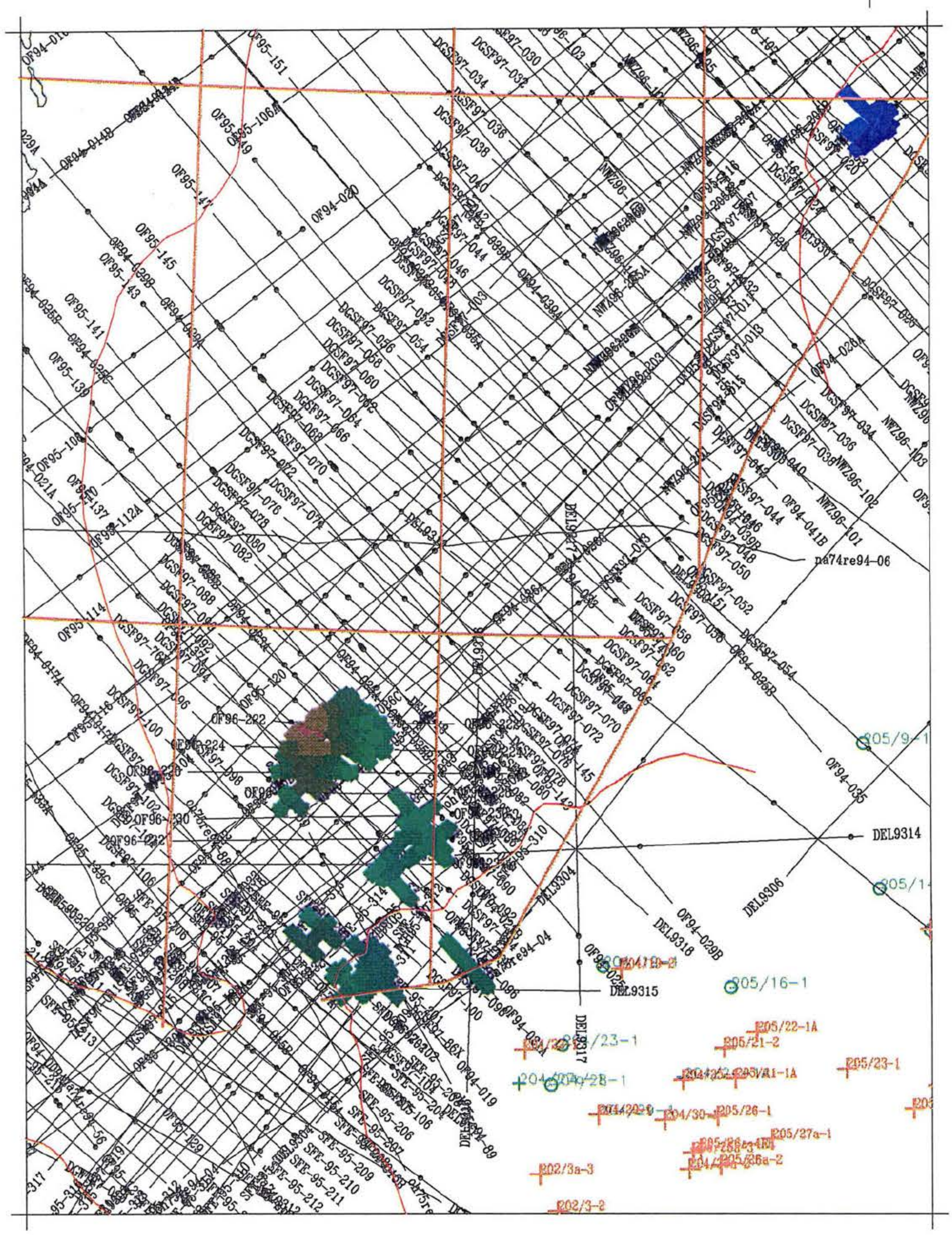
Prospect_1

Paleocene amp anomal.

0m 50000m 100000m

1cm. = 10000 meters

Figure 53



HRZ:(1483.34,4122.00) Prospekt_2

Prospekt_2

8-Nov-2000 16:26

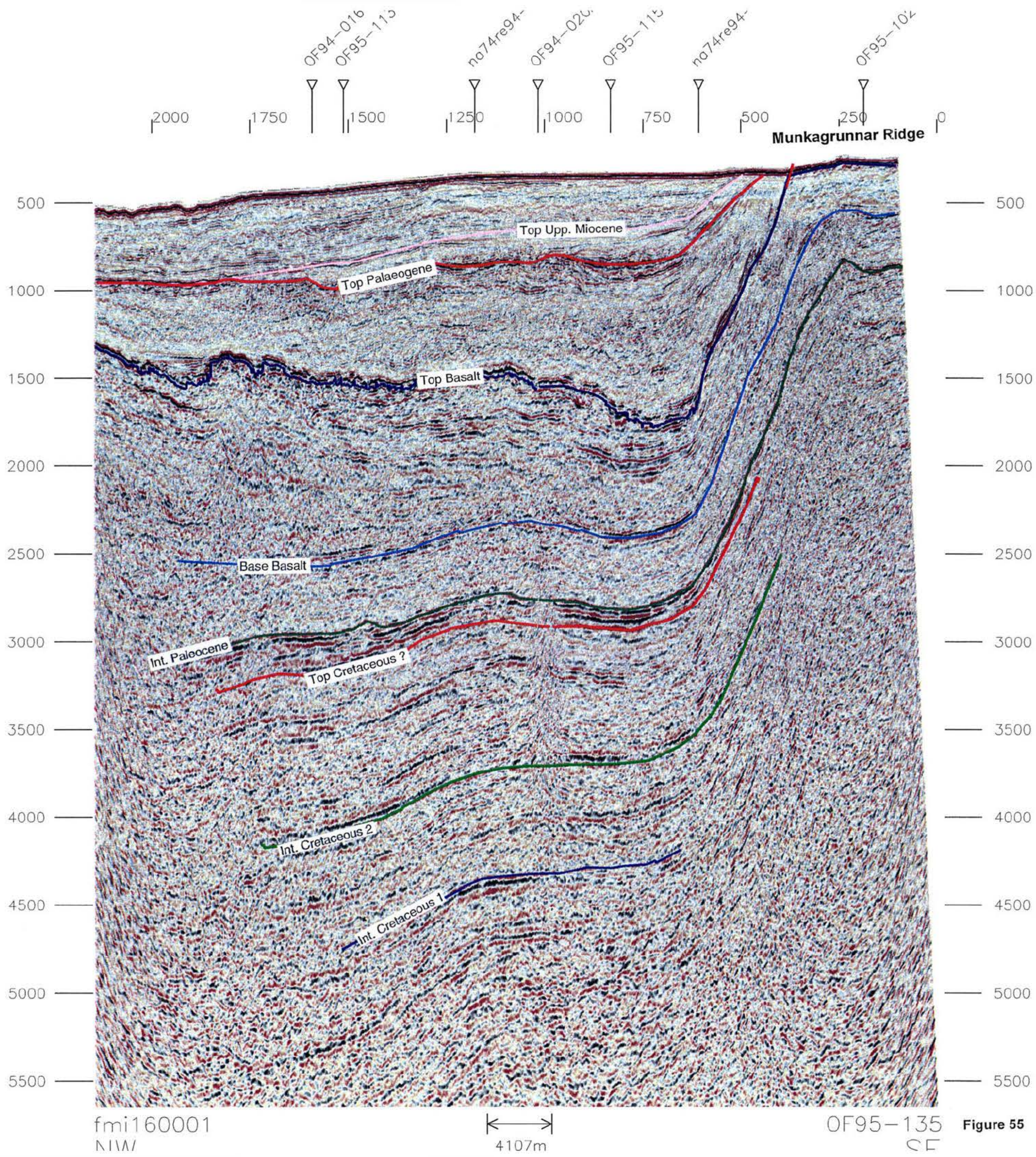
prosp_Eocene

Eocene amp anomal.

0m 50000m 100000m

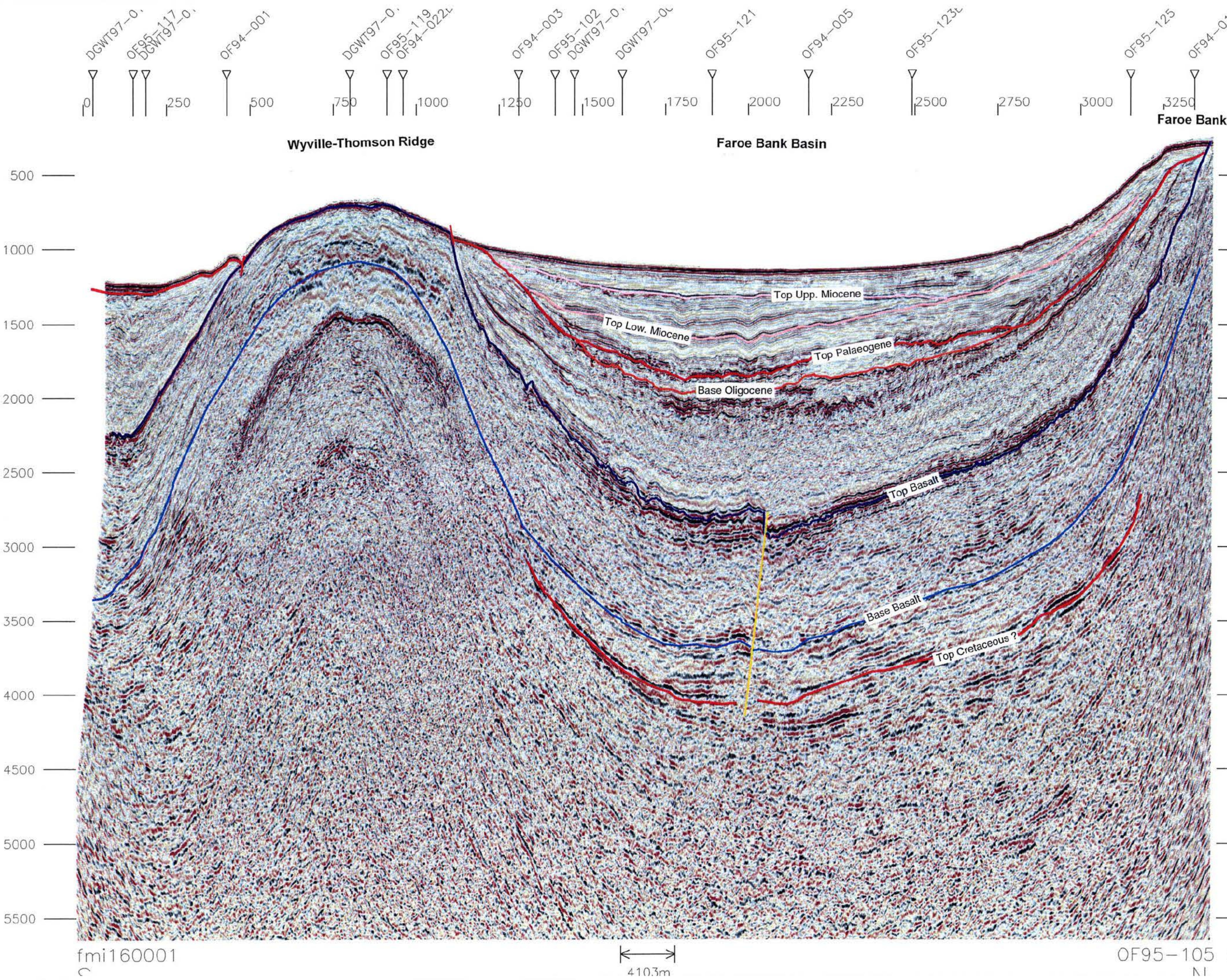
1cm. = 10000 meters

Figure 54



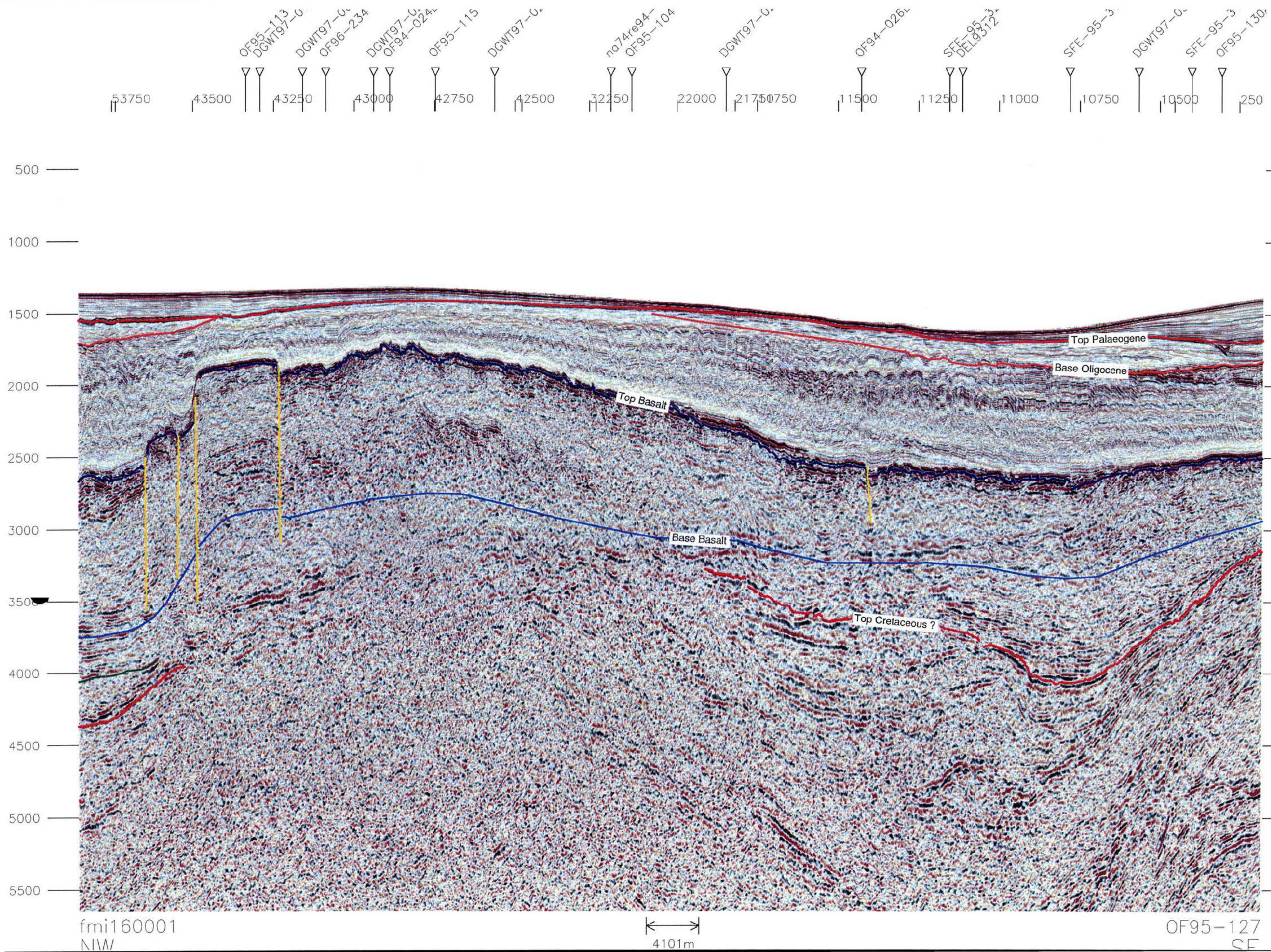
OF94-016
OF95-113
na74re94-
OF94-020
OF95-113
na74re94-
OF95-102
2000
1750
1500
1250
1000
750
500
250
0
Munkagrunnar Ridge
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
Top Upp. Miocene
Top Palaeogene
Top Basalt
Base Basalt
Int. Paleocene
Top Cretaceous ?
Int. Cretaceous 2
Int. Cretaceous 1
fmi160001
NW
4107m
OF95-135
SE

Figure 55



OF95-117
OF94-001
OF95-119
OF94-003
OF95-102
OF95-121
OF94-005
OF95-125
OF94-016
Faroe Bank
Wyville-Thomson Ridge
Faroe Bank Basin
Top Upp. Miocene
Top Low. Miocene
Top Palaeogene
Base Oligocene
Top Basalt
Base Basalt
Top Cretaceous ?
fmi160001
OF95-105
4103m

Figure 56



Top Palaeogene
Base Oligocene
Top Basalt
Base Basalt
Top Cretaceous ?
fmi160001
NW
OF95-127
SE
4101m

Figure 57

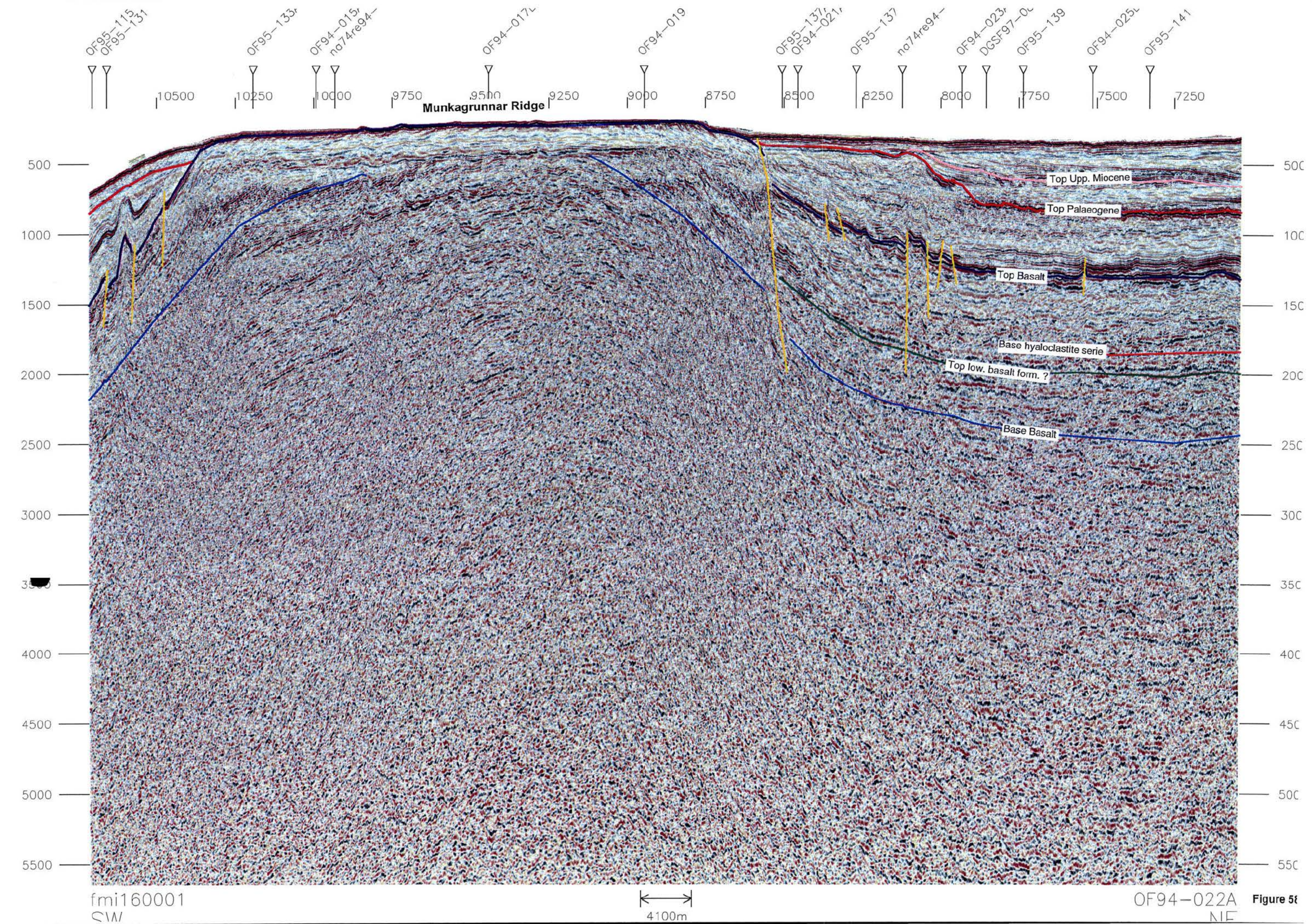
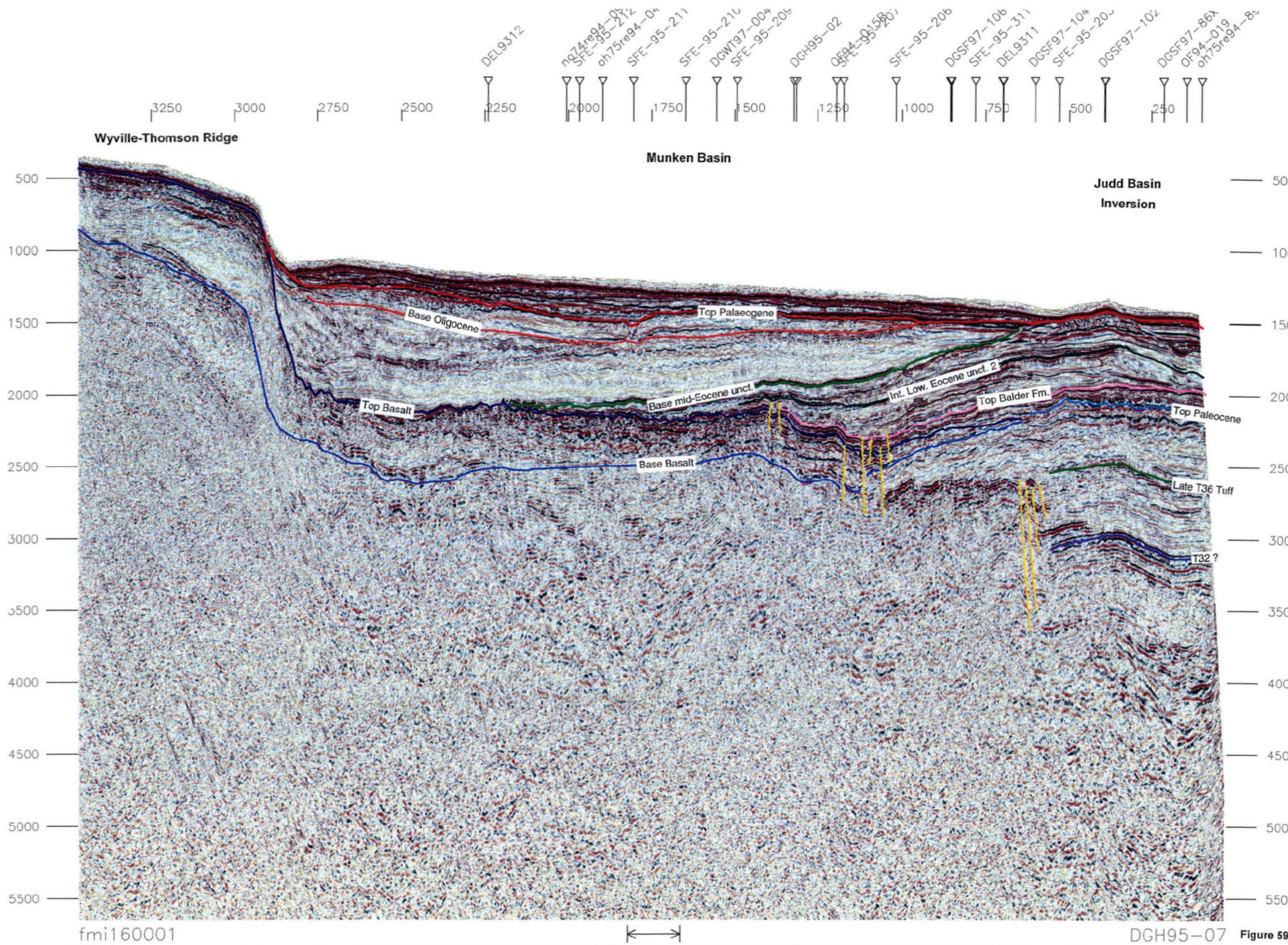
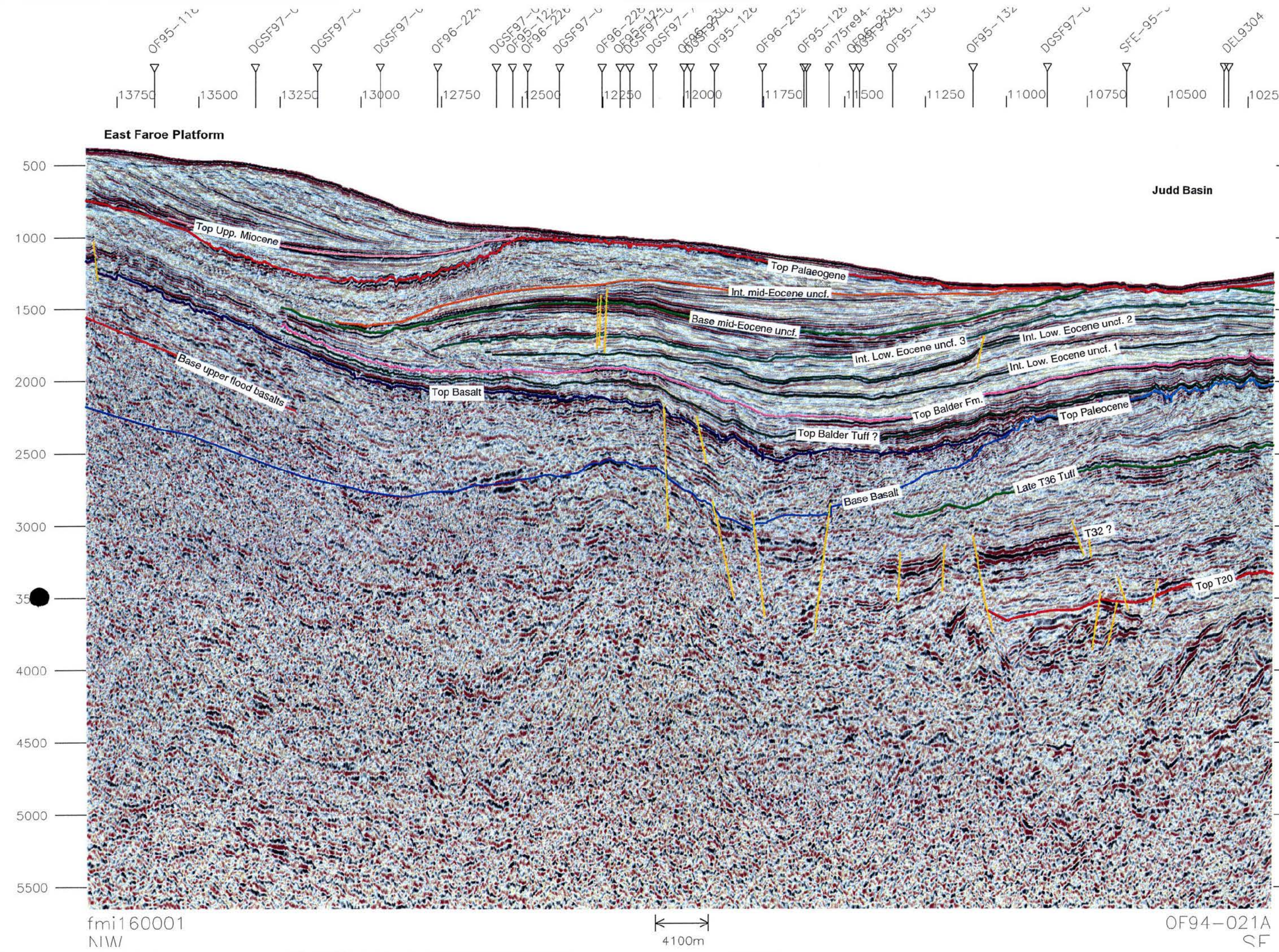

Munkagrunnar Ridge
OF95-139
OF94-019
OF95-141
10500
10250
10000
9750
9500
9250
9000
8750
8500
8250
8000
7750
7500
7250
Top Upp. Miocene
Top Palaeogene
Top Basalt
Base hyaloclastite serie
Top low. basalt form. ?
Base Basalt
500
1000
1500
2000
2500
3000
4000
4500
5000
5500
fmi160001
4100m
OF94-022A

Figure 5



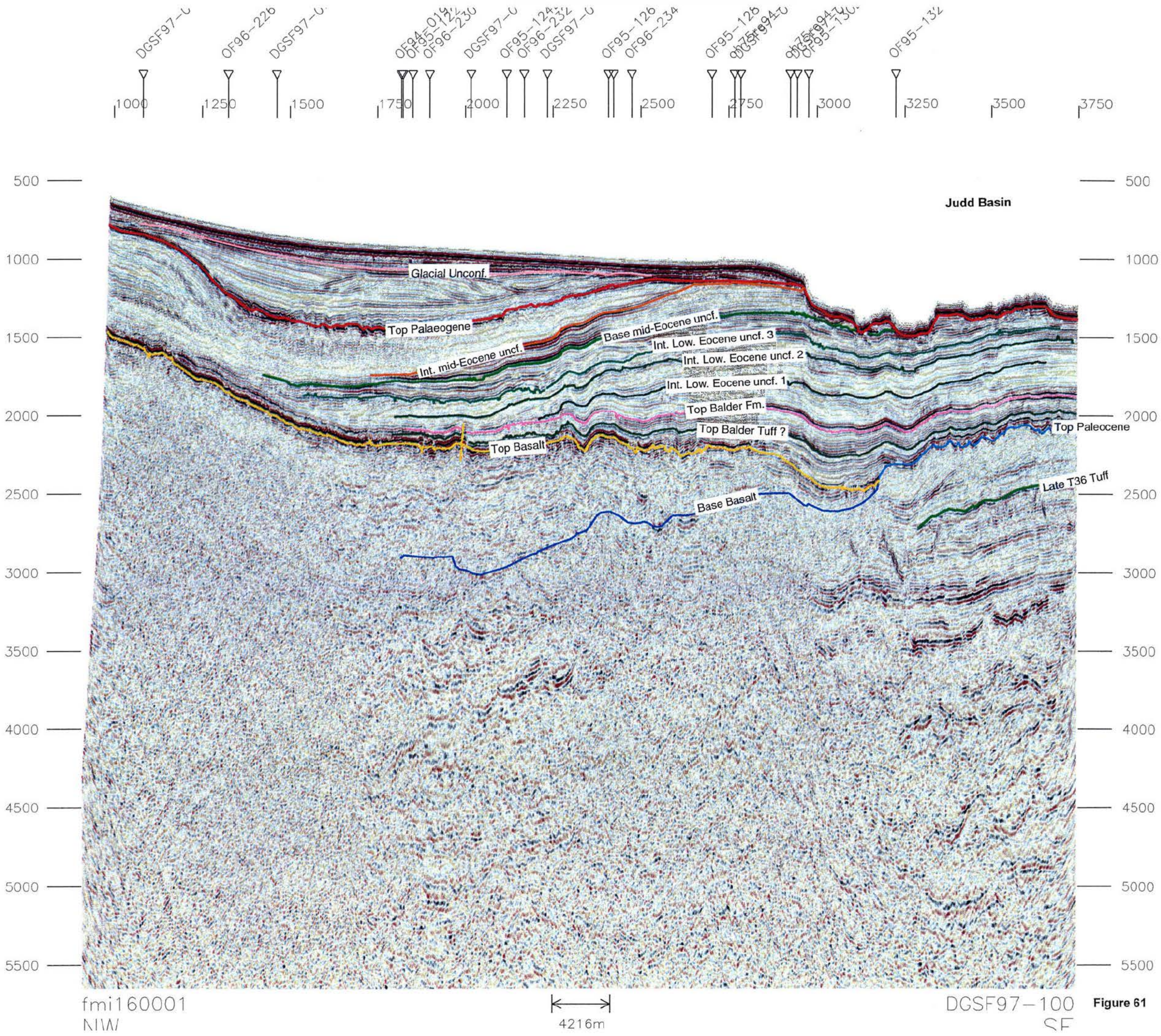
DEL9312
SFE-95-211
SFE-95-210
DCWT97-004
DGH95-02
SFE-95-206
DGSF97-106
DEL9311
DGSF97-104
DGSF97-102
DGSF97-86x
OF94-019
Wyville-Thomson Ridge
Munken Basin
Judd Basin
Inversion
Base Oligocene
Top Palaeogene
Base mid-Eocene unct.
Int. Low. Eocene unct. 2
Top Balder Fm.
Top Paleocene
Top Basalt
Base Basalt
Late T36 Tuff
T32 ?
fmi160001
DGH95-07

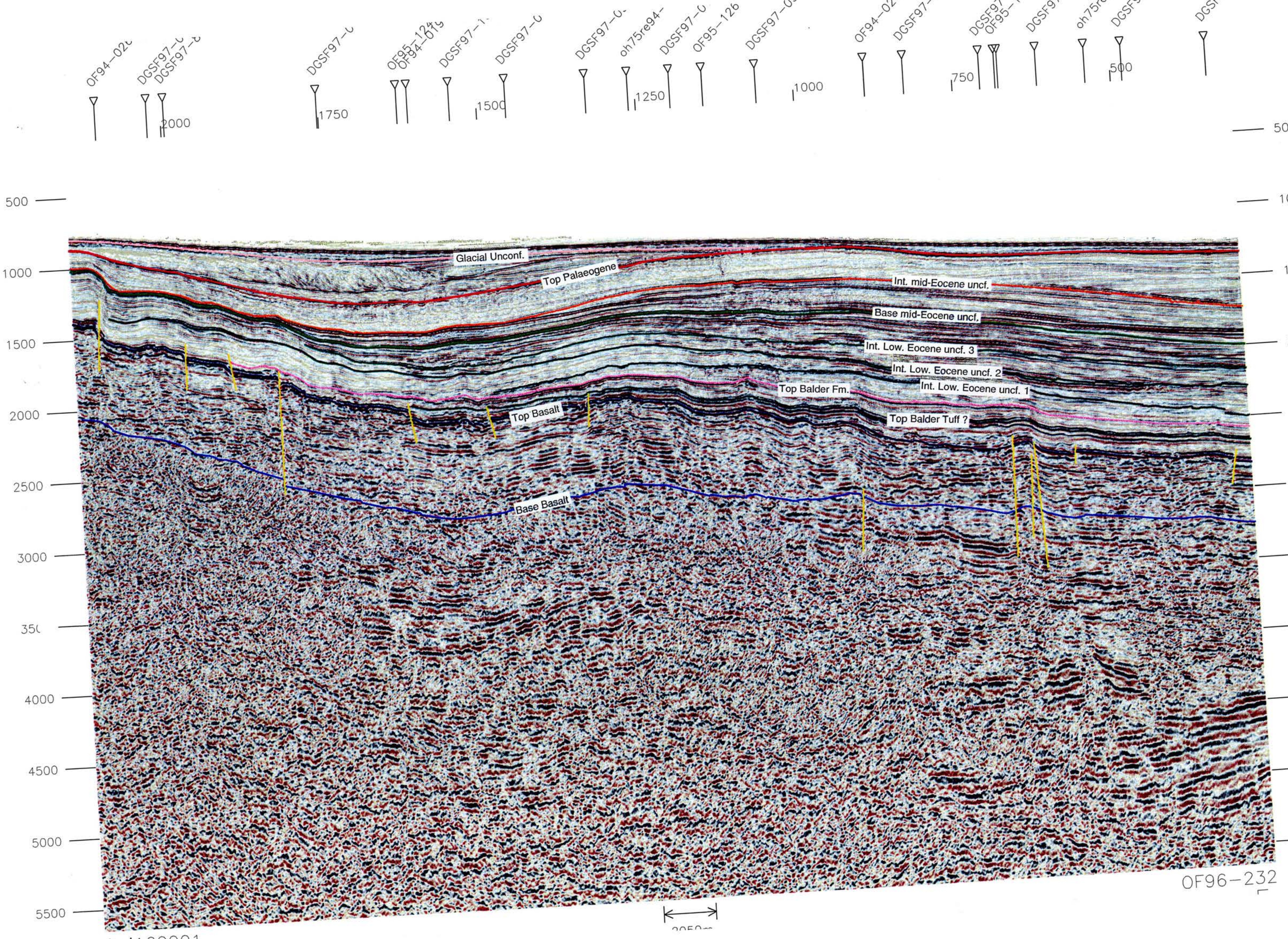
Figure 59



OF95-118
DGSF97-0
DGSF97-0
DGSF97-0
OF96-224
DGSF97-0
OF95-122
OF96-226
DGSF97-0
OF96-228
OF95-124
DGSF97-0
DGSF97-1
OF96-230
DGSF97-0
OF95-126
OF96-232
OF95-128
oh75re94-
OF96-234
DGSF97-0
OF95-130
OF95-132
DGSF97-0
SFE-95-5
DEL9304
13750
13500
13250
13000
12750
12500
12250
12000
11750
11500
11250
11000
10750
10500
10250
East Faroe Platform
Judd Basin
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
Top Upp. Miocene
Top Palaeogene
Int. mid-Eocene uncf.
Base mid-Eocene uncf.
Int. Low. Eocene uncf. 3
Int. Low. Eocene uncf. 2
Int. Low. Eocene uncf. 1
Base upper flood basalts
Top Basalt
Top Balder Fm.
Top Paleocene
Top Balder Tuff ?
Late T36 Tuff
Base Basalt
T32 ?
Top T20
fmi160001
NW
4100m
OF94-021A
SE

Figure 60


DGSF97-0
OF96-226
DGSF97-0
OF94-019
OF95-122
OF96-230
DGSF97-0
OF95-124
OF96-232
DGSF97-0
OF95-126
OF96-234
OF95-128
DGSF97-0
OF95-130
OF95-132
1000
1250
1500
1750
2000
2250
2500
2750
3000
3250
3500
3750
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
Judd Basin
Glacial Unconf.
Top Palaeogene
Int. mid-Eocene uncf.
Base mid-Eocene uncf.
Int. Low. Eocene uncf. 3
Int. Low. Eocene uncf. 2
Int. Low. Eocene uncf. 1
Top Balder Fm.
Top Balder Tuff ?
Top Basalt
Top Paleocene
Late T36 Tuff
Base Basalt
fmi160001
NW
4216m
DGSF97-100
SE
Figure 61



Glacial Unconf.
Top Palaeogene
Int. mid-Eocene uncf.
Base mid-Eocene uncf.
Int. Low. Eocene uncf. 3
Int. Low. Eocene uncf. 2
Int. Low. Eocene uncf. 1
Top Balder Fm.
Top Balder Tuff ?
Top Basalt
Base Basalt
OF96-232

Figure 6

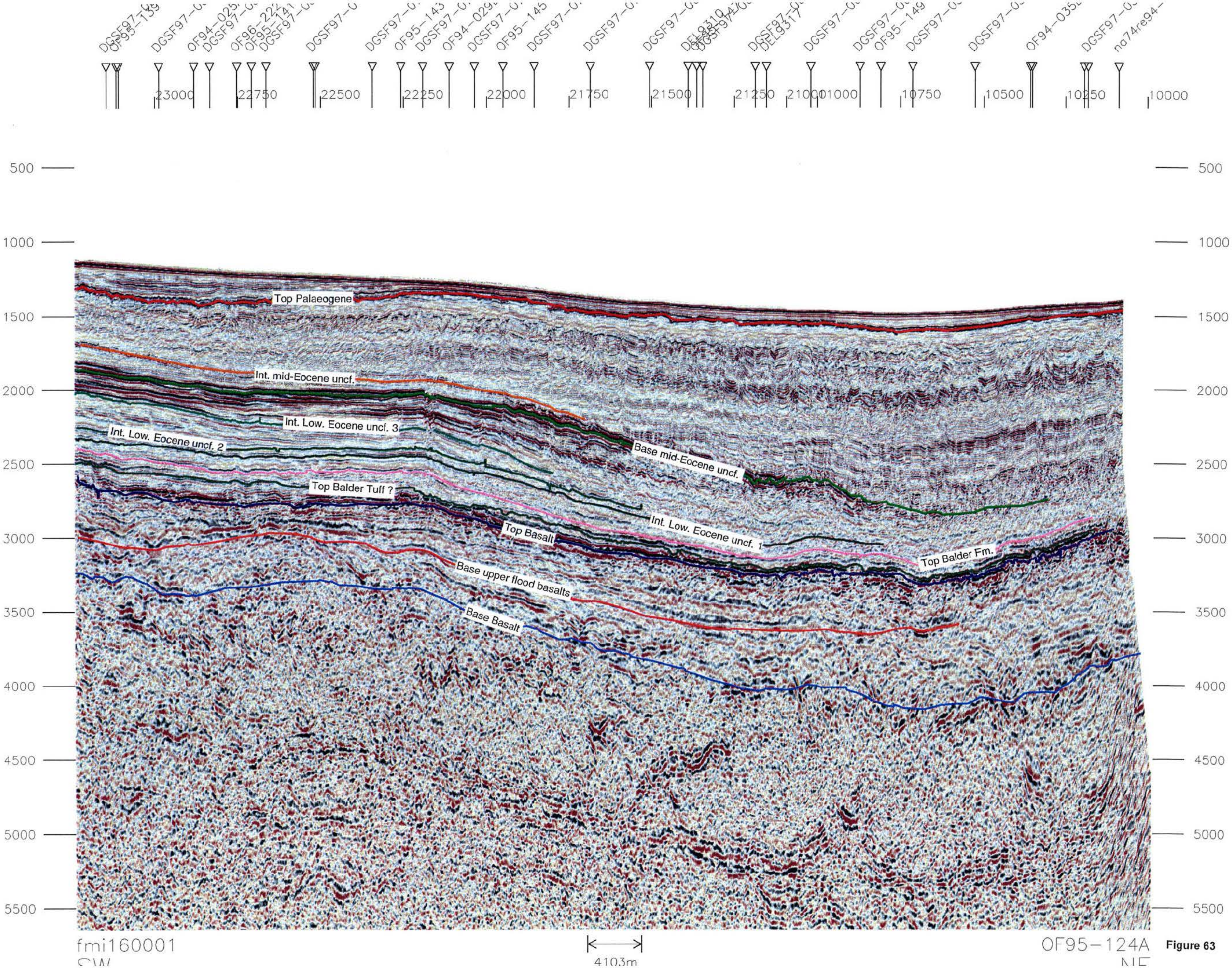
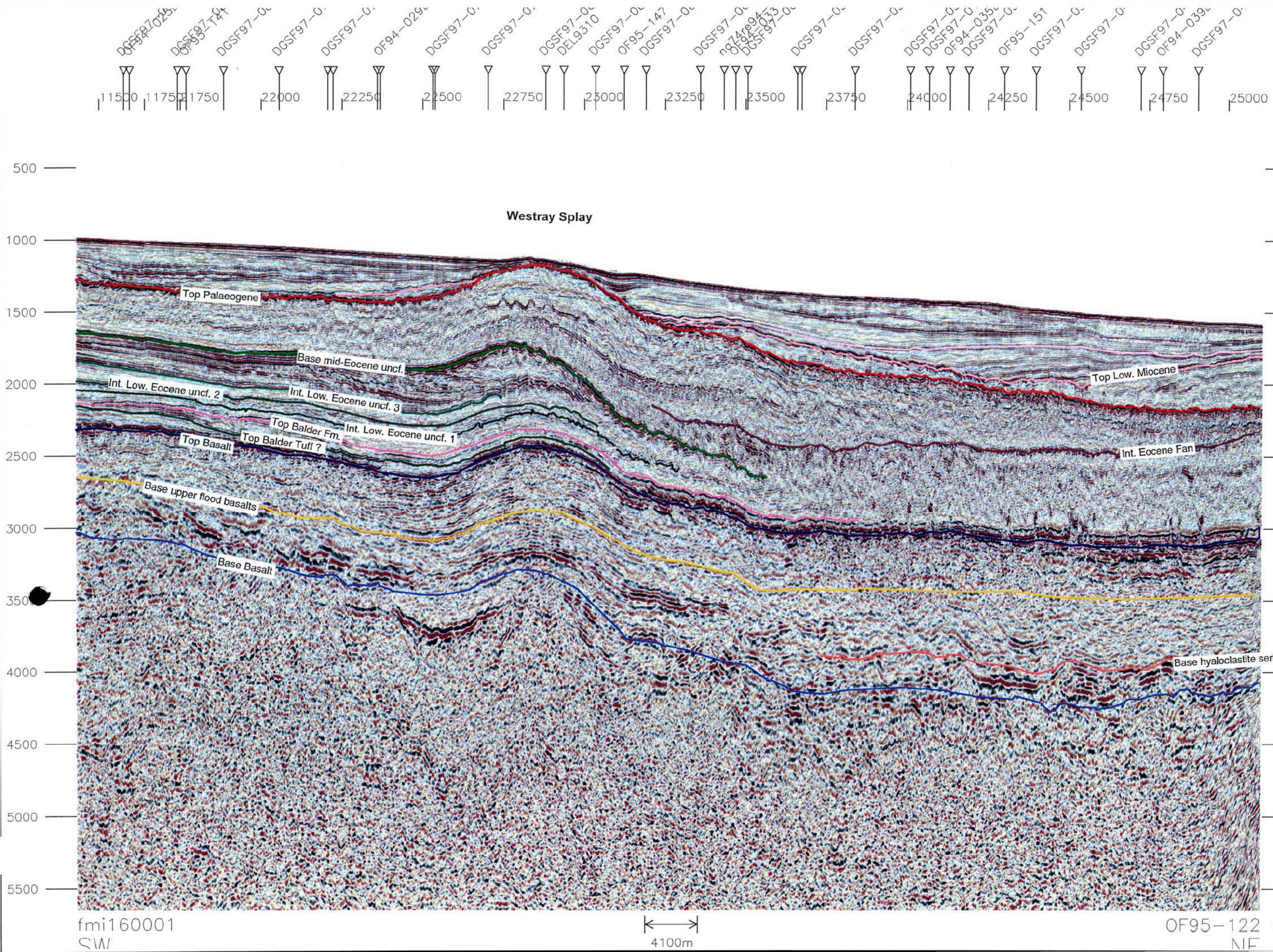
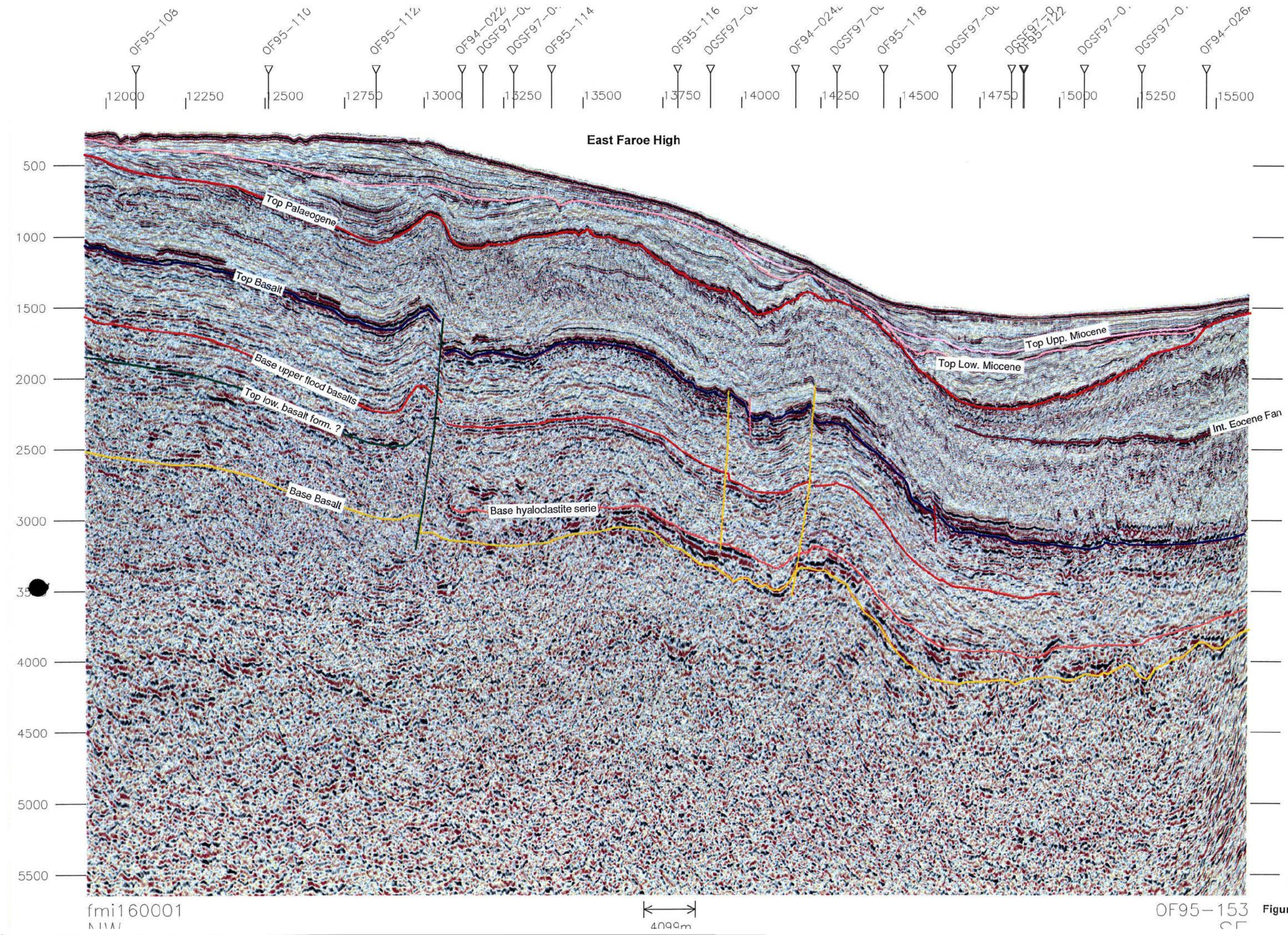

Top Palaeogene
Int. mid-Eocene uncf.
Int. Low. Eocene uncf. 3
Int. Low. Eocene uncf. 2
Base mid-Eocene uncf.
Top Balder Tuff ?
Int. Low. Eocene uncf. 1
Top Basalt
Top Balder Fm.
Base upper flood basalts
Base Basalt
fmi160001
SW
4103m
OF95-124A
NE

Figure 63



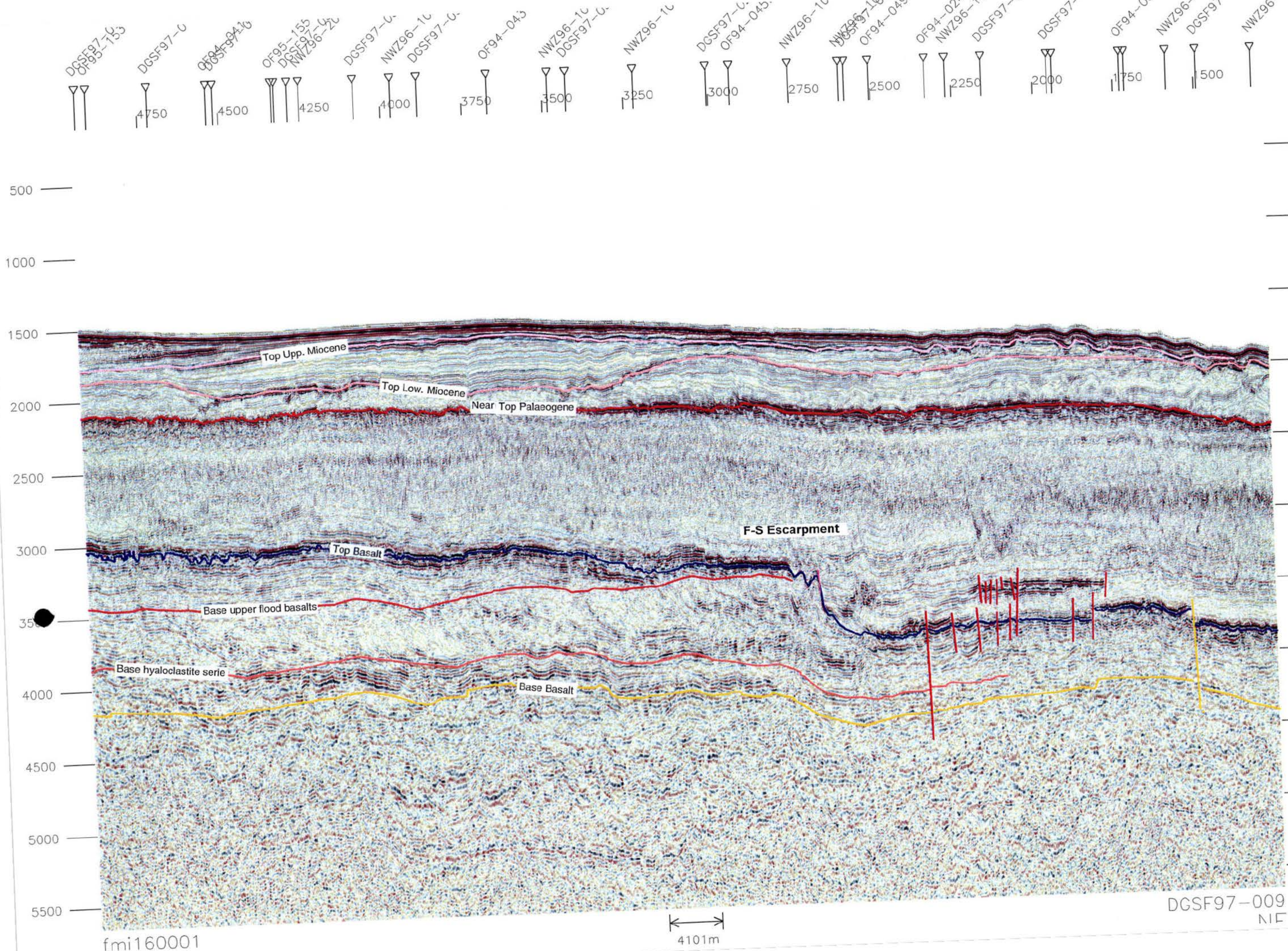
Westray Splay
Top Palaeogene
Base mid-Eocene uncf.
Int. Low. Eocene uncf. 2
Int. Low. Eocene uncf. 3
Top Balder Fm.
Int. Low. Eocene uncf. 1
Top Basalt
Top Balder Tuff ?
Base upper flood basalts
Base Basalt
Top Low. Miocene
Int. Eocene Fan
Base hyaloclastite serie
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
fmi160001
SW
4100m
OF95-122
NE

Figure 64



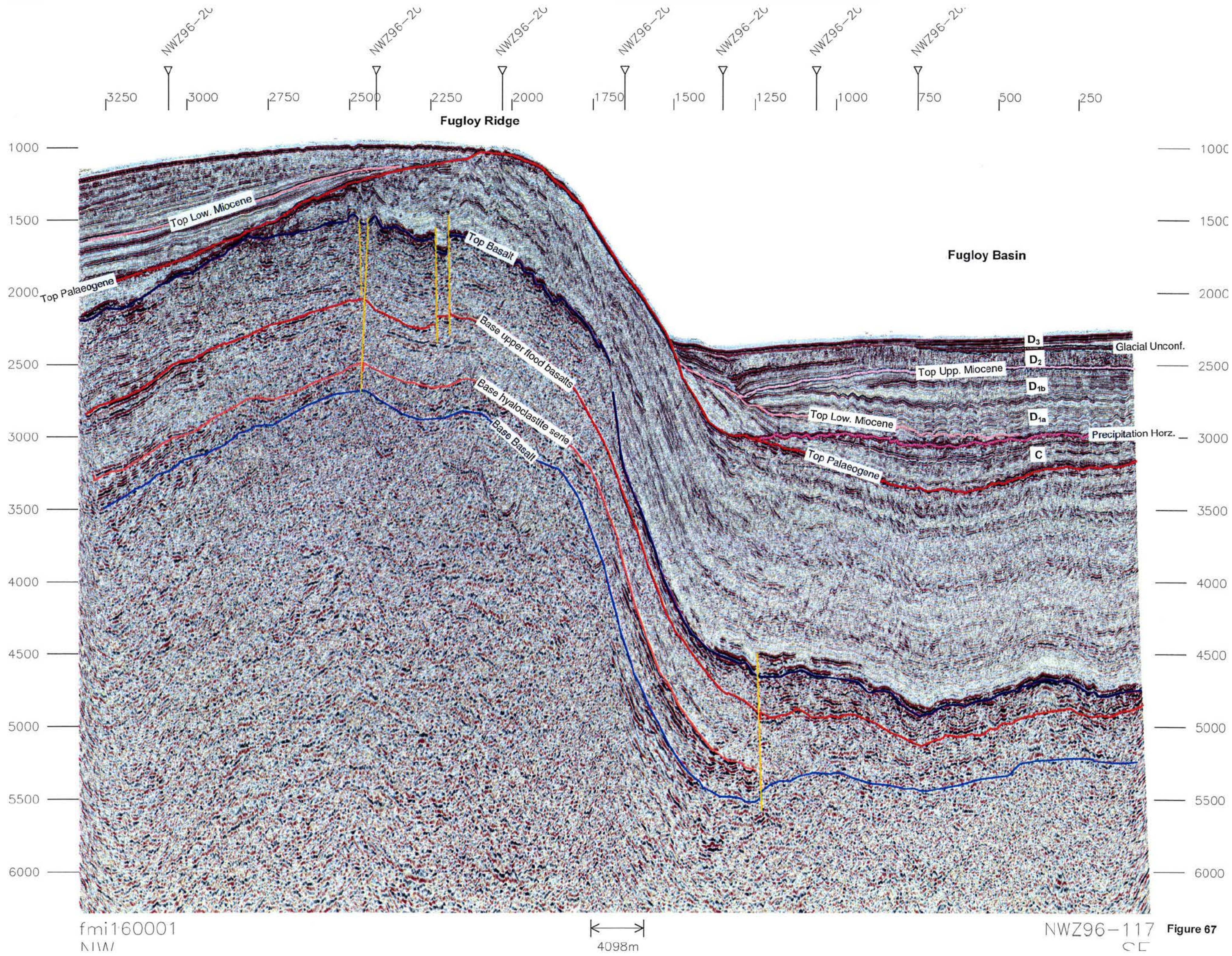
East Faroe High
Top Palaeogene
Top Basalt
Base upper flood basalts
Top low. basalt form. ?
Base Basalt
Base hyaloclastite serie
Top Upp. Miocene
Top Low. Miccene
Int. Eocene Fan
fmi160001
NW
4099m
OF95-153
SE

Figure 65



Top Upp. Miocene
Top Low. Miocene
Near Top Palaeogene
F-S Escarpment
Top Basalt
Base upper flood basalts
Base hyaloclastite serie
Base Basalt
4101m
DGSF97-009
fmi160001

Figure 66


NWZ96-20
3250
3000
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
Fugloy Ridge
Fugloy Basin
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
Top Low. Miocene
Top Palaeogene
Top Basalt
Base upper flood basalts
Base hyaloclastite serie
Base Basalt
D3
Glacial Unconf.
D2
Top Upp. Miocene
D1b
Top Low. Miocene
D1a
Precipitation Horz.
C
Top Palaeogene
fmi160001
NW
4098m
NWZ96-117
SE
Figure 67

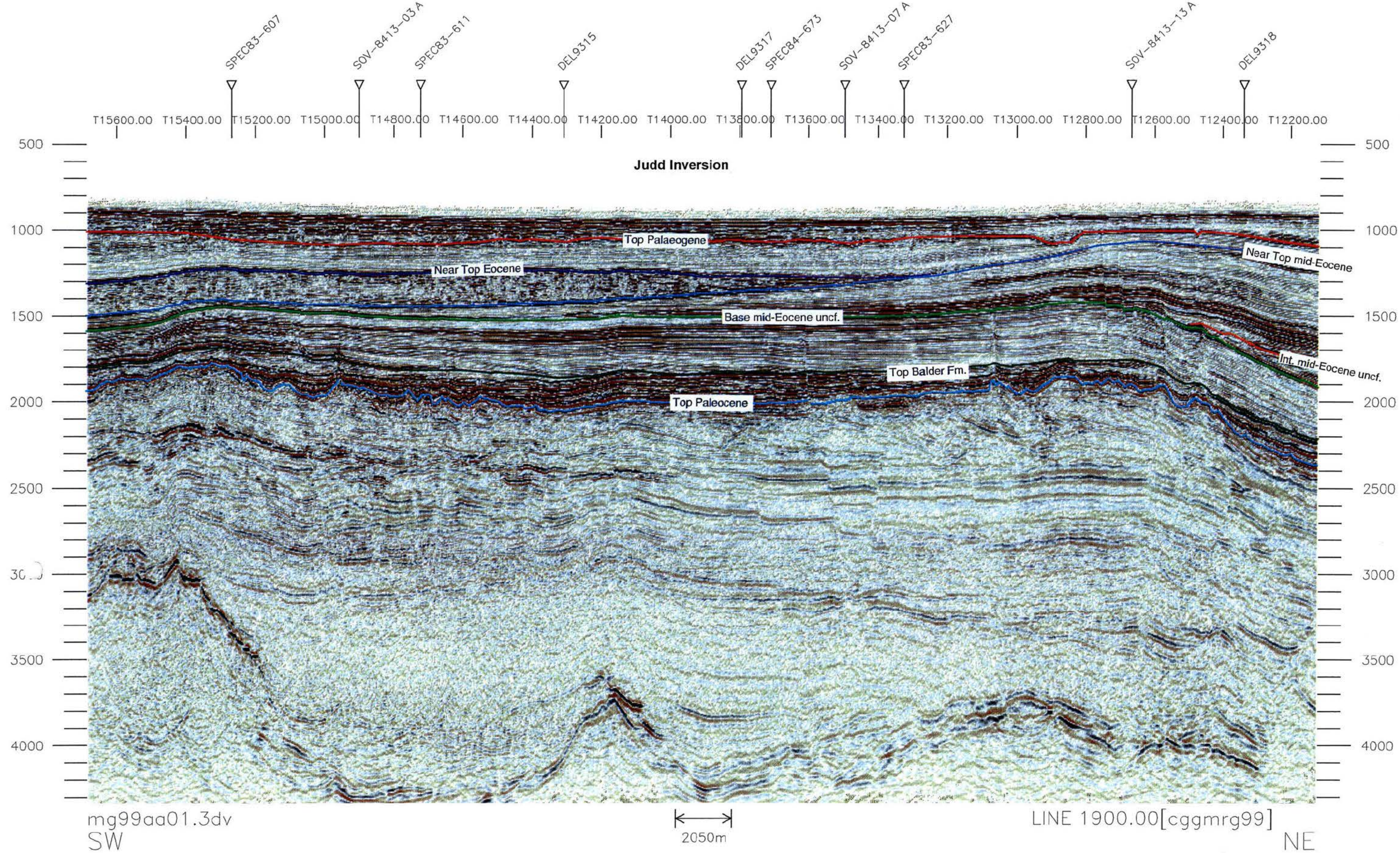
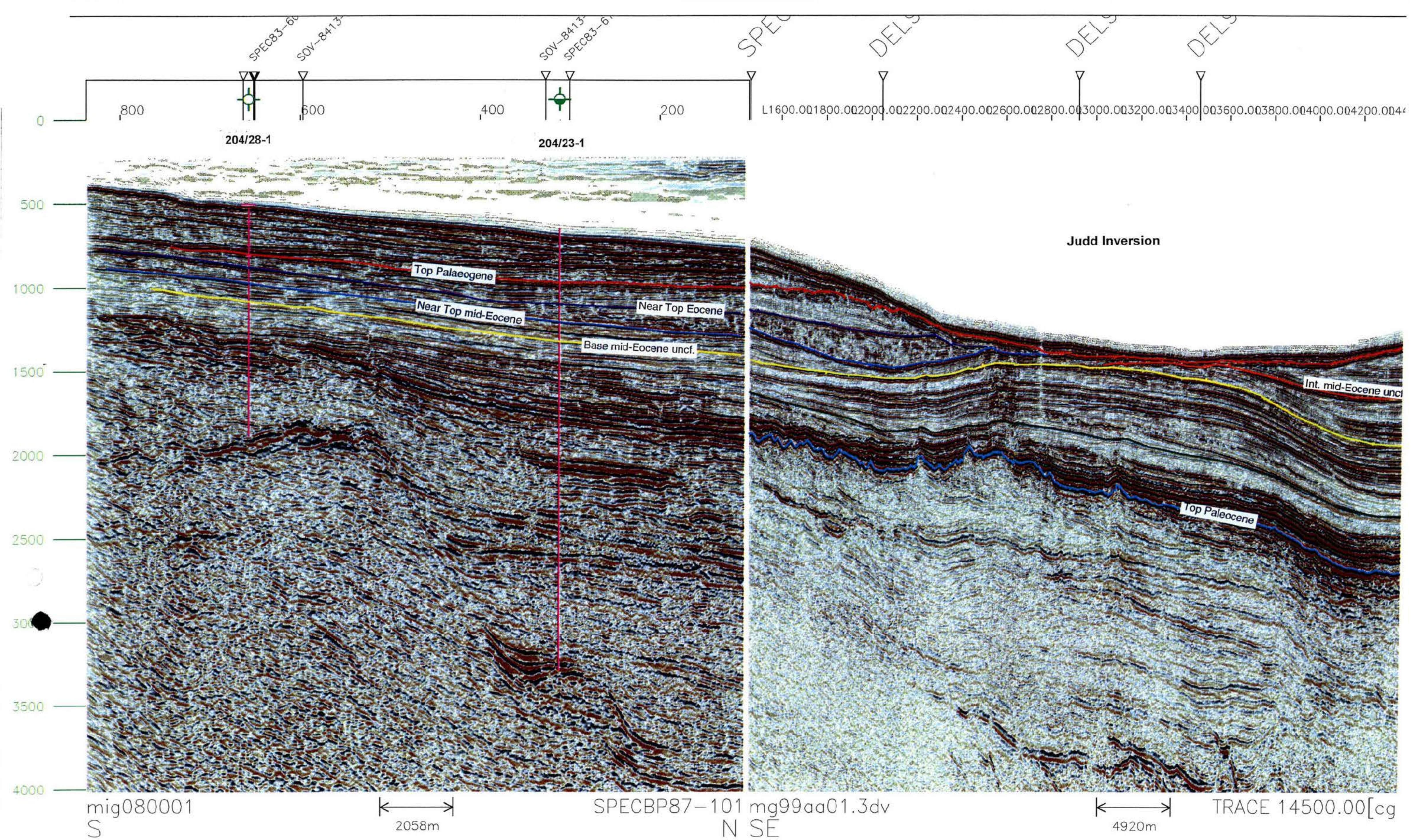
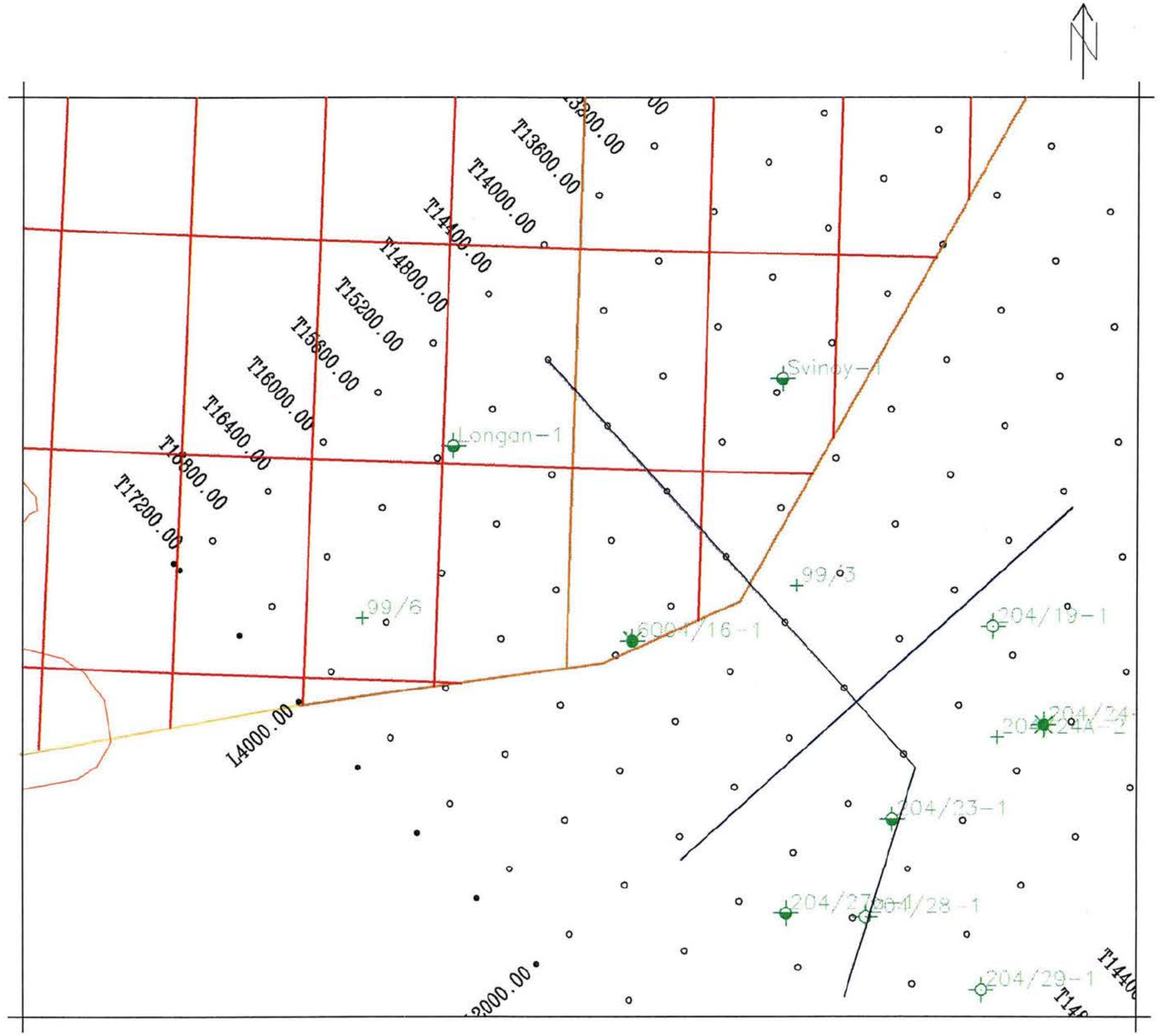

SPEC83-607
SOV-8413-03 A
SPEC83-611
DEL9315
DEL9317
SPEC84-673
SOV-8413-07 A
SPEC83-627
SOV-8413-13 A
DEL9318
T15600.00
T15400.00
T15200.00
T15000.00
T14800.00
T14600.00
T14400.00
T14200.00
T14000.00
T13800.00
T13600.00
T13400.00
T13200.00
T13000.00
T12800.00
T12600.00
T12400.00
T12200.00
Judd Inversion
500
1000
1500
2000
2500
3000
3500
4000
Top Palaeogene
Near Top Eocene
Near Top mid-Eocene
Base mid-Eocene uncf.
Int. mid-Eocene uncf.
Top Balder Fm.
Top Paleocene
mg99aa01.3dv
SW
2050m
LINE 1900.00[cggmrg99]
NE

Figure 68



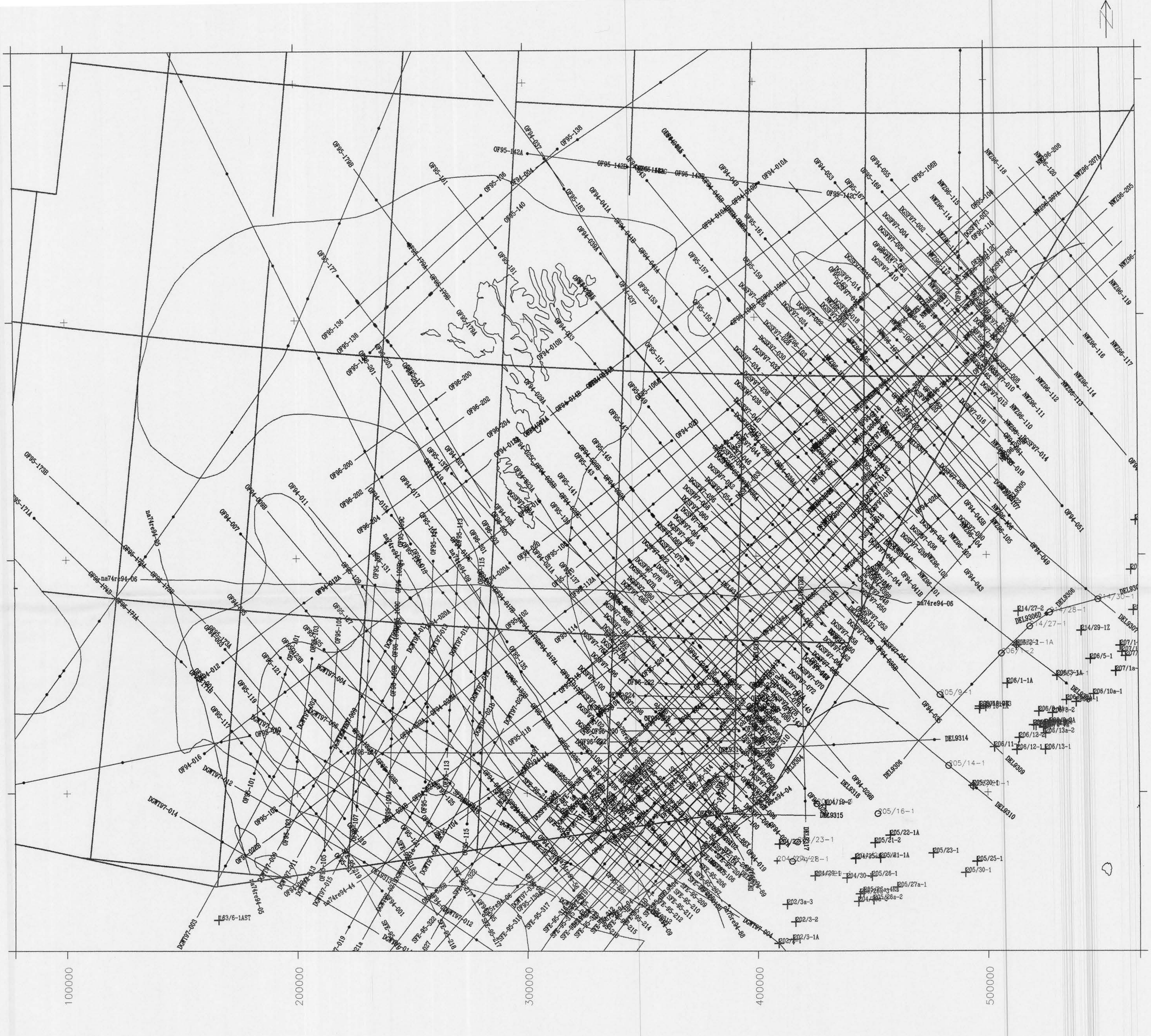
SPEC83-60
SOV-8413
SOV-8413
SPEC83-61
SPEC
DELS
DELS
DELS
0
800
600
400
200
L1600.00
1800.00
2000.00
2200.00
2400.00
2600.00
2800.00
3000.00
3200.00
3400.00
3600.00
3800.00
4000.00
4200.00
204/28-1
204/23-1
500
1000
1500
2000
2500
3500
4000
Judd Inversion
Top Palaeogene
Near Top mid-Eocene
Near Top Eocene
Base mid-Eocene uncf.
Int. mid-Eocene uncf
Top Paleocene
mig080001
S
2058m
SPECBP87-101
N
mg99aa01.3dv
SE
4920m
TRACE 14500.00[cg

Figure 69



T13600.00
T14000.00
T14400.00
T14800.00
T15200.00
T15600.00
T16000.00
T16400.00
T16800.00
T17200.00
14000.00
Svinoy-1
Longan-1
99/3
99/6
6004/16-1
204/19-1
204/24A-2
204/23-1
204/27
204/28-1
204/29-1

Figure 70



Faroes Seismic line database
Interp. Pr. Faroe_ab

0m 50000m 100000m

1cm. = 10000 meters

Figure 51