A preliminary seismic study of part of the pre-Paleocene section offshore southern West Greenland between 66°N and 68°N

Thomas G. Ottesen

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ABSTRACT

Seismic data acquired during the 1970s in an area betweeen 66° and 68°N offshore West Greenland have been reinterpreted. The present report concerns the pre-Paleocene section where four major seismic units have been identified. Seismic facies analysis of the youngest unit suggests that it was deposited by a south-westward prograding wave-dominated delta, the development of which was probably controlled by eustatic changes in sea level. The unit underlying the delta unit is interpreted as shales deposited in a deep-marine environment. Thus a possible target for hydrocarbon exploration has been identified.

The deepest unit has been affected by normal faulting in response to extensional stresses. If reservoirs and seals are present within this unit, structural traps could be generated by the major fault blocks which are situated in a sub-basin some 30 km by 100 km.

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INTRODUCTION

The first period of hydrocarbon exploration on the West Greenland shelf came to an end in 1979 when the last of the concessions held by the oil industry were relinquished. Prior to that, several multichannel seismic surveys had been carried out and five exploration wells were drilled, all of them dry. The Kangâmiut-1 well, which was drilled on the western flank of a N-S trending basement high, was the only well to penetrate a reservoir lying under a seal. Otherwise, the wells appeared to show that there is a general absence of reservoir rocks in the deeper parts of the sedimentary section, where on the other hand potential source rocks are present. However, the source rocks identified so far are mainly gas-prone and they are largely immature in the drilled sections (Rolle, 1985).

Until recently these discouraging observations, combined with the political decision to give onshore exploration first priority, formed an impediment to resumed hydrocarbon exploration activities in the region. However, application of the seismostratigraphic interpretation techniques of Vail *et al.* (1977) has lead to the realization that the five wells are probably not regionally representative (Ottesen, 1991 ; Chalmers & Pulvertaft, in press).

Following the conclusions of a pilot study that the existing data were of adequate quality to enable a re-evaluation of the area and that the West Greenland shelf was not adequately evaluated by the oil industry in the 1970s (Chalmers, 1989), project VEST SOKKEL was initiated in 1988. VEST SOKKEL is Danish for "west shelf" and the aim of the project is to re-evaluate the

West Greenland shelf where adequate data exist, i.e. between 64°N and 68°N (Chalmers, 1990).

The results obtained from re-interpretation of the old seismic data so far have been encouraging. Based on regional interpretation of seventeen identified seismic sequences of Paleocene-Eocene age, Ottesen (1991) concluded that the stratigraphy of the area is much more complex than hitherto recognized from well data alone (Rolle, 1985). In particular, it was shown that Rolle's shaly and clayey Ikermiut Formation contains the condensed sections of seismic sequences considered to be sand-prone elsewhere, thus invalidating the earlier inference that deep reservoirs do not exist offshore West Greenland.

The present report deals with the regional seismic interpretation of the uppermost pre-Paleocene section in the same area as studied by Ottesen (1991), between 66°N and 68°N. A more detailed and complete study is planned in 1992-1994 as part of project VEST SOKKEL. At present seismostratigraphic analysis of the area between 64°20'N and 66°N is nearing completion (Chalmers, 1990).

SEISMIC DATA

The present study is based mainly on the northern parts of two regional surveys: that carried out by Occidental in 1970, and the Burmah Group's 1971 survey. The two surveys combined have a total length of about 3200 km and form a grid whose size varies from place to place but is typically 5-10 km by 10-15 km. The area covered is about 20 000 square kilometres (Map 1). It has been divided into Quadrants each 1° of latitude by 1° of longitude. Quadrants are named after their south-eastern corner and are again subdivided into 12 Blocks each 10′ of latitude by 30′ of longitude. Blocks 1 and 2 are the northernmost pair within each Quadrant, Blocks 11 and 12 the southernmost pair. The southern Quadrants are densely covered by detailed surveys, but appear to provide only limited information on the geological section in question. Quadrants 6754 and 6755 seem especially interesting from a seismostratigraphic point of view and parts of the section are quite amenable to detailed interpretation. Unfortunately only regional surveys with fairly open grids exist here. Lines from surveys other than the two mentioned were occasionally used as an aid in identifying horizons and describing units, but mainly as tie lines.

SEISMIC INTERPRETATION

Four horizons interpreted as representing major changes in the geologic development of the area have been identified and traced round the seismic grid. The two deepest horizons, Horizon I and Horizon II, are defined conventionally as seismic "markers", while Horizon III and Horizon IV have been identified using the seismostratigraphic interpretation techniques of Vail *et al.* (1977). They thus represent the boundaries of seismic sequences. Each horizon relates to the geological unit below it: Horizon I is the top of Unit I, Horizon II is the top of Unit II etc. Seismic facies analysis techniques (Vail *et al.*, 1977) have been applied only to Unit IV. Reliable stratigraphic interpretation of the deeper units is not considered feasible at present because of the quality of the existing data.

Structural interpretation has been limited to identifying faults and to mapping those faults whose effect on thicknesses and depths is considerable on a regional scale. Faults marked on the maps often represent fault zones.

UNIT I

Description

Horizon I corresponds to what was denoted Level 0 by Ottesen (1991) and roughly to what was mapped as basement by Henderson *et al.* (1981). At the Kangâmiut-1 exploration well (Block 6656/12) Horizon I ties to Precambrian basement. The depth to Horizon I and its main features are outlined in Map 2.

The Nukik Platform occupies Quadrant 6654 and the eastern half of 6655 and is illustrated in Figs 1 and 2. On the Nukik Platform, Unit I can be divided into an upper reflective and a deeper transparent section, both of which are less easy to trace south on the platform due to a high noise level. A conspicuous feature of Unit I on the Nukik Platform is the transparent domal high (Block 6655/4) and the zones of progradation flanking it (Figs 1 and 2). The platform is bounded by two fault zones, one striking N-S and one merging with the northern progradation zone. The north-west extension of the high forms a ridge as the two fault zones converge. The elongate mounded zone trending roughly N-S along 55°W at about 66°30′N is possibly connected to and genetically similar to the transparent high seen in Figs 1 and 2. It is flanked to the west by divergent reflectors.

The Nagssugtôq Sub-basin is situated in Quadrant 6754 (Map 2). A seismic cross-section is shown in Fig. 3. At present the structural interpretation is highly tentative and is likely to be revised as more detailed evaluation of the area proceeds. The eastern limit of the sub-basin is generally beyond the end of the seismic grid. The exposures on the coast are however Precambrian basement, so the apparent N-S elongate shape of the sub-basin is considered real.

The regional south-westward dip in Quadrant 6755 and the eastern half of 6756 is about 2°. The typical appearance of Unit I in this area can be seen in Fig. 5. The depth contours of Map 2 smooth over the rapid but comparatively small depth variations associated with the faults and fault blocks. To the west of the Nukik Platform the dip is more westerly and steeper.

The Hellefisk fault zone is illustrated in Fig. 4. The Kangâmiut fault zone is associated with the Kangâmiut Ridge in Quadrant 6656, Blocks 8, 10 and 12. Unlike the Hellefisk fault zone faulting did not affect the Tertiary section to any considerable extent.

Linking these two zones, in the southern Blocks of 6756 and the northern Blocks of 6656, is an area of complex structure and poor data quality. Henderson *et al.* (1981) suggested that this structure is due to shale diapirs, but Chalmers & Pulvertaft (in press) and Ottesen (1991) speculated that the structures could be due to compressional tectonics. The exploratory well Ikermiut-1 was drilled on a dome in this area.

The Kangeq High and the bordering Subunit I (shaded on Map 2) are illustrated in Fig. 4. It is not certain if and how this subunit continues westwards beyond the Hellefisk fault zone, where on Block 6756/1 the exploratory well Hellefisk-1 bottomed in about 700 metres of Paleocene basalt without reaching the base of the lavas (Rolle, 1985; Hald & Larsen, 1987).

Interpretation

On the Nukik Platform, the main problem is the nature and origin of the transparent high (Block 6655/4) and its bordering progradation zones (Figs 1 and 2, Map 2).

Several observations combine to suggest that the transparent high represents a pluton or a volcanic centre. The main seismic observations are: domal shape, acoustically characterless interior, and the overlying and bordering reflectors associated with the high. Gravity measurements show that a positive anomaly of 15-20 milligals coincides with the high. The exact shape of the anomaly is however uncertain, due to a rather open gravity grid. Magnetic measurements show rapid variations in magnetic intensity over the Nukik Platform. This suggests that it forms an area of relatively shallow magnetic basement.

Connected to the question whether the transparent dome is an intrusive body or a volcanic centre is the interpretation of the divergent/prograding reflectors. Two possibilities are considered:

A: The observed diverging reflector pattern could be lava flows, sourced from the domal volcanic centre. The lava flows eventually prograded into the surrounding sea (depth ~1000 m, cf. Fig. 2) where quenching of the subaerial flows occurred.

On the Nûgssuaq peninsula, some 300 km to the north of this region, Clarke & Pedersen (1976) report on a similar feature. This feature consists of several hundred metres thick breccia units which show prominent cross-bedding with well-developed steeply-dipping foreset beds. Frequently a normal subaerial basaltic flow can be traced laterally into a brecciated foreset bed, brecciation having occurred as the flow reached the lake then present. The cross-bedded breccia sets are up to 600 metres thick which must be less than or equal to the depth of water into which the lava flowed.

On Nûgssuaq the breccias lie on Cretaceous and Danian sediments (ibid.). The basalts of the present study would probably be older than that and (pene)-contemporaneous with early deposition of Unit III in the sea surrounding the Nukik Platform.

Thus according to this interpretation the Nukik Platform could have formed mainly by the build-up of basaltic flows subsequent to the emplacement of the volcanic centre. The up-doming of the centre could have caused the normal fault pattern bordering on the platform.

B: An alternative interpretation is that the transparent high represents a pluton and that the upper section of strong reflectors represents pre-existing sediment under/into which the intrusion took place. The resulting up-doming created areas of erosion (e.g. Fig. 1, sp 1050), which acted as the source for the sediments of the prograding clinoforms. Again the bordering fault pattern could be related to the up-doming, or one could be dealing with a much older pluton which acted as a stable area while subsidence took place around it.

Seismic interval velocities obtained from the stacking velocities typically lie in the range 3800-4200 m/s, which is relatively high for clastic sediments and relatively low for basalts. Thus the velocity information does not seem to favour either of the two interpretations.

Magnetic modelling supports the interpretation that the transparent high represents a pluton or a volcanic centre. Models (Fig. 6) suggest that the high forms the reversely magnetized causative body for a negative magnetic anomaly of about -700 gammas. Fig. 6 also illustrates that an upper magnetized layer alone cannot account for the observed anomaly, but that a reasonable fit to the observations can be obtained both with and without an upper magnetized layer associated with the pluton/-volcanic centre. Thus the modelling does not determine whether or not the upper reflective and progradational zone is magnetized (i.e. basaltic).

Outside the volcanic centre/pluton, the acoustically transparent section probably represents Precambrian basement. This is especially likely to the east, where its rugged surface subcrops at the sea floor and where Precambrian rocks are exposed slightly farther east on the Greeenland coast.

In the <u>area outside the Nukik Platform</u>, interpretation is mainly concerned with the nature of the strong band of reflectors, what lies underneath it, and with the nature and dating of the inferred tectonic phases.

At present not much can be concluded with certainty. The strong reflectors (Figs 1, 2 and 5) are generated either by subaerial basalts or by sediments causing a high acoustic impedance contrast. It is not clear to what extent the common complex reflector configuration is due to primary deposition and to what extent post-depositional structuring has overprinted this pattern. Finally it is not possible to decide if sediments are present within the underlying acoustically rather transparent section, because of the poor quality of the available seismic data. If sediments are present, the possibility of structural closures associated with the faults and fault blocks should be considered, especially in the Nagssugtôq Sub-basin.

A future comprehensive structural analysis of the area will have to incorporate several tectonic phases. The small faults and fault blocks present almost everywhere in the study area are associated with an extensional phase, which clearly postdates the deposition of Unit I and predates that of Unit III. Possibly incipient formation of the Nukik Platform occurred in response to the same extensional stress. At present it is not clear how this phase is related to the extensional phase that caused the formation of the Nagssugtôq Sub-basin (Quadrant 6754, Fig. 3).

At least two tectonic phases are also needed to explain the Hellefisk and Kangâmiut fault zones and the Kangeq High: one which affected the Paleocene section to a considerable extent (Fig. 4) and an older one, which caused the formation of the Kangâmiut Ridge (Quadrant 6656, Blocks 8, 10 and 12). Upwards movement of the Kangeq High along faults just east and south of the area shown in Fig. 4 continued well into Neogene times.

Subunit I in Blocks 6756/2 and 4, between the Hellefisk fault zone and the Kangeq High (Fig. 4), is tentatively suggested to be of extrusive nature with an origin and development similar to that of the Nukik Platform according to interpretation alternative A. This is based on the observation that they occupy the same stratigraphic level and are of similar seismic appearance.

UNIT II

Description

Unit II is essentially confined to the Nagssugtôq Sub-basin in Quadrant 6754. Thicknesses of the unit and major faults affecting it are shown in Map 3. An E-W seismic cross-section of the sub-basin and Unit II is shown in Fig. 3. Its general seismic appearance is strongly marked by structural influence and by a high noise level.

Interpretation

The interpretation is mainly concerned with the relative ages of Unit II and formation of the sub-basin and with the nature of the upper band of strong reflectors beneath Horizon II (Fig. 3). This band often merges with the similar band constituting the top of Unit I at the rim of the sub-basin. It is suggested that these bands are of identical nature. Either the tops of the bands, respectively Horizon I and Horizon II, represent erosional surfaces with sediment underneath them causing a strong acoustic impedance contrast, or they represent subaerial basalt flows that probably flowed over an erosional surface.

In either case the present occurrence of Unit II probably consists of the downfaulted remains of an originally more widespread occurrence. This interpretation assumes that the formation of the Nagssugtôq sub-basin postdates the deposition of Unit II. Faulting is seen to affect Unit II strongly, but whether these faults are related to the actual formation of the basin is not clear at present.

If, however, the sub-basin formed prior to or during deposition of Unit II in response to an incipient rifting phase, it could have existed as a deep intracratonic basin. Restricted circulation and rather anoxic conditions could have prevailed in the sub-basin if only weak connections to a wider sea existed. Therefore Unit II could contain interesting hydrocarbon source rocks.

The sub-basin is suggested to be of Early Cretaceous to early Late Cretaceous age. On Baffin Island, Canada, Aptian-Cenomanian deposits in half-grabens mark the latest date for the onset of crustal attenuation and faulting in Baffin Bay (Burden & Langille, 1990).

Unit III

Description

Unit III occurs extensively to the north of 67°N and in a more restricted area to the west of the Nukik Platform. The two areas are connected only by a very narrow zone (Block 6656/1 and 2). Depths to Horizon III are shown on Map 4, thicknesses of Unit III on Map 5. Unit III is noisy or acoustically transparent over the greater part of its occurrence (e.g. Figs 1 and 2) and reverberations possibly make up a significant part of the features apparent within it. The exception is in the northern half of Quadrant 6754 where subparallel reflectors with dip towards the south-west are observed (e.g. Figs 3 and 5). Fig. 5 suggests that these reflectors downlap onto the top of the transparent section. Horizon III is defined seismo-stratigraphically by the downlapping reflectors of the overlying

Unit IV. Comprehensive seismo-stratigraphic interpretation, however, is not considered feasible at present due to the high noise level.

Interpretation

Two observations combine to suggest that Unit III contains rather homogeneous deep-marine shales. Firstly, the basin in which Unit III was deposited had a depth of at least 1000 metres, not taking into account the effect of compaction (cf. Fig. 2). Secondly: that homogeneous material is contained in Unit III is indicated by its acoustically transparent, characterless appearance. There is no evidence for either major breaks in deposition or any major lithological boundaries. Such deep-marine shales could form a good quality hydrocarbon source rock.

The interpretation of Unit III in terms of deep water shales implies that a marked change took place in the area prior to deposition of Unit III. It is suggested that an opening to a wider basin to the south-west led to the formation of the deep sedimentary basin in an area that hitherto was characterized by subaerial basalts or subaerial erosion. Possibly the narrow zone (Blocks 6656/1 and 2) west of the Nukik Platform extension then formed a strait leading to a wider sea.

Unit IV

Description

Horizon IV corresponds to what was previously denoted Level A by Ottesen (1991) and forms the base of the section interpreted in that report. Depths to and thicknesses of Unit IV are shown on Maps 6 and 7.

Unit IV is the only one of the four units to which seismo-stratigraphical techniqnes can be applied. By means of seismic sequence analysis, Unit IV was subdivided into twelve sequences, Seq 1-Seq 12. This sub-division is shown on the generalized cross-section (Fig. 7A), which also shows the main reflector configurations of each sequence. The seismic appearance of Unit IV is shown in Fig. 5.

Seismic facies analysis of the identified sequences revealed a similarity between the progradational sequences <u>Seq 1, 3, 5, 6, 7, 8, 10</u>, and <u>11</u>. As is illustrated for sequence Seq 10 on Map 7, the occurrence of each progradational sequence can be subdivided roughly into four areas of different seismo-facies characteristics (Fig. 7B):

Area A is characterized by sub-parallel reflectors which onlap towards the north and east or are too thin for internal reflections to be visible on the seismic sections.

Area B is characterized by (locally very conspicuous) eastward and northward onlap and by downlap towards the south and west.

Area C is an area of distinct southward or westward progradation. The reflector configuration is predominantly oblique. At right angles to the direction of progradation, the configuration is generally subparallel or that of broad flat mounds.

Area D forms the distal part of the progradation system and is generally characterized by being too thin to contain internal reflectors or by southward and westward downlap of subparallel reflectors.

The only major deviation from this picture concerns sequence Seq 11. Replacing its areas A and B is an area characterized by small stacked mounds or hummocks and locally well defined constructional mounds of considerable size (> 5 km across). Westward prograding clinoforms or westward developing mounds respectively form the configuration at right angles to these mounds. Other deviations from the outlined general description are minor and are considered unimportant to the overall interpretation of Unit IV. Maximum thicknesses of individual progradational sequences are 300-450 metres.

The elongate occurrences of the non-progradational sequences Seq 2 and Seq 4 strike NW-SE and are limited to areas just basinwards of Seq 1 and Seq 3 respectively. The predominant reflector configuration is that of hummocky clinoforms (e.g. Seq 2, Fig. 5), often with associated southward and westward development. The lowermost portion of Seq 8 may form a separate sequence similar to Seq 2 and 4. Maximum thicknesses are 200-250 metres.

Sequence Seq 9 occurs to the west of the Nukik Platform and in a 20 km broad zone north of it. To the north the most conspicuous reflector configuration is hummocky clinoforms and constructional mounds (Fig. 1). Southward and westward development is indicated. To the west, the noise level is considered too high to allow reliable observations of reflector configurations.

The youngest sequence, Seq 12, only occurs west of 55°30'W, Locally hummocky clinoforms and westwards oblique or shingled progradation are observed. In places progradation seems associated with flat overlapping mounds. As is the case for Seq 9 the occurrence of Seq 12 is divided into a northern and southern part by the north-west extension (Blocks 6656/1 and /2) of the Nukik Platform. Maximum thicknesses of Seq 9 and 12 are 350-400 metres.

A recurring feature of the individual sequences of Unit IV is the prevailing south-westward development (e.g. Fig. 5). This is also the direction of development of Unit IV itself, as is seen on Map 6. The locations of the progradation zones (Areas C) of the progradational sequences show an overall south-westward shift, with the exception of Seq 10, which shows a reverse shift. Also evident from Maps 6 and 7 is the general NW-SE strike of seismo-facies units.

Interpretation

Unit IV is interpreted to represent a southward to south-westward prograding delta, the overall development of which was to a considerable extent determined by changes in relative sea level. The delta was probably wave dominated. The general absence of constructional features (e.g. coast-parallel bars) associated with the progadation suggests that a rather high energy regime prevailed along the NW-SE striking palaeo-coast.

The concepts of depositional systems tracts and sea level changes (Vail, 1987) seem readily applicable to the description of the development of Unit IV:

Sequences Seq 2 and 4 plus the deeper part of Seq 8 (Fig. 7A) were deposited as submarine fans on the basin floor during a rapid fall in sea level. The hummocky clinoforms represent channel sediments, which were deposited by submarine gravity flows.

The formation of the progradational sequences begins with the lowstand wedge, deposited during a lowstand to incipient rise in sea level. It is characterized by aggradational progradation and marine onlap onto the foresets of the preceding progradational sequence (cf. Fig. 5). The lowstand wedge corresponds to the lower part of seismo-facies area B (Fig. 7B). During deposition of the lowstand fan and wedge the landward areas acted as areas of sedimentary by-pass or erosion. Continued rise in sea level led to the formation of the transgressive systems tract, characterized by retrogradational development and landward onlap. The sediments of area A and the upper part of area B (Fig. 7B) are of coastal or nearshore origin and belong to the transgressive systems tract and the early stage of the highstand systems tract. With the exception of Seq 11, indications of fluvial influence are sparse (Seq 10, Fig. 5, sp 6000) or absent. This may, however, be due to erosion as the depocentre moved progressively basinwards. In Seq 11 fluvial channel deposits are indicated by constructional mounds with associated progradation. The progradation area (area C on Map 7 and Fig. 7B) corresponds to the highstand systems tract, deposited during a still-stand to incipient fall in sea level. Area D forms the distal, marine part of the prograding system.

How sequences Seq 9 and Seq 12 fit into this descriptive framework is not certain. Seq 9 was possibly deposited during lowstand conditions as its top is observed to be strongly downlapped by the prograding clinoforms of Seq 10. It may be a well developed submarine channel and fan system, as indicated by the predominantly hummocky reflector pattern (Fig. 1).

Seq 12 is tentatively considered to form a shelf-margin systems tract, which is characterized by aggradation and weak progradation. Channel deposits may be indicated by hummocks and progradational mounds.

A semi-quantitative sea level curve (Fig. 8) has been constructed based from the above interpretation and the following guide-lines: Formation of submarine fans (e.g. Seq 2) was taken to indicate an especially pronounced fall in sea level, and the extent of transgression (i.e. occurrence of area A) reflects the magnitude of sea level rise. The reverse shift of Seq 10 was taken to reflect an especially marked sea level rise. Note that in doing this, the effects on the development of Unit IV of changes in sediment input rate, changes in rate of (differential) subsidence and other tectonic influence were disregarded. Furthermore, as the present sea level curve is of semi-quantitative nature only, a correlation to the global sea level curve of Haq *et al.* (1987) is not considered feasible at present.

Horizon IV represents an unconformity of at least regional scale. It is onlapped and downlapped by the reflectors of overlying Paleocene sequences (Ottesen, 1991) and the reflectors of the underlying Unit IV show toplap onto Horizon IV. As deposition of Unit IV proceeded and the depocentre moved progressively south-westward (cf. Map 6 & Fig. 5) an increasing part of the area north of 67°N became an area of sedimentary by-pass or erosion. Erosion, however, probably did not cut very deeply. In the Kangâmiut-1 exploration well (Block 6656/12), Horizon IV represents a hiatus, possibly covering the upper part of the Campanian to the lower part of the Paleocene (Rolle, 1985). However, in the Ikermiut-1 well, some 100 km to the north (Block 6656/1), biostratigraphic studies showed that continuous sedimentation across the Cretaceous-Tertiary boundary could be accommodated within the biostratigraphic constraints (Toxwenius, 1986). Thus the well information does not unambiguously explain the nature of Horizon IV. These wells are situated on stratigraphically and structurally atypical locations and it is possible that the information they provide does not apply regionally.

The lithological interpretation is mainly concerned with locating potential reservoir sands. Sandy deposits are expected in the upper proximal parts of the prograding clinoforms, given a favourable sediment source area. These potential reservoir sands form elongate bodies generally striking NW-SE along the palaeo-coastline and correspond in occurrence to the progradation zones shown on Map 6. Other sand-prone facies are associated with the submarine channels and fans of Seq 2, Seq 4 and Seq 8 (deeper part), with the coastal zones of the lowstand wedges and with the fluvial channels (if preserved) of the delta plain.

Fine-grained sediments may form the inter-channel deposits on the delta plain. Their sealing potential and source rock potential, however, may be limited due to erosion and to mainly terrestial organic input. Fine-grained deposits are also expected to form the distal parts of the prograding clinoforms and of the lowstand wedges.

CONCLUSIONS

This report presents a description and a provisional interpretation of the deeper section in an area offshore West Greenland. A study of the Paleocene-Eocene section in this area has been published by Ottesen (1991).

The main conclusions of the present study are:

1) Four major seismic units have been identified, the youngest of which has been subdivided into twelve sequences and interpreted seismo-stratigraphically.
2) Only two of the five wells drilled during the 1970's penetrated (part of) the studied section. These suggest that the section is predominantly of pre-Paleocene age, but the applicability of the information they provide is in general strongly affected by their location in structurally and stratigraphically atypical areas.
3) In major parts of the area sediments interpreted to have been deposited by a south-westward prograding delta system directly overlie what are interpreted to be deep marine shales. The delta deposits could provide reservoirs for hydrocarbons expelled from the potential source rocks of these marine shales. A seal could be provided by the Late Campanian-Early Eocene shaly and clayey Ikermiut Formation of Rolle (1985). Potential hydrocarbon traps are mainly stratigraphic.

4) This juxtaposition of deep-marine shales and overlying coastal sands has not previously been tested and may well become an important target for future exploration efforts in the area.

5) In the Nagssugtôq Sub-basin (Quadrant 6754) structural traps could be associated with major fault blocks - provided that sediments do exist there.

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References

Burden, E.T. & Langille, A.B. 1990: Stratigraphy and sedimentology of Cretaceous and Paleocene strata in half-grabens on the southeast coast of Baffin Island, Northwest Territories. *Bull. Can. Petrol. Geol.* **38**, 185-196.

Chalmers, J.A. 1989: A pilot seismo-stratigraphic study on the West Greenland continental shelf. *Rapp. Grønlands geol. Unders.* **142**, 16 pp.

Chalmers, J.A. 1990: Re-evaluation of the geology of the southern West Greenland shelf-Project VEST SOKKEL. *Rapp. Grønlands geol. Unders.* **148**, 29-32.

Chalmers, J.A. & Pulvertaft, T.C.R. (in press): The southern West Greenland continental shelf - was petroleum exploration abandoned prematurely? *In* Vorren, T.O. *et al.* (eds) Arctic Geology and Petroleum Potential. Elsevier for Norwegian Petroleum Society.

Clarke, D.B. & Pedersen, A.K. 1976: Tertiary volcanic province of West Greenland. *In* Escher, A. & Watt, W.S. (eds) *Geology of Greenland*, 364-385. Copenhagen. Geological Survey of Greenland.

Hald, N. & Larsen, J.G. 1987: Early Tertiary, low-potassium tholeiites from exploration wells on the West Greenland shelf. *Rapp. Grønlands geol. Unders.* **136**, 25 pp.

Haq, B.U., Hardenbol, J. & Vail, P.R. 1987: Chronology of fluctuating sea levels since the Triassic. *Science* **235**, 1156-1167.

Henderson, G., Schiener, E.J., Risum, J.B., Croxton, C.A. & Andersen, B.B. 1981: The West Greenland Basin. *In* Kerr, J.W. &

Fergusson, A.J. (eds) Geology of the North Atlantic border-lands. *Can. Soc. Petrol. Geol. Memoir* **7**, 399-428.

Larsen, H.C. & Pulvertaft, T.C.R. 1990: Regional marine seismic reconnaissance. *Rapp. Grønlands geol. Unders.* **148**, 32-35.

Ottesen, T.G. 1991: A preliminary seismic stratigraphic study of the Paleocene-Eocene section offshore southern West Greenland between 66° and 68°N. *Open File Ser. Grønlands geol. Unders.* **90/1**, 46 pp.

Roest, W.R. & Srivastava, S.P. 1989: Sea-floor spreading in the Labrador Sea: a new reconstruction. *Geology* **17**, 1000-1003.

Rolle, F. 1985: Late Cretaceous-Tertiary sediments offshore central West Greenland: lithostratigraphy, sedimentary evolution, and petroleum potential. *Can. J. Earth Sci.* **22**, 1001-1019.

Srivastava, S.P. & Arthur, M.A. 1989: Tectonic evolution of the Labrador Sea and Baffin Bay: constraints imposed by regional geophysics and drilling results from leg 105. *In* Srivastava, S.P., Arthur, M.A., Clement, B. *et al.* Proceedings of the Ocean Drilling Program, scientific results **105**, 989-1009.

Toxwenius, B.B. 1986: Biostratigraphical zonation and correlation of the Late Cretaceous Tertiary wells, offshore central West Greenland. *Rapp. Grønlands geol. Unders.* **130**, 36-43.

Vail, P.R., Mitchum, R.M., Todd, R.G., Widmier, J.M., Thomson, S., Sangree, J.B., Bubb, J.N. & Hatlelid, W.G. 1977: Seismic stratigraphy and global changes of sea level. *In* Payton, C.E. (ed.) Seismic stratigraphy - applications to hydrocarbon exploration. *Amer. Ass. Petrol. Geol. Memoir* **26**, 49-205.

Vail, P.R. 1987: Seismic stratigraphy interpretation using sequence stratigraphy. Part 1: Seismic stratigraphy interpretation procedure. *In* Bally, A.W. (ed.) Atlas of seismic stratigraphy vol. 1. *Amer. Ass. Petrol. Geol. Studies in Geology* **27**, 1-10.

APPENDIX : Depth Conversion

The depth conversion velocity functions applied are as follows:

Seawater:	V = 1490 m/s	
Section above Horizon IV:		
	V = 2050 + 670 x TM m/s;	TM ≤0.7 s
	V = 2746 - 104 x TM m/s;	0.7s < TM ≤1.4 s
	V = 2600 m/s;	1.4s < TM ≤5.0 s
Unit IV:	V = 2600 + 400 x TM m/s;	TM ≤2.5 s
	V = 3600 m/s;	2.5s < TM ≤5.0 s
Unit III:	V = 2700 + 400 x TM m/s;	TM ≤2.5 s
	V = 3700 m/s;	2.5s < TM ≤5.0 s
Unit II:	V = 3700 m/s	
Unit I:	V = 4500 m/s	

TM is two-way-travel time in seconds to the middle of the unit. For the section above Horizon IV, velocities were obtained from the calibrated sonic log of exploration well Kangâmiut-1.

The velocity functions applied to Unit IV were in part obtained from analysis of the seismic stacking velocities and their derived interval velocities and in part obtained by analogy to the velocities of overlying seismic sequences (Ottesen, 1991).

The seismic interval velocities of Unit III and Unit II show scatter to such an extent that no meaningful velocity-depth relationship can be derived. The velocities used are inferred by analogy to Unit IV and the younger sequences of Ottesen (1991). Thus the depth conversion may be significantly in error and should be regarded with circumspection.

LINE BUR/BG-25N (IN PART)

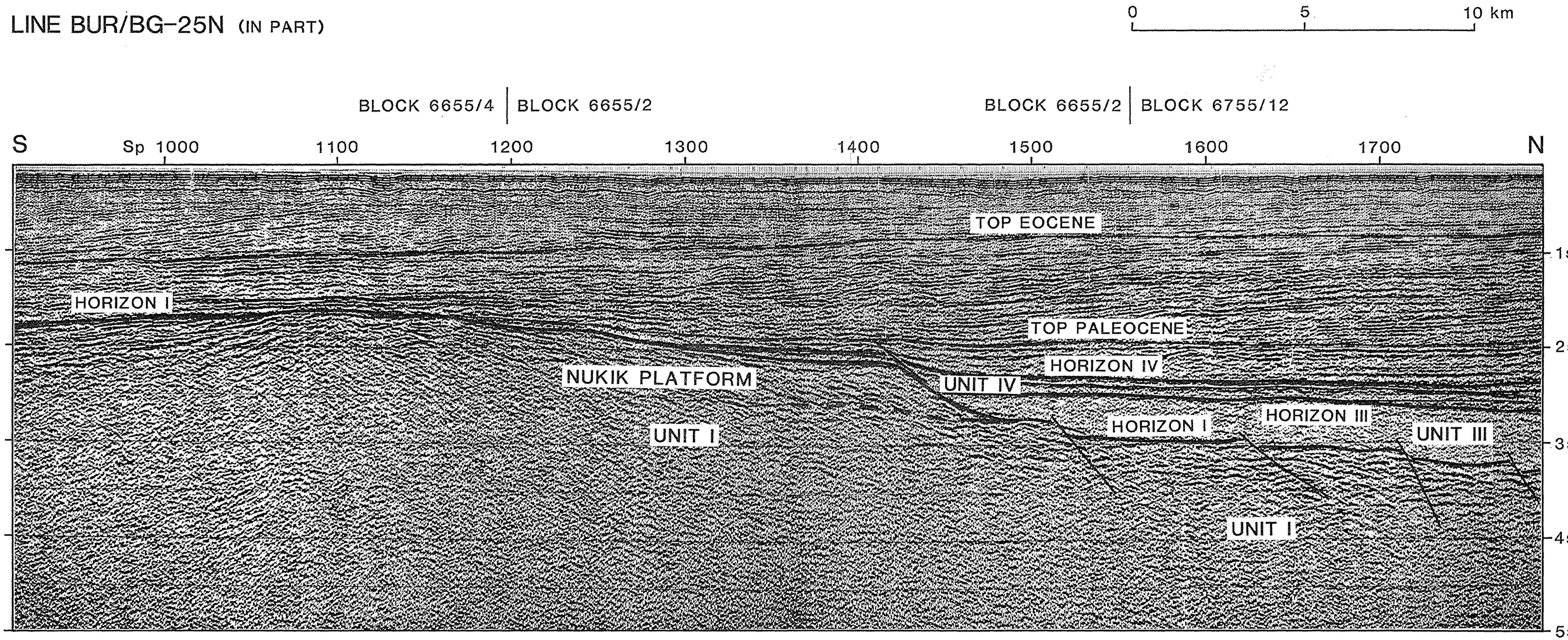


Fig. 1, General observations.

Unit I here comprises the Nukik Platform composed of an upper band of strong reflectors overlying a transparent and noisy section. The up-domed high (Map 2, Block 6655/4) is centered on shotpoint 1100 and is flanked by reflectors which diverge away from it towards the south and north. Farther to the north this divergent pattern grades into progradation. Reflector terminations below Horizon I (sp. 1000-1050) suggest erosional truncation. Note the possible velocity pull-up at the rim of the platform and that the prograding clinoforms downlap onto what forms Unit I outside the platform. Here Unit I consists of an upper strongly reflective zone and an underlying transparent/noisy section. The normal fault pattern is tentative and does not adequately represent the structures present.

Unit III is almost acoustically transparent. It onlaps onto and possibly interfingers with strata of the Nukik Platform.

Unit IV here contains sequences Seq 8, Seq 9 and Seq 11. North of sp. 1750 onlap onto Seq 9 is observed. Within it constructional mounds and hummocks are present. Faulting (or flexuring) slightly north of sp 1400 could be due to differential compaction over the boundary of the Nukik Platform.

The Top Paleocene and Top Eocene boundaries are approximate and are taken from Ottesen (1991).

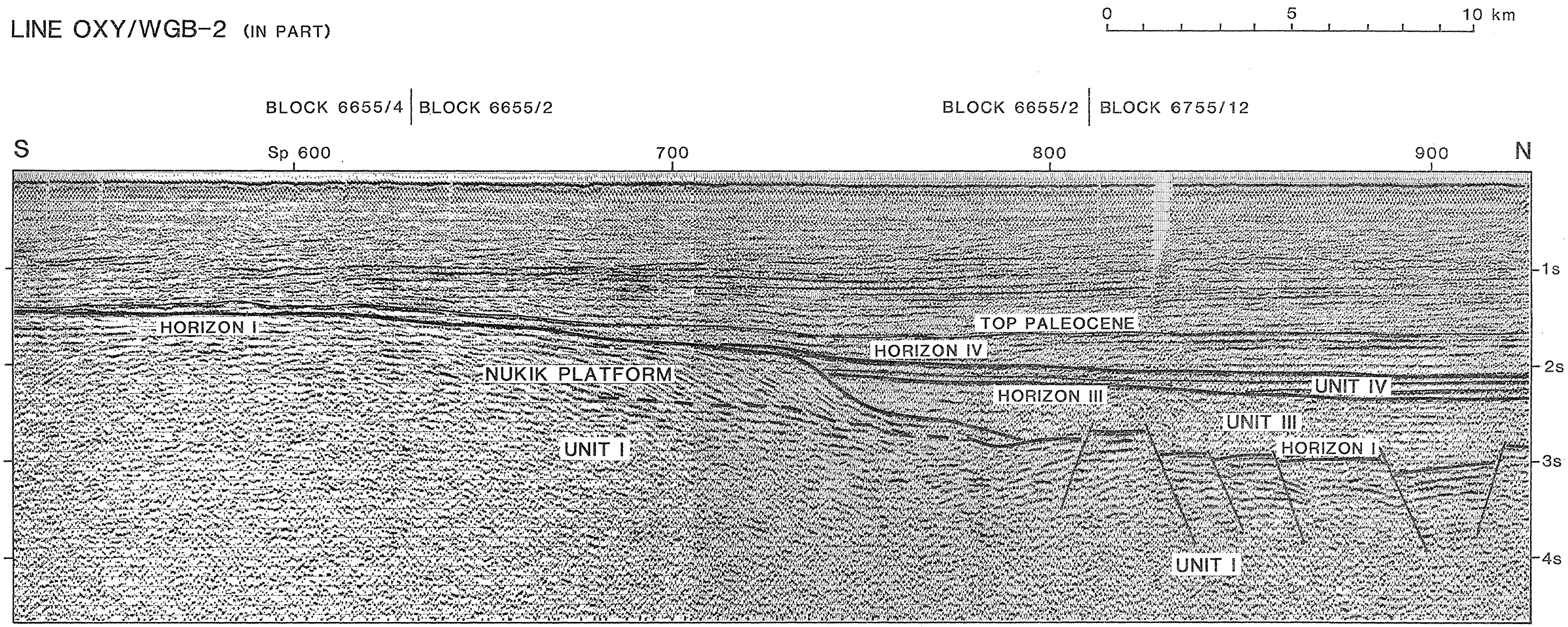


Fig. 2, General observations.

Unit I here comprises the Nukik Platform, composed of an upper band of strong reflectors overlying a deep transparent and noisy section. Just to the south of sp 600 the vague outline of the transparent high (Map 2, Block 6655/4) can be discerned. It is flanked on either side by reflectors dipping away from it. Northwards this reflector pattern grades into that of sigmoid-oblique prograding clinoforms. The thickness from top to base of these clinoforms is *c.* 500 ms TWT. With an inferred seismic velocity of 4000 m/s this indicates that the surrounding basin was about 1000 metres deep. Note that the clinoforms seem to downlap onto what forms Unit I outside the Nukik Platform and that a velocity pull-up effect may be visible at the rim of it. Outside the Nukik Platform, Unit I has been subjected to normal faulting and consists of an upper band of strong reflectors overlying an acoustically transparent and noisy section.

Unit III is rather transparent. The reflectors apparently present may actually be reverberations amplified by the automatic gain procedure. Unit III onlaps onto and possibly interfingers with strata of the Nukik Platform.

Unit IV contains, in ascending order, sequences Seq 8, Seq 9 and Seq 11. Note the hummocky clinoforms within Seq 11 around shotpoint 800.

The Top Paleocene boundary is approximate and is taken from Ottesen (1991).

LINE OXY/WG-23 (IN PART)

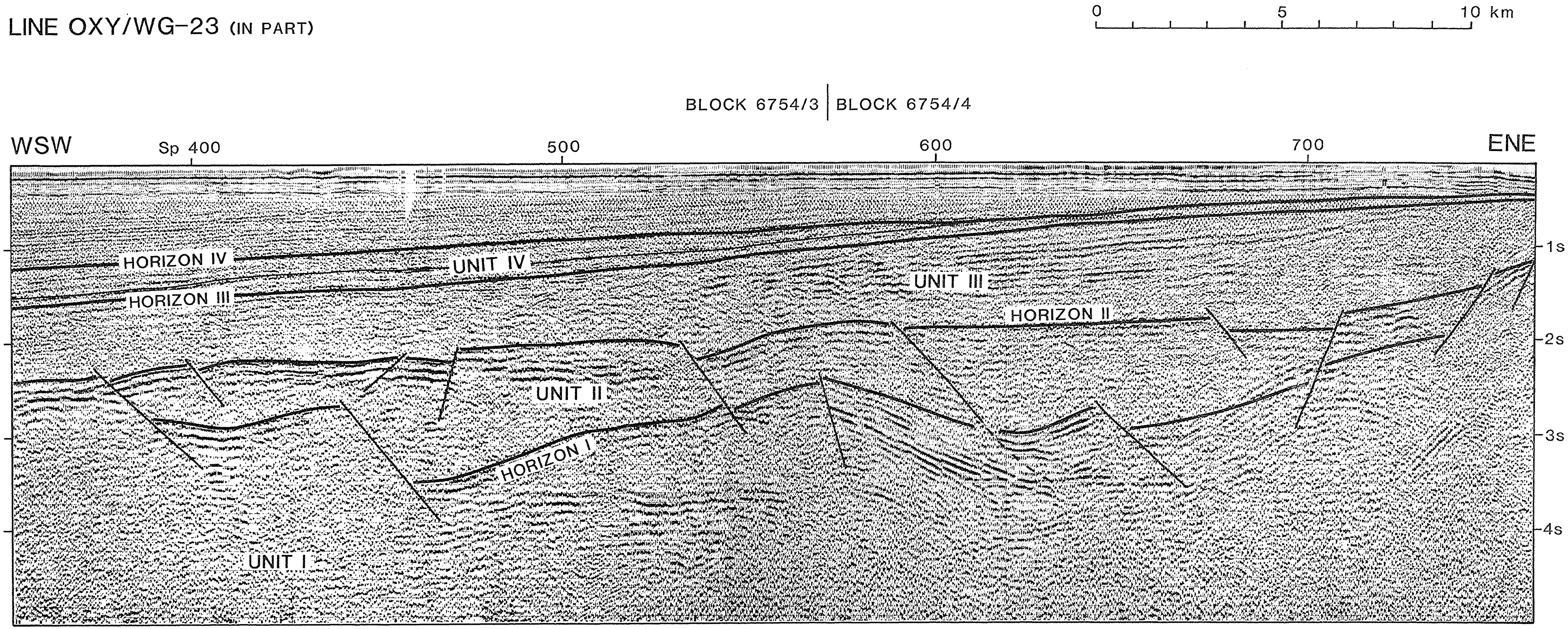


Fig. 3, General observations.

Unit I consists of a band of strong reflectors overlying a noisy or transparent deeper section. The inferred fault pattern is tentative and does not provide a detailed picture of the actual structures present. Note that some faults seem to affect Unit II as well, while others do not.

Unit II forms the sub-basin fill. A band of strong reflectors overlies a more characterless zone. Note that the strongly reflective band of Unit II seems to merge with that of Unit I to the extreme left.

Unit III is transparent to the left (WSW) but becomes increasingly reflective towards the east, where some structuring seems to have taken place.

Unit IV contains sequences Seq 1 and Seq 3 here. Westwards progradation occurs within Seq 1 between shotpoints 400 and 500 approximately. Reflectors of Seq 3 are seen to onlap onto the sequence boundary.

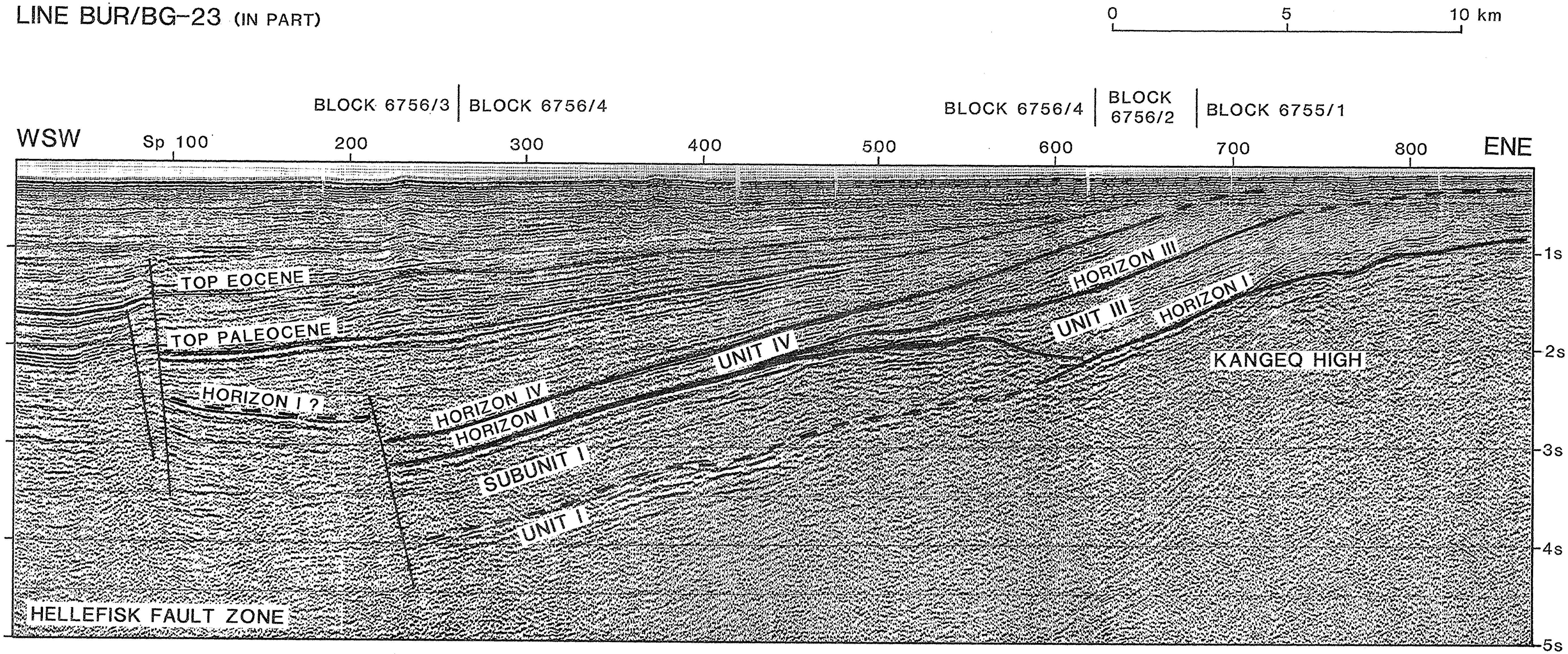


Fig. 4, General observations.

Unit I here comprises the Kangeq High and Subunit I. Unit I consists of an upper strongly reflective band overlying a transparent/noisy section. The subunit consists mainly of sub-parallel reflectors, with a more complex divergent to prograding configuration close to its eastern rim. Its appearance resembles that of the Nukik Platform (Figs 1 and 3) and it occupies the corresponding stratigraphic level. It is uncertain how Unit I and its sub unit continue westwards beyond the fault-zone.

Unit III contains reflectors which downlap onto Subunit I. However, if Horizons I and III (and IV) are rotated back to horizontal it becomes clear that this downlap actually represents palaeo-onlap.

Unit IV probably includes sequences Seq 1, Seq 3, Seq 5, Seq 10 and Seq 11, which are all very thin and whose boundaries are not determined with certainty.

Note that faulting in the Hellefisk Fault-zone affected major parts of the Tertiary section. Note also that rotation of the Kangeq High (fault block) probably persisted well into Neogene times as suggested by the divergent reflector-pattern.

The Top Paleocene and Top Eocene boundaries are approximate and are taken from Ottesen (1991).

LINE BUR/BG-26N (IN PART)

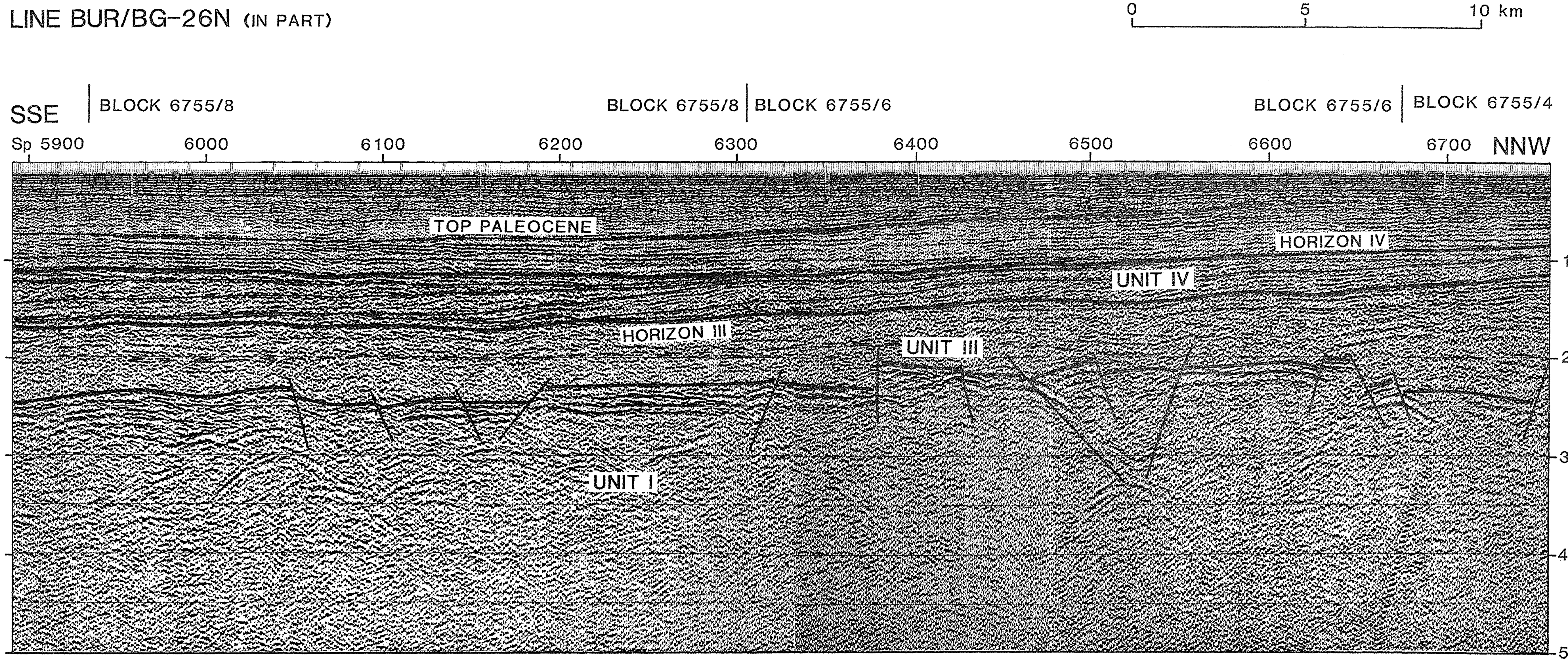


Fig. 5, General observations.

Unit I consists of an upper strongly reflective band overlying a noisy/transparent section. The illustrated fault pattern is tentative only and does not provide an adequate description of the structures present. Note the indications of deep structuring in the transparent section. This structuring may be related to the Nagssugtôq Sub-basin (Map 3 & Fig. 4).

Unit III contains a lower transparent section and an upper reflective one. The boundary between them (broken line) seems to be downlapped here, but cannot be traced round the seismic grid regionally.

Unit IV here includes sequences Seq 1, 2, 3, 5, 7 and Seq 10. Seq 1 shows oblique southwards progradation and terminates by downlap onto Horizon III just north of sp 6200. To its south, Seq 2 covers the basin floor. It is thin and where internal reflectors exist, they are of hummocky configuration. Seq 3, Seq 5 and Seq 7 all contains a zone of northwards onlap, a zone of southwards progradation and a mounded zone between them. The mounded zones are centered respectively on sp's 6300, 6150 and 6050. It is most well-developed in Seq 3 as is the northwards onlap. Progradation is clearest in Seq 5 and 7. Seq 10 onlaps to the north onto Seq 7. Reflector configuration is hummocky (fluvial channels?) between sp 5900-6000. Note that several sequences terminate onto Horizon IV, which is probably slightly erosional.

The Top Paleocene boundary is approximate and is taken from Ottesen (1991).

Fig. 6. Observed and calculated magnetic anomalies along seismic line BG-25N (cf. Fig. 1; note different scales)
(M: Magnetization, I: Inclination, D: Declination)

Model A:

Upper reflective zone magnetized only

Model B:

Transparent high magnetized

Model C:

Upper reflective zone and transparent high magnetized

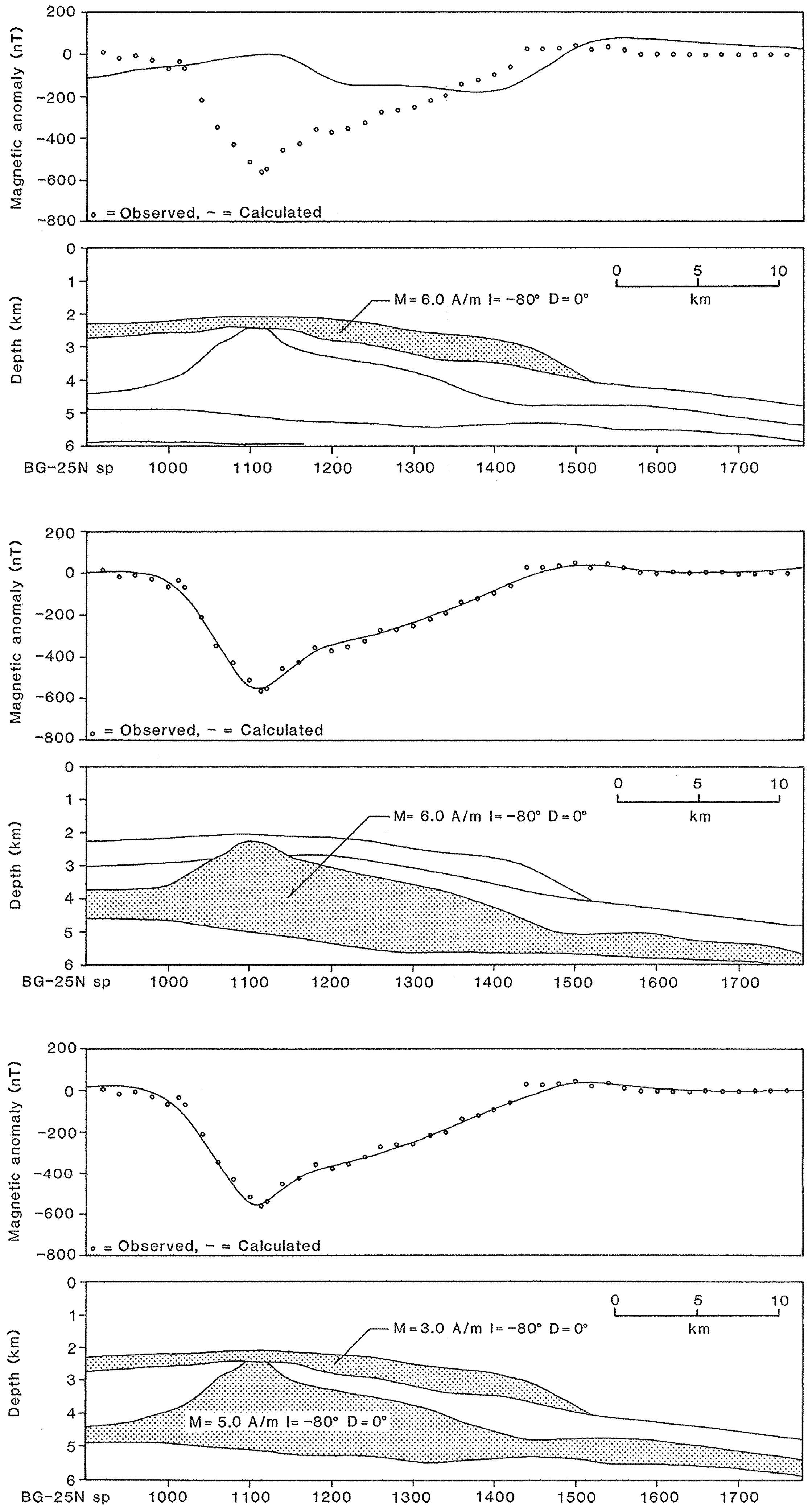


Fig. 7A Generalized cross-section of Unit IV (Thicknesses not to scale)

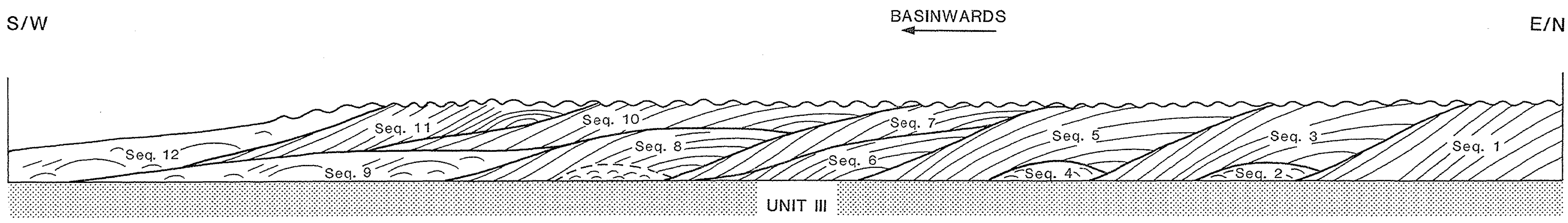


Fig. 7B Schematic cross-section of a retrogradational – progradational sequence

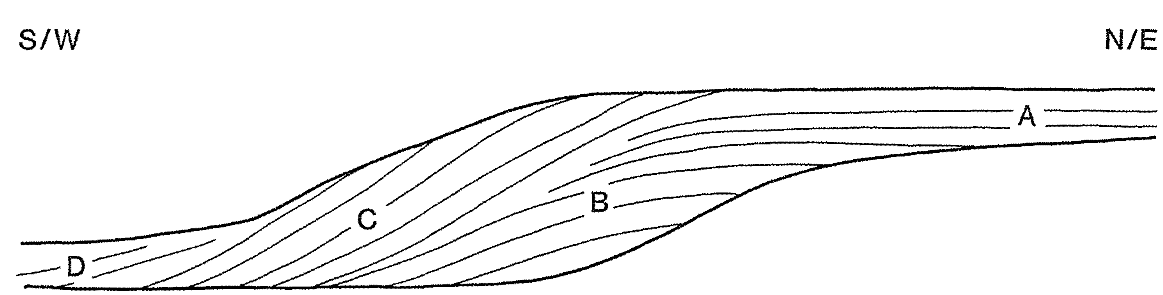
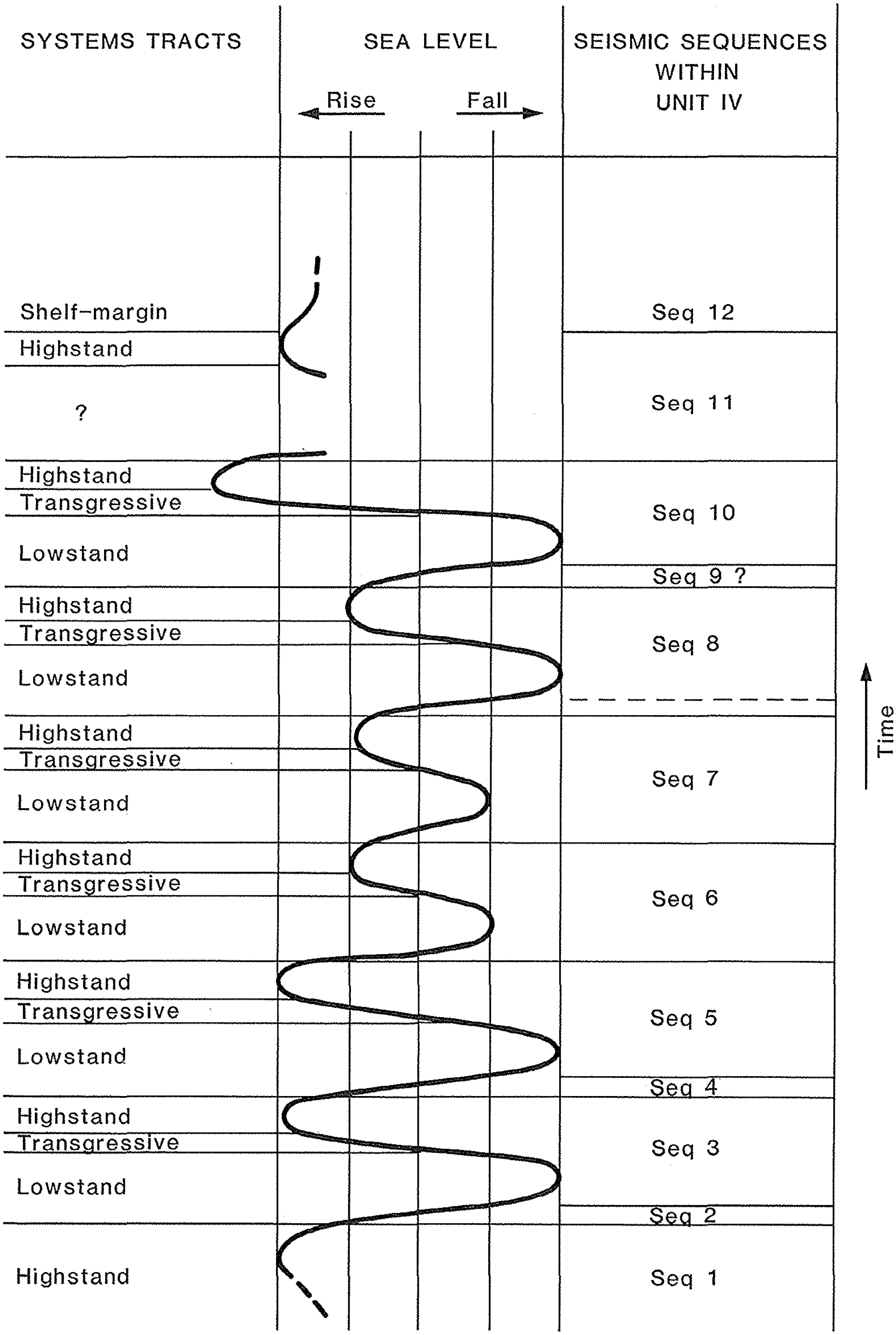
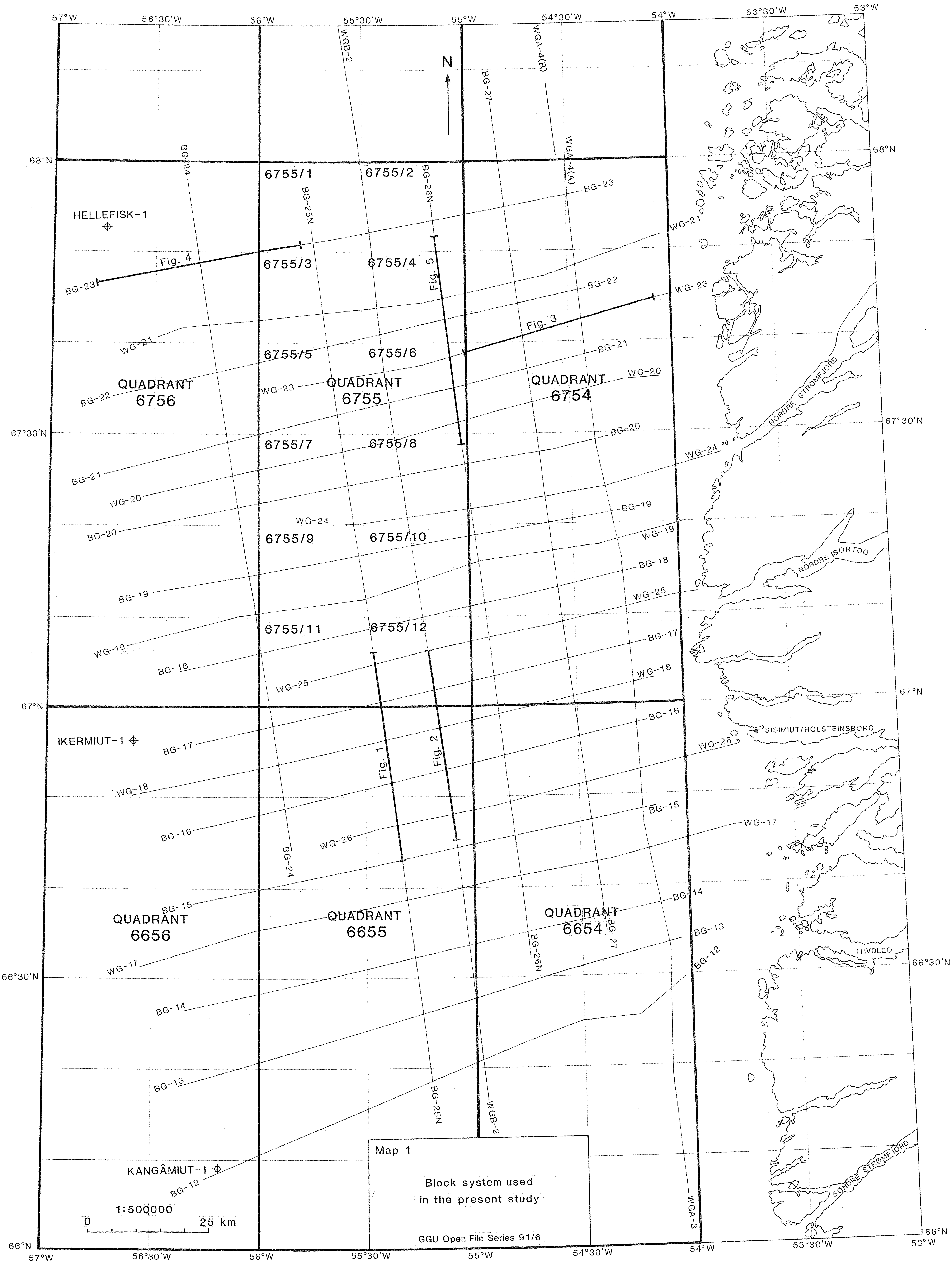


Fig. 8 Sea level curve based on interpretation of Unit IV





Map 1

Block system used in the present study

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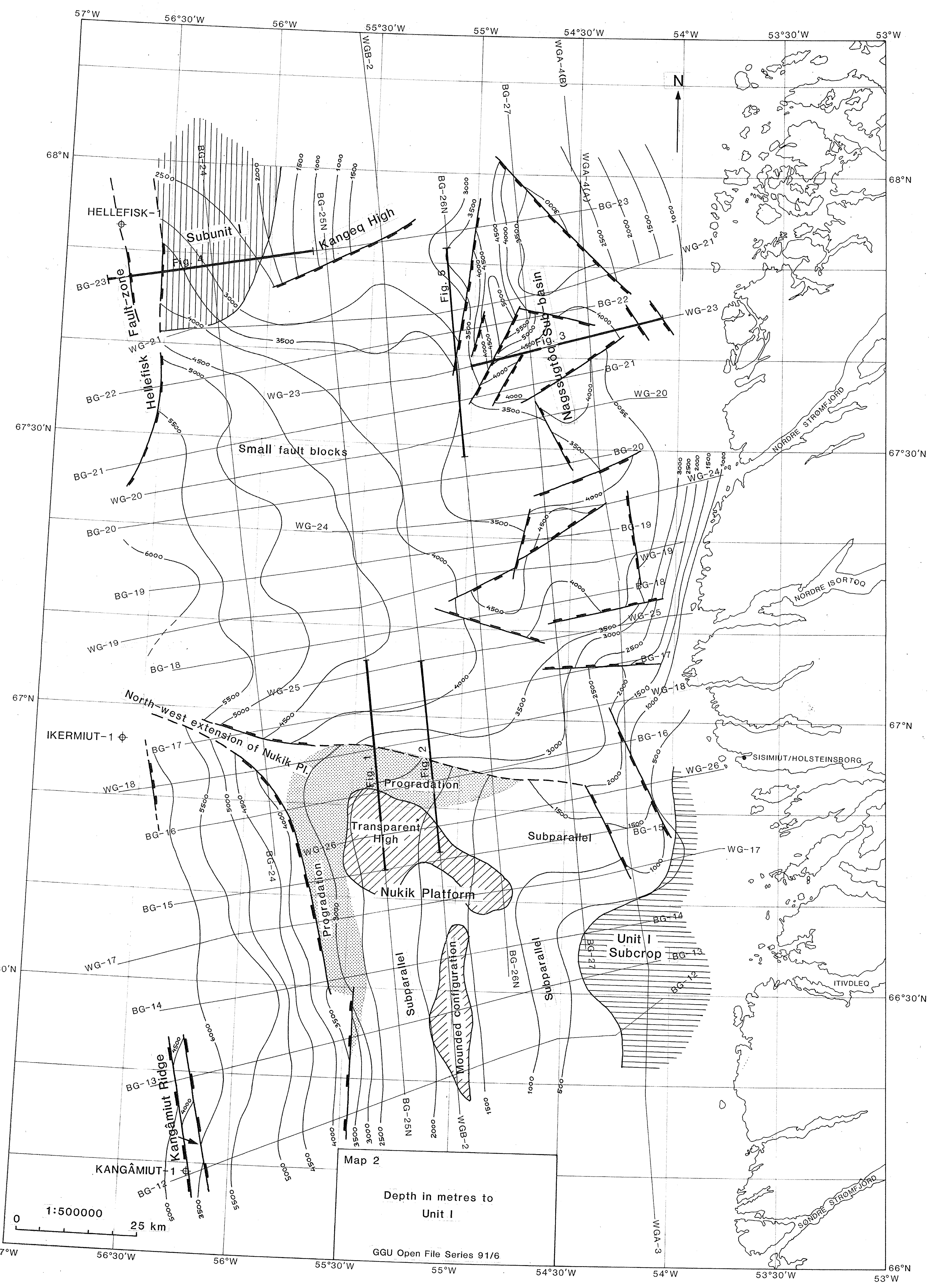
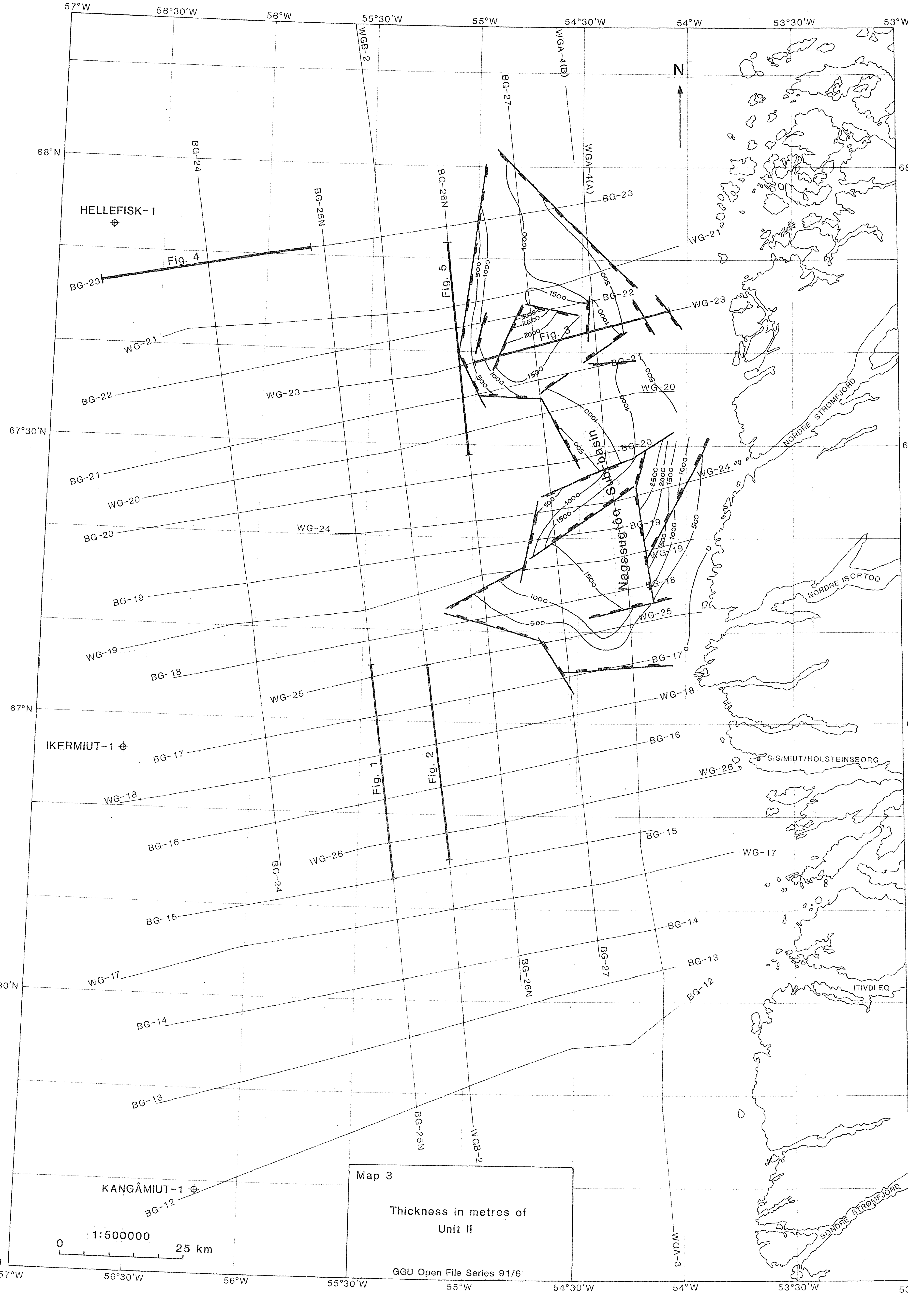
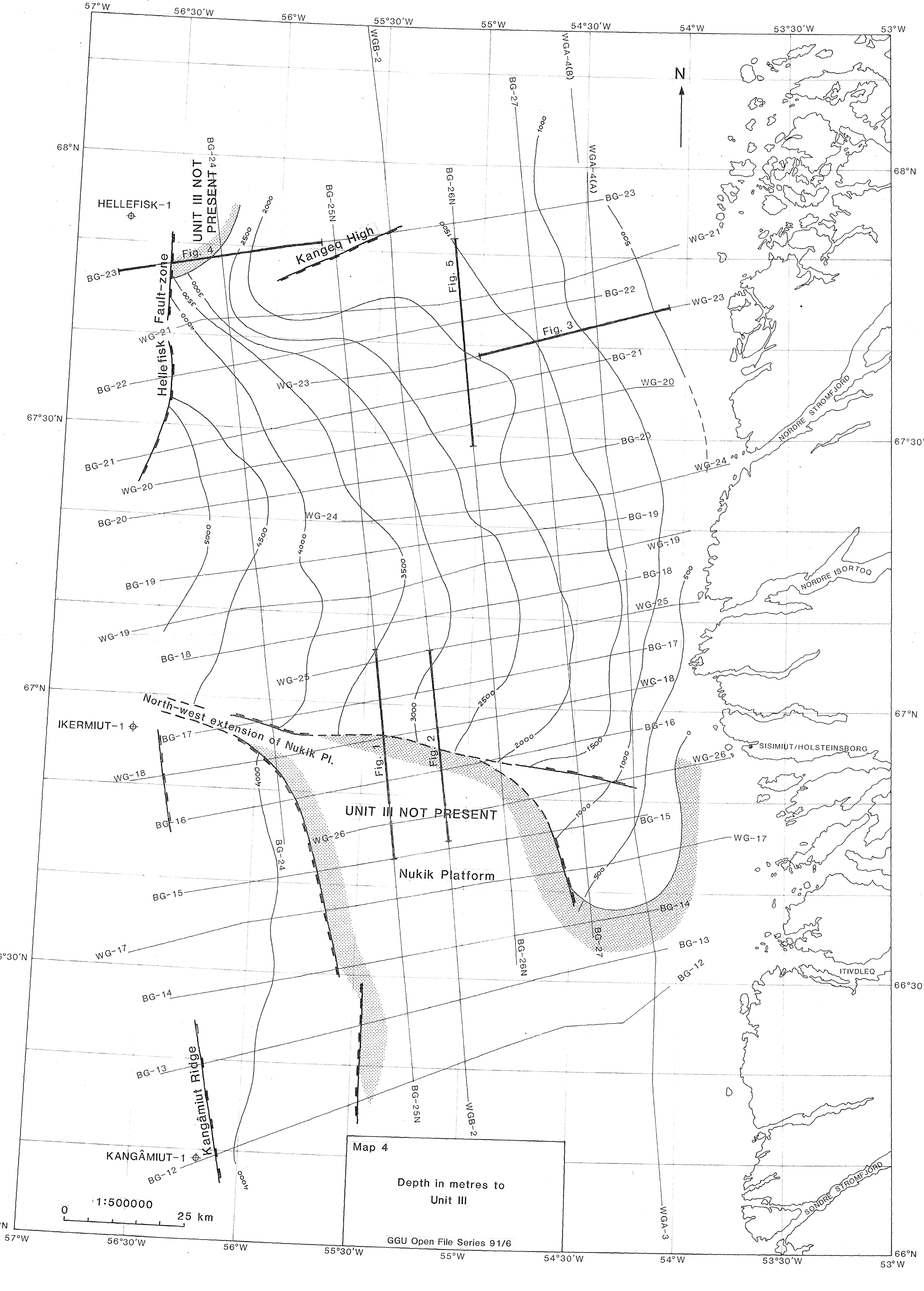


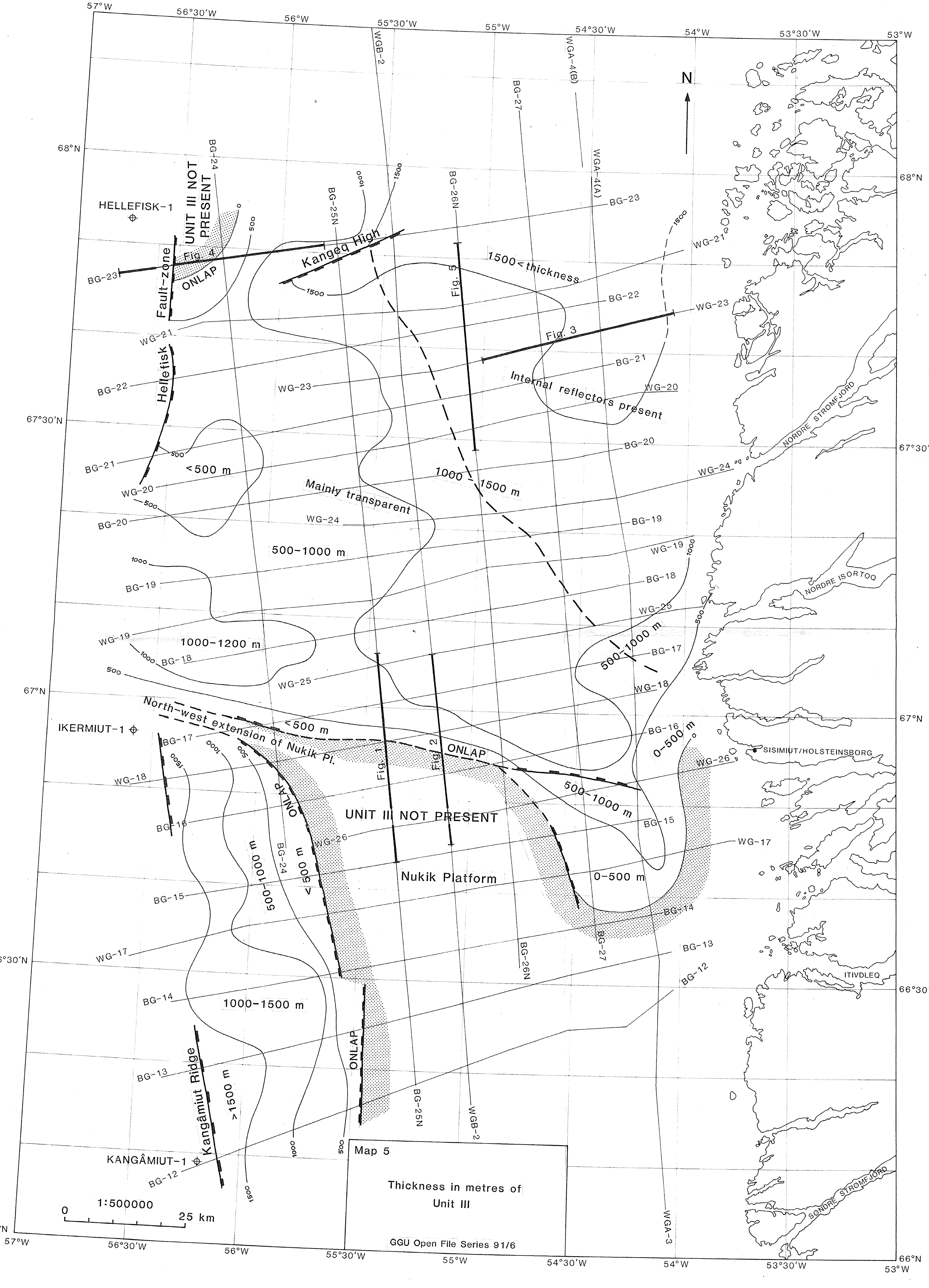
Map 2
Depth in metres to Unit I
GGU Open File Series 91/6
1:500000
0
25 km
N
HELLEFISK-1
IKERMIUT-1
KANGÂMIUT-1
Hellefisk Fault-zone
Subunit I
Kangeq High
Fig. 4
Fig. 5
Fig. 3
Fig. 1
Fig. 2
Nagssugtôq Sub-basin
Small fault blocks
North-west extension of Nukik Pl.
Progradation
Transparent High
Nukik Platform
Subparallel
Mounded configuration
Unit I Subcrop
Kangâmiut Ridge
NORDRE STRØMFJORD
NORDRE ISORTOQ
SISIMIUT/HOLSTEINSBORG
ITIVDLEQ
SØNDRE STRØMFJORD
57°W
56°30'W
56°W
55°30'W
55°W
54°30'W
54°W
53°30'W
53°W
68°N
67°30'N
67°N
66°30'N
66°N



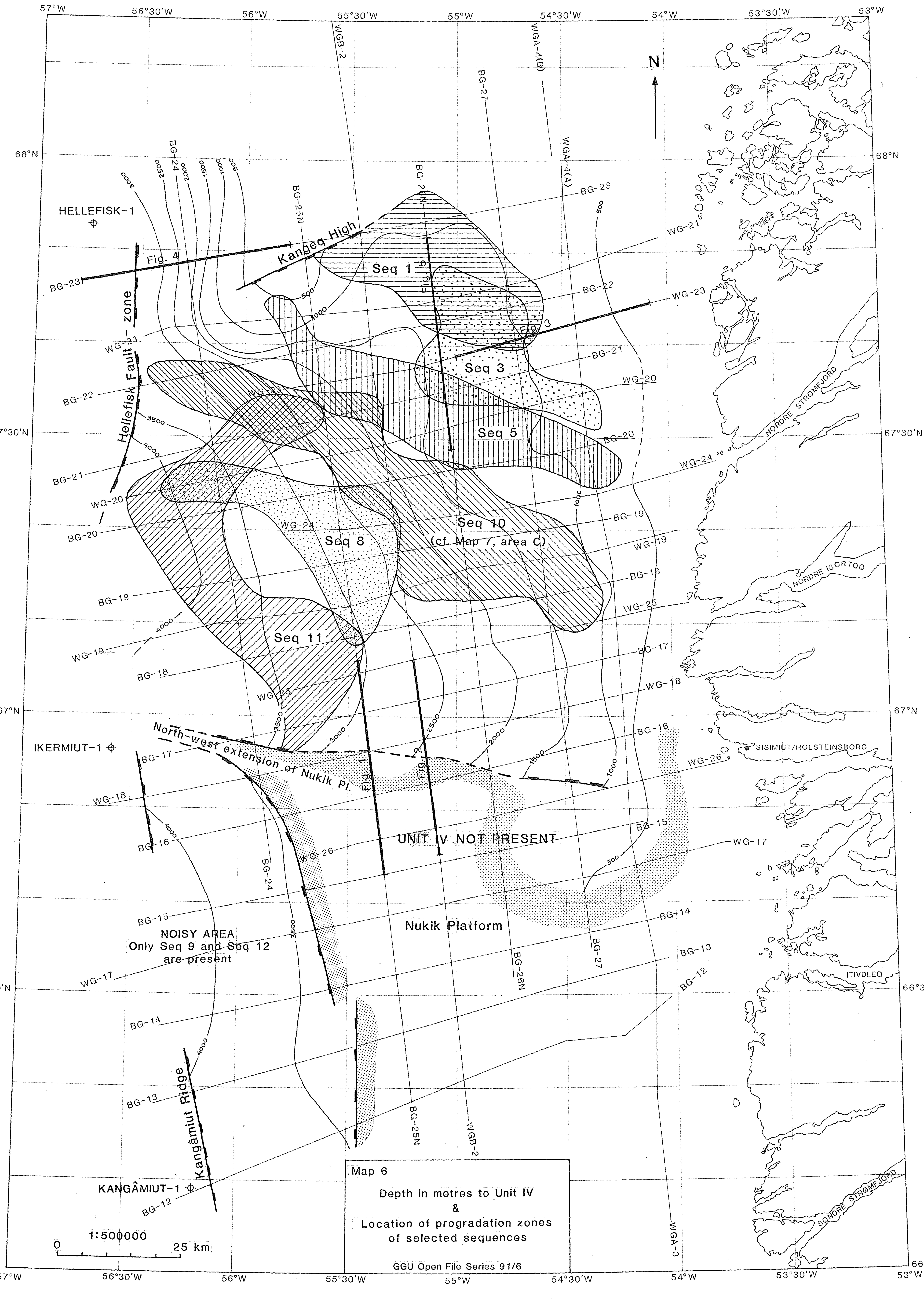
57°W
56°30'W
56°W
55°30'W
55°W
54°30'W
54°W
53°30'W
53°W
68°N
67°30'N
67°N
66°30'N
66°N
N
HELLEFISK-1
IKERMIUT-1
KANGÂMIUT-1
Fig. 1
Fig. 2
Fig. 3
Fig. 4
Fig. 5
Nagssugtôq Sub-basin
NORDRE STRØMFJORD
NORDRE ISORTOQ
SISIMIUT/HOLSTEINSBORG
ITIVDLEQ
SØNDRE STRØMFJORD
BG-12
BG-13
BG-14
BG-15
BG-16
BG-17
BG-18
BG-19
BG-20
BG-21
BG-22
BG-23
BG-24
BG-25N
BG-26N
BG-27
WG-17
WG-18
WG-19
WG-20
WG-21
WG-23
WG-24
WG-25
WG-26
WGA-3
WGA-4(A)
WGA-4(B)
WGB-2
1:500000
0
25 km
Map 3
Thickness in metres of Unit II
GGU Open File Series 91/6

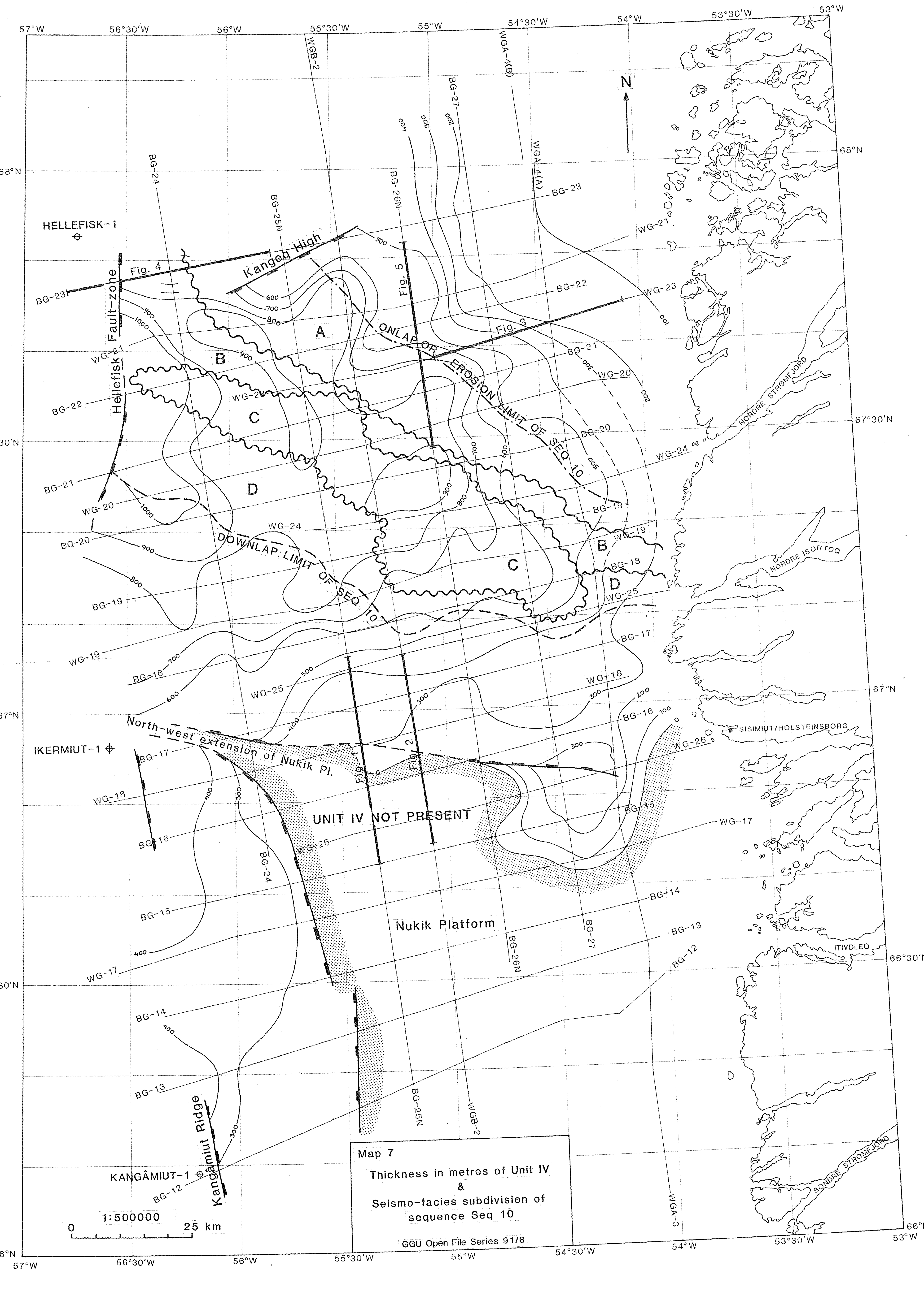


Map 4
Depth in metres to Unit III
GGU Open File Series 91/6
1:500000
0
25 km
N
HELLEFISK-1
IKERMIUT-1
KANGÂMIUT-1
UNIT III NOT PRESENT
Kangeq High
Hellefisk Fault-zone
North-west extension of Nukik Pl.
UNIT III NOT PRESENT
Nukik Platform
Kangâmiut Ridge
Fig. 1
Fig. 2
Fig. 3
Fig. 4
Fig. 5
NORDRE STROMFJORD
NORDRE ISORTOQ
SISIMIUT/HOLSTEINSBORG
ITIVDLEQ
SØNDRE STROMFJORD
57°W
56°30'W
56°W
55°30'W
55°W
54°30'W
54°W
53°30'W
53°W
68°N
67°30'N
67°N
66°30'N
66°N



57°W
56°30'W
56°W
55°30'W
55°W
54°30'W
54°W
53°30'W
53°W
68°N
67°30'N
67°N
66°30'N
66°N
N
HELLEFISK-1
UNIT III NOT PRESENT
Fig. 4
ONLAP
Fault-zone
Kangeq High
Fig. 5
1500<thickness
Fig. 3
Hellefisk
Internal reflectors present
<500 m
1000 – 1500 m
Mainly transparent
500-1000 m
1000-1200 m
500-1000 m
IKERMIUT-1
North-west extension of Nukik Pl.
<500 m
ONLAP
Fig. 1
Fig. 2
0-500 m
500-1000 m
UNIT III NOT PRESENT
Nukik Platform
0-500 m
500-1000 m
<500 m
1000-1500 m
ONLAP
Kangâmiut Ridge
>1500 m
KANGÂMIUT-1
1:500000
0
25 km
NORDRE STRØMFJORD
NORDRE ISORTOQ
SISIMIUT/HOLSTEINSBORG
ITIVDLEQ
SØNDRE STRØMFJORD
WGB-2
WGA-4(B)
WGA-4(A)
BG-27
BG-26N
BG-25N
BG-24
BG-23
BG-22
BG-21
BG-20
BG-19
BG-18
BG-17
BG-16
BG-15
BG-14
BG-13
BG-12
WG-17
WG-18
WG-19
WG-20
WG-21
WG-23
WG-24
WG-25
WG-26
WGA-3
Map 5
Thickness in metres of Unit III
GGU Open File Series 91/6


57°W
56°30'W
56°W
55°30'W
55°W
54°30'W
54°W
53°30'W
53°W
68°N
67°30'N
67°N
66°30'N
66°N
N
HELLEFISK-1
IKERMIUT-1
KANGÂMIUT-1
Kangeq High
Hellefisk Fault - zone
Kangâmiut Ridge
North-west extension of Nukik Pl.
Nukik Platform
UNIT IV NOT PRESENT
NOISY AREA
Only Seq 9 and Seq 12
are present
Seq 1
Seq 3
Seq 5
Seq 8
Seq 10
(cf. Map 7, area C)
Seq 11
Fig. 1
Fig. 2
Fig. 3
Fig. 4
Fig. 5
NORDRE STRØMFJORD
NORDRE ISORTOQ
SISIMIUT/HOLSTEINSBORG
ITIVDLEQ
SØNDRE STRØMFJORD
WGB-2
WGA-4(B)
WGA-4(A)
WGA-3
BG-12
BG-13
BG-14
BG-15
BG-16
BG-17
BG-18
BG-19
BG-20
BG-21
BG-22
BG-23
BG-24
BG-25N
BG-26N
BG-27
WG-17
WG-18
WG-19
WG-20
WG-21
WG-23
WG-24
WG-25
WG-26
1:500000
0
25 km
Map 6
Depth in metres to Unit IV
&
Location of progradation zones
of selected sequences
GGU Open File Series 91/6



Map 7

Thickness in metres of Unit IV & Seismo-facies subdivision of sequence Seq 10

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