GRØNLANDS GEOLOGISKE UNDERSØGELSE
RAPPORT Nr. 142

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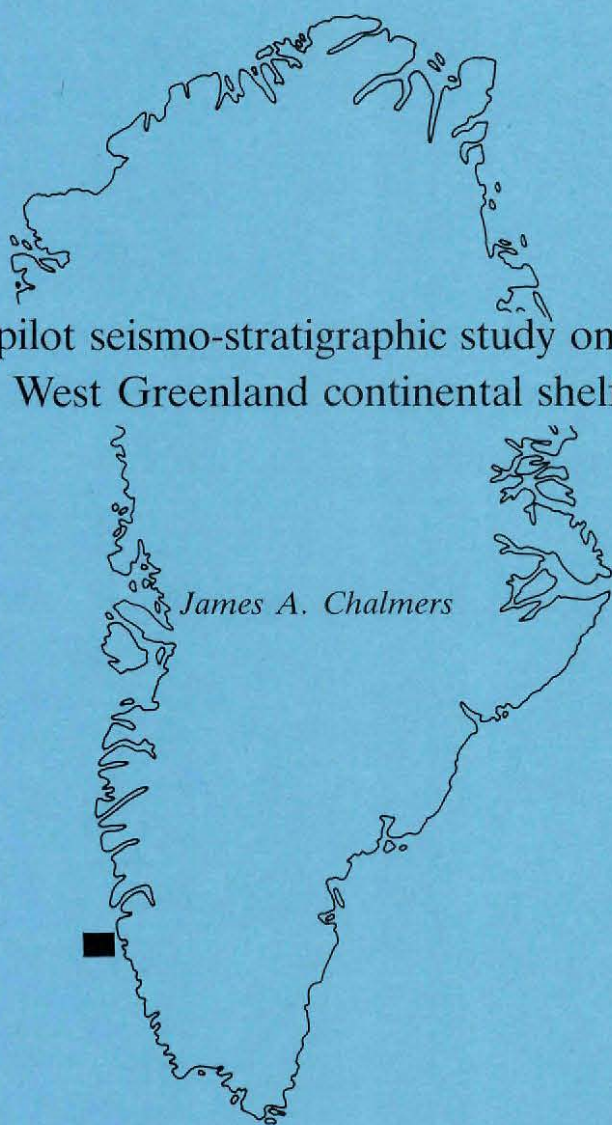
A pilot seismo-stratigraphic study on the West Greenland continental shelf

James A. Chalmers



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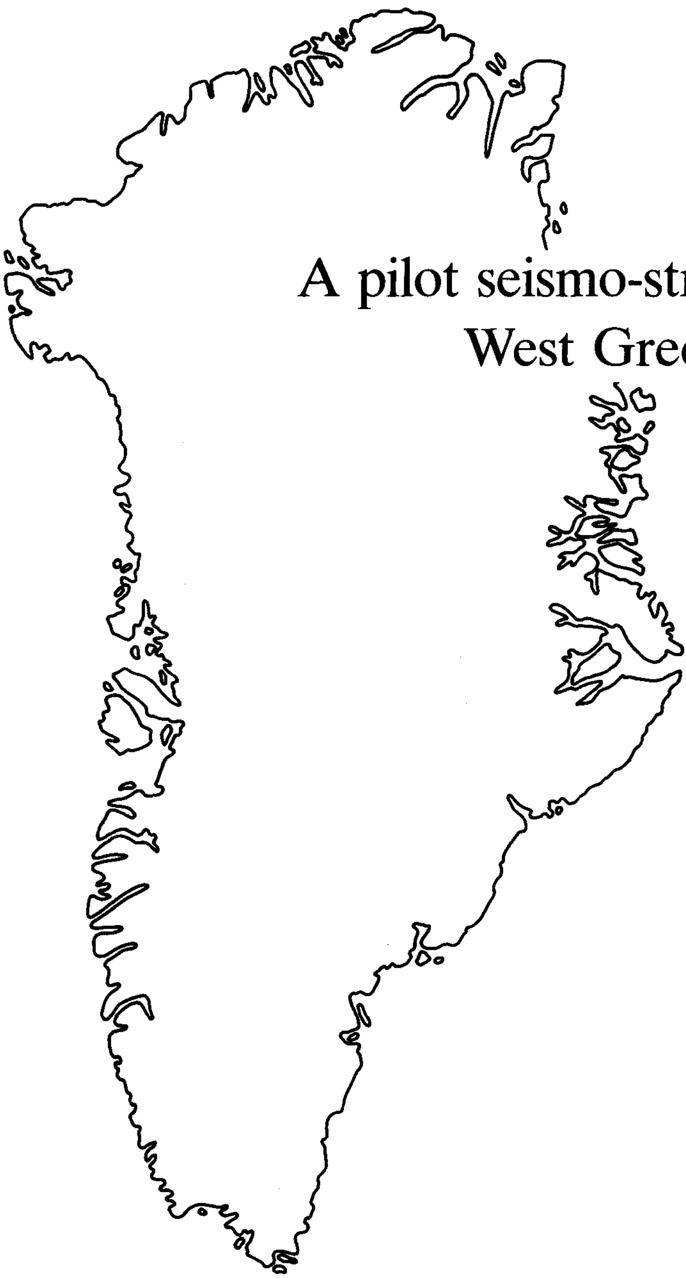

A pilot seismo-stratigraphic study on the West Greenland continental shelf

James A. Chalmers

1989

Contents

Abstract

Seismo-stratigraphic interpretation of seismic sections dating from the mid-1970s has disclosed the existence of four megasequences of sediments, the oldest of which has not previously been reported from West Greenland. The basins containing these sediments developed as a series of coalescing half graben, in which the main site of tectonic activity changed with time. A structural closure of sufficient size to contain interesting quantities of hydrocarbons, given suitable source rocks, reservoir and seal, is identified. The study has shown that the evaluation of the West Greenland Basin during the 1970s was inadequate, and that abandonment of exploration by the petroleum industry may have been premature.

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Introduction

During the period 1970 to 1979, the West Greenland Continental Shelf south of Disko Bugt was the scene of a search for hydrocarbons. In the earlier part of that period, much of the shelf between 62°N and 70°N was surveyed by a regional grid of multichannel seismic lines. After the award of licenses in 1975, this effort was followed by much more detailed surveying, particularly in the areas between 64°N and 68°N and between 63°N and 63° 30′N. Five wells were drilled, but none of them found hydrocarbons. Source rocks found onshore in the Disko–Nûgssuaq area were found to have 'excellent generating potential for gas and gas-condensate but ... have only very limited potential for generating oil.' (Schiener & Leythaeuser, 1978).

These negative conclusions led the industry into relinquishing all concessions by 1979.

The understanding of the regional offshore geology that resulted from this phase of exploration has been summarized by Manderscheid (1980) and Henderson *et al.* (1981). They show the West Greenland Basin between 64° 20′N and 68°N to consist of fairly uniformly westward dipping sediments bordered near the shelf-break by a basement ridge. The Kangâmiut 1 well was drilled on that ridge and Ikermiut 1 near it. To the north, Hellefisk 1 was drilled into an offshore extension of the Paleocene flood basalts exposed onshore in the Disko–Nûgssuaq area. Nukik 2, to the south, also terminated in Paleocene basalts but the nearby well, Nukik 1, found Precambrian basement lying immediately under Lower Eocene sediments (Rolle, 1985; Toxwenius, 1986a,b).

The seismic studies undertaken at that time used what may be termed 'conventional' techniques of interpretation. However, since the late 1970s, the techniques of seismo-stratigraphy (Vail *et al.*, 1977; Hubbard *et al.*, 1985) have become established. They have now been applied to the study of some of the seismic data acquired during the 1970s. A preliminary note on this work has already been published (Chalmers, 1988).

Seismic interpretation

The southernmost of the concessions granted during the 1970s was Concession 26. It lay over Fiskenæs Banke, one of a series of shallow banks of less than 100 m water depth which lie offshore central West Greenland (fig. 1). The banks are separated by channels which reach depths of over 500 m in places.

The holders of the Concession 26 license were Deminex Denmark A/S, PanCanadian Petroleum Denmark A/S and Amoco Greenland Oil Co., who was the operator. The concession was awarded in 1975 and relinquished in 1978. No wells were drilled and all seismic data have now been released.

Seismic data

The seismic data consist of two interleaved surveys plus an additional single line (GL–71–59) from a more regional survey. The resulting grid is around 3 km × 5 km. The AGDF survey, of around 400 km, was acquired in 1975, and the AGD 77 survey, of around 470 km, in 1977. Both surveys are fairly similar, though the 1975 data were acquired using only a 1200 m cable, in contrast to the 2400 m cable used for the 1977 survey. Processing proceeded to the stack phase only and no migrations were undertaken. A summary of the acquisition and processing parameters for the two surveys is shown in Tables 1 and 2.

By modern standards, the data quality is only fair. The lack of migrated sections hampers structural interpretation and no attempt, other than deconvolution, has been made to shape the wavelet. The AGDF survey, in particular, suffers from noise problems and poor multiple attenuation, possibly due to the short cable used. Lines shot over the channels flanking Fiskenæs Banke are of such poor quality as to be uninterpretable. The reason is not understood.

Seismo-stratigraphic interpretation

Using the techniques described by Vail *et al.* (1977), depositional sequence boundaries were identified and traced round the seismic grid. It was found that there

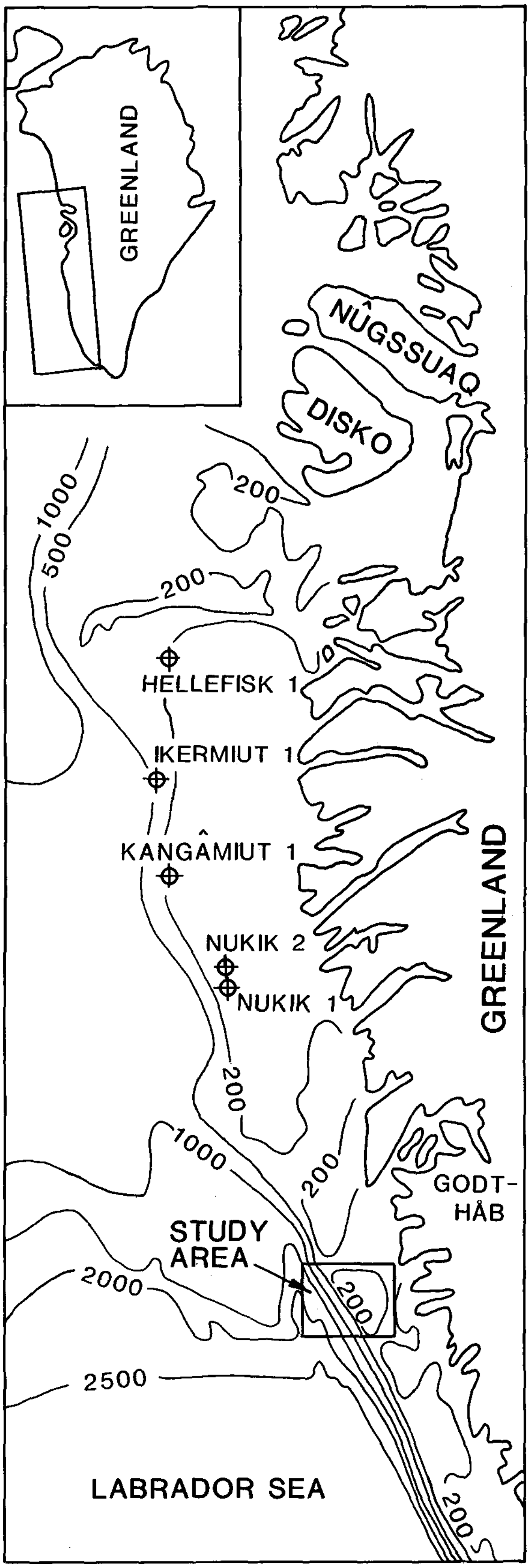


Fig. 1. Bathymetric map of offshore West Greenland between 60°N and 65°N showing the location of former Concession 26.

exist four megasequences in the sense defined by Hubbard *et al.* (1985). Examples of the sequence boundaries are shown on Plates 1, 2 and 3.

Megasequence 1

On seismic line AGD–77–09 (Plate 1), top basement has been taken to be acoustic basement. Between shotpoints (S.P.s) 150 and about 900, this is at the base of a band of sub-parallel strong reflections. What these are is not clear from the present data quality, but they could be sediments with rapidly varying acoustic impedences (sand/shales or carbonates/evaporites), or they could represent lava flows.

Above this section there is in places a more acoustically transparent zone which is terminated by an unconformity which has cut downwards into the M1 sediments and onto which the overlying sediments lap. This unconformity is most clearly seen between S.P.s 600–750 at around 1500 to 1600 ms TWT. To the northeast (right) the strongly reflective band becomes weaker and the acoustically transparent zone thicker. To the southwest, the unconformity cuts right down onto the strong reflections.

On line AGD–77–19, (Plate 2), Megasequence 1 is present as an acoustically fairly transparent band between S.P.s 300 and 1. The strong reflections are not present, and the unconformity is not so marked, but is present. Basement is taken as the last weak reflection.

Megasequence 1 clearly consists of at least two sequences. However, it is felt that present data quality is insufficient to enable further analysis of their details. Reprocessing of at least some of the seismic data is necessary. This would need to include at least improved wavelet shaping and migration.

Megasequence 2

On seismic lines AGD–77–09 and AGD–77–19 (Plates 1, 2), above the unconformity that terminates Megasequence 1 is another band of acoustically fairly transparent sediments. It is in turn terminated upwards by another unconformity above which is a much more reflective sequence. The upper unconformity is marked by strong downlapping events clearly seen between S.P.s 150–550 on line AGD–77–09 (Plate 1). In places, such as on line AGD–77–09, S.P.s 950 to 1000, this second unconformity cuts right down onto the top of Megasequence 1. Megasequence 2 may consist of only 1 sequence.

Table 1. Acquisition and processing parameters for survey AGDF

Acquisition		
Energy source		
Type	Airgun	
Pressure	1800 psi	
Volume	1200 cu.ins.	
Depth	10.5 metres	
Streamer		
Length	1200 metres	
Depth	13 metres	
No. of traces	48	
Group interval	25 metres	
Parameters		
Recording Fold	2400%	
Sample interval	4 msec.	
Shot spacing	25 metres	
Record length	6 secs.	
Recording filter	Low 8 Hz, 18db/oct.	
	High 62 Hz, 72db/oct.	
Processing		
1. Demultiplex		
2. Deconvolution	Active operator	300 msec.
	Gap	28 msec.
	Derivation window	0 – 2500 msec.
3. Velocity analysis every 2 km		
4. Mute		
5. Stack 2400%		
6. Deconvolution	Active operator	400
	Gap	spike
	Derivation window	500 – 4000 msec.
7. Filter	From 0 – 400 msec.	15 – 60 Hz
	From 1600 – 5000 msec.	5 – 40 Hz
	Filters gradually merged 400 – 1600 msec.	
8. Equalisation	AGC 750 msec. window	
9. Display	Polarity reverse from SEG convention	

Table 2. Acquisition and processing parameters for survey AGD 77

Acquisition		
Energy source		
Type	Airgun	
Pressure	?	
Volume	?	
Depth	7 metres	
Streamer		
Length	2400 metres	
Depth	15 metres	
No. of traces	96	
Group interval	25 metres	
Parameters		
Recording fold	4800%	
Sample interval	4 msec.	
Shot spacing	25 metres	
Record length	6 secs.	
Recording filter	Low 8 Hz, 18db/oct.	
	High 64 Hz, 70db/oct.	
Processing		
1. Demultiplex		
2. Horizontal mix 2:1 of adjacent field traces		
3. Velocity filter using dips of + 12 to − 4 msec./trace		
4. Time variant scaling; 200 msec. gates		
5. Velocity analysis every 3 km plus 2400% brute stacks		
6. Mute		
7. Stack 2 × 2400%		
8. Deconvolution	Active operator	400 msec.
	Gap	32 msec.
	Derivation window	100 – 3600 msec.
9. Filter	Time	Frequency
	0	12.5 – 45
	500	12.5 – 45
	1000	10 – 35
	3688	7.5 – 30
10. Equalisation	500 msec. gates starting 50 msec. above water bottom	
11. Display	to 3688 msec. using normal SEG polarity convention	

Megasequence 3

The much more strongly reflecting band of sediments above Megasequence 2 has been termed Megasequence 3. This is the most easily interpreted megasequence on the data and can readily be divided into at least 5 sequences at un- and disconformity boundaries within the megasequence (Plate 1). No work has yet been done to identify the depositional environments within these sequences, but it should be possible in principle and it is hoped that such work will be done in future.

Megasequence 4

On line AGD–77–09, the top of Megasequence 3 is obscured within multiples below the sea-bed. However, on line AGD–77–19 (Plate 2), fairly clear evidence of an unconformity cutting down into M3 can be seen, for instance around S.P. 400 and between S.P.s 250 to 150. There is still considerable interference from multiples at these locations, but on line AGD–77–02 (Plate 3) the unconformity can clearly be seen. This line is at right angles to the other two and runs along an area of rather shallow basement just northeast of the shelf break. Between S.P.s 120 and 350, an unconformity can clearly be seen cutting out the uppermost two sequences of M3. Above this unconformity and extending to the sea-bed is Megasequence 4. There is some evidence of sequences within it, but no attempt has been made to subdivide it during this study. A summary of the sea-bed geology in this region has been made by Roksandić (1979).

Structural interpretation

The interpretation was carried out in an interactive way. The initial interpretation was inspected to determine the probable direction of extension. The sections were then inspected for consistency in transferring the sequence boundaries across the faults to ensure that the sections balanced along the direction of extension. Discrepancies were re-interpreted on the seismic sections until a satisfactory result was achieved.

The structural development of the area is discussed below.

Depth conversion

In the absence of local well control, a simple method of depth conversion, using a depth versus two-way time curve was used. This curve is shown in fig. 2. It is based on the stacking velocities used to process the seismic data. The velocities so derived have a scatter, but a plot of the extreme values (the dashed lines in fig. 2) shows that the technique should be accurate to around ± 10%.

The curve was extended to beyond 2200 msec. (3150 m) using a constant velocity of 4800 m/s (the trend of the last measured portion of the curve). This assumption of a constant velocity may underestimate depths in this deeper area, but the velocity is already high for a sedimentary section. To extrapolate to higher velocites would be tantamount to making assumptions about the diagenesis of the sediments which may not be justified.

Because this portion of the curve is an extrapolation, depths greater than 3 km may be significantly in error, and should be treated circumspectly.

Geological identification of the megasequences

There is no direct way to identify the megasequences. Interpretation northwards to tie to the various wells has not yet been done, and may not be possible on the existing seismic data base. Nonetheless, the existence of several marked unconformities allows some reasonable speculation as to the age and provenance of the sedimentary layers.

Megasequence M4

There are unconformities of Early Oligocene and Miocene age which exist around the North Atlantic and adjacent continental margins (Vail *et al.*, 1977; Miller & Tucholke, 1983). The seismic reflector corresponding to the Oligocene event is normally termed R4 and that to the Miocene event is termed R2. It is thought that R4 results from erosion at the onset of strong bottom water circulation from the Arctic Ocean between Greenland and Svalbard. Early Oligocene is also the time (magnetic anomaly 13) at which sea-floor spreading is thought to have ceased in the Labrador Sea (Srivastava, 1978).

A regional unconformity of Miocene age (R2) may have resulted from a second alteration in North Atlantic circulation patterns when the Iceland–Faeroe Ridge subsided below sea level (Miller & Tucholke, 1983).

In the Labrador Sea area, there appears to be a prominent unconformity of Miocene age, but an Oligocene one is either not present or is intermittent in occurrence. DSDP Hole 112 (Laughton *et al.*, 1972) and ODP Hole 647 (Srivastava *et al.*, 1987) were both drilled in the southern Labrador Sea. Sedimentation at both well locations appears to have been continuous across the Eocene–Oligocene boundary (equivalent to R4), with only a change from siliceous to calcareous biogenic claystones to mark the equivalent of horizon R4. Reflector R2 appears to be an unconformity of Middle Miocene age in both holes.

On the Labrador Shelf, McWhae *et al.* (1980) show an unconformity of Middle Miocene age, named by them the Beaufort Unconformity. Their Baffin Bay Unconformity, of Early Oligocene age, is shown as much more poorly developed. In contrast, Balkwill (1987), in his more recent study of the same area based on seismostratigraphy, shows many well developed Tertiary unconformities. However, he puts the boundary between his 'drift' and 'post-drift' megasequences at the most prominent one in the upper Eocene, which is significantly earlier than anomaly 13 on most time scales.

A prominent unconformity of Miocene age is present

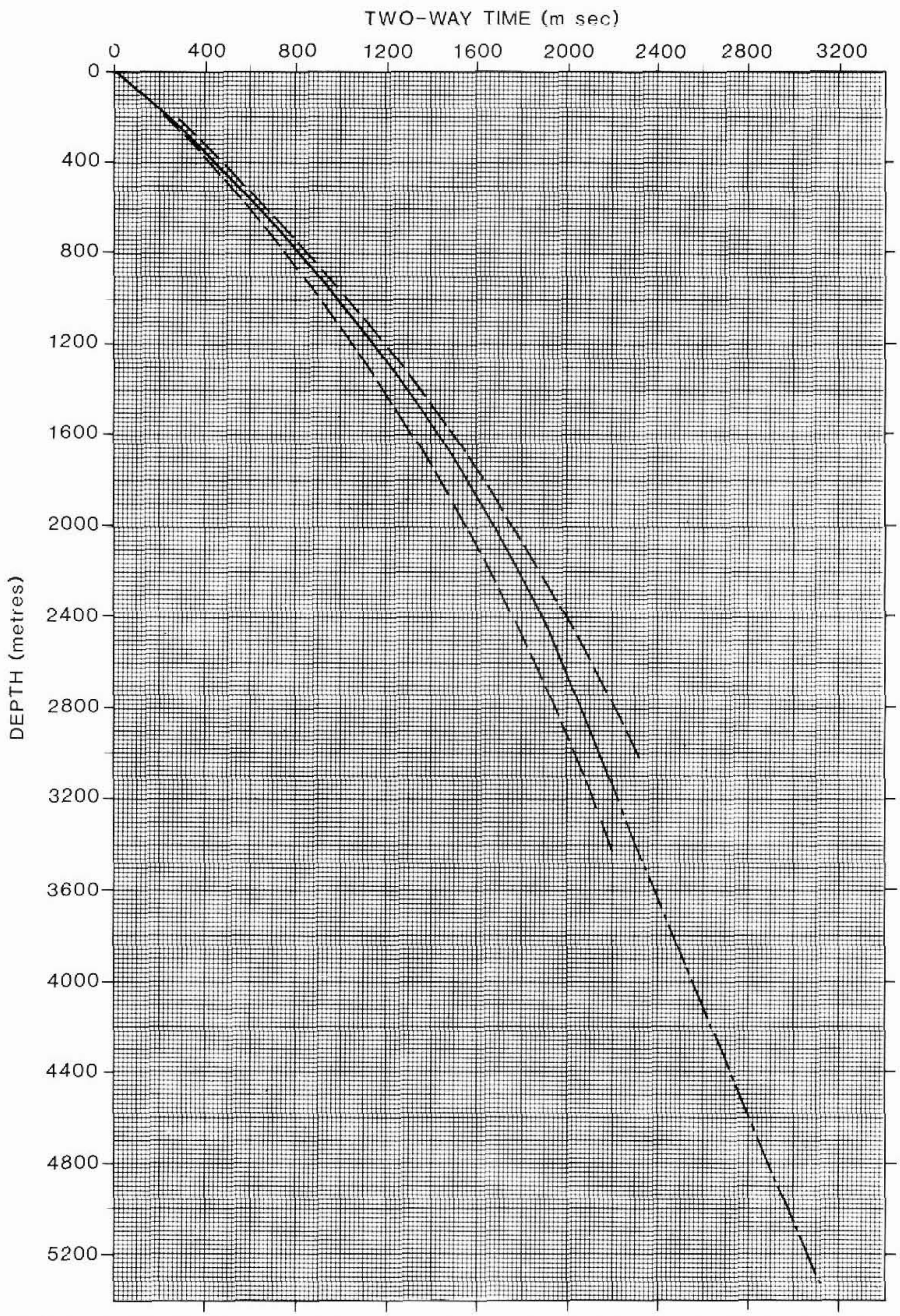


Fig. 2. Graph of Two-Way Time versus depth used to depth convert the seismic interpretation. The line derived from the seismic stacking velocities is shown continuous and its extrapolation as dash–dot. The dashed lines on either side of the continuous one show confidence limits based on the scatter among the stacking velocities.

in the wells drilled on the West Greenland shelf (Toxwenius, 1986a,b), within Rolle's (1985) Manîtsoq Formation. According to Rolle (1985), before the unconformity, deposition was on a shallow shelf, whereas after it a deeper water environment with prograding fan deltas was established.

Equating Megasequences 3 and 4 with Balkwill's 'drift' and 'post-drift' megasequences would put the M3/M4 boundary either at the base of or low within Rolle's (1985) Kangâmiut Formation. This could be a possible equivalent for it despite the fact that Toxwenius (1986a,b) shows no substantial breaks here.

It is thus difficult to give a definitive dating for the M3/M4 unconformity without more detailed correlation to the West Greenland wells farther north. This work has not yet been done. However, a date somewhere in the range from Late Eocene to Middle Miocene seems most probable.

Attempts were made to tie across the Labrador Sea using the seismic survey acquired by BGR in 1977 (Hinz *et al.*, 1979). However, multiples obscure the data on the shelf and along the shelf edge on the Greenland side and only Miocene or younger horizons can be followed across the mid-Labrador Sea Ridge from the Canadian side.

Megasequence M3

Balkwill (1987) considers that on the Labrador Shelf all the sediments from Coniacian to Late Eocene in age belong to his 'drift' megasequence. It is possible that M3 could cover the same range of ages.

However, in the Disko–Nûgssuaq area of West Greenland, sediments of Paleocene age rest unconformably on Cretaceous sediments ranging in age from Maastrichtian to Albian (Henderson *et al.*, 1981). In the West Greenland wells, there is also an unconformity of Paleocene age (Toxwenius, 1986a,b). In Nukik 1, Paleocene sediments rest directly on Precambrian basement, while in Kangâmiut 1 and Ikermiut 1 they rest on Campanian sediments.

Balkwill (1987) shows that there is a major unconformity of Paleocene age on the Labrador Shelf, but he includes it within his 'drift' megasequence. McWhae (1980) called it the Bylot Unconformity, and an unconformity of this age is well known from northern Europe (e.g. Anderton *et al.*, 1979; Buchardt, 1981).

It seems most likely that M3 is of Paleogene age and that its base is the Bylot Unconformity. This would also fit Issler & Beaumont's (1987) subsidence curves for the West Greenland wells. They assumed that the 'instantaneous stretching' event (in the sense of McKenzie, 1978) was at 63 Ma for the Greenland wells, but at 113 Ma for the Labrador Shelf wells.

If this is the case, then the unconformity at the base of M3 could be the equivalent of the F-horizon of Henderson *et al.* (1981) which has been tied to the Kangâmiut well and there dated as Upper Paleocene.

Megasequence M2

The sediments of Megasequence M2 seem to occupy half-graben rift-like structures. It is possible, therefore, that they could be correlated with Balkwill's 'rift' megasequence. In which case they would be equivalent of the Bjarni Formation of the Labrador Shelf, of Early Cretaceous age.

However, as discussed above it seems more likely that the unconformity between M2 and M3 is of Paleocene age.

In the Disko–Nûgssuaq area, the early Tertiary sediments rest unconformably on sediments of Albian to Maastrichtian age (Henderson *et al.*, 1981). Also, two of the West Greenland wells penetrated Campanian sediments lying immediately under Lower Tertiary sediments (Toxwenius, 1986a,b). It therefore seems reasonable that the M2 sediments should be of Upper Cretaceous age.

Apart from Kangâmiut 1 on a basement ridge, none of the West Greenland wells found a base to the Upper Cretaceous sediments. The problems attending Cretaceous stratigraphy onshore West Greenland are many, and Pulvertaft (1987) has recently given a review of them. Nonetheless, some general conclusions can be drawn of relevance to the present study.

Despite speculation (Pedersen, 1968) that the oldest beds (the Kome Formation) are of Early Cretaceous age, they have now been shown to be the equivalent of the Albian–Cenomanian Atane Formation (Ehman *et al.*, 1976). In the Kûk area on north Nûgssuaq they rest unconformably on Precambrian basement.

It is suggested that M2 should, therefore, be correlated with the Markland Formation (Balkwill, 1987; McWhae *et al.*, 1981) on the Labrador Shelf. If this is the case, then the unconformity between M1 and M2 could be the equivalent of McWhae *et al.*'s (1980) Avalon Unconformity.

An unconformity of late Early Cretaceous age is also well known from around the North Atlantic, for instance from southern England (Anderton *et al.*, 1979). However, the various unconformities appear to be at slightly different times, perhaps reflecting a degree of local tectonic control.

Megasequence 1

No Phanerozoic sediments of ages between Late Cretaceous (Henderson *et al.*, 1981) and Ordovician (Peel & Secher, 1979) are known from West Greenland. Thus there is no obvious local correlation for the sediments of Megasequence 1.

If M3 is correlated with Balkwill's 'drift' megasequence, and M2 with his 'rift' megasequence, then M1 consists of a thick sequence of sediments not present on the Labrador Shelf.

If, on the other hand, M3 is of Paleogene age and M2 of Late Cretaceous age, then it might be argued that the most obvious identification for M1 would be Lower Cretaceous, with the upper acoustically transparent rocks being equivalent to the Barremian to Aptian Bjarni Formation, and the lower reflective sequence being the equivalent of the basic volcanics of the Valanginian–Barremian Alexis Formation (McWhae *et al.*, 1980).

While this is perhaps the most obvious correlation, there is no *a priori* reason for it to be the only one. Also, if the identification of M2 with Balkwill's 'rift' megasequence can be maintained, then the sediments of M1 are of unknown age. Further south on the Canadian margin, Jurassic sediments are well known (Hubbard *et al.*, 1985; Meneley, 1986; Grant *et al.*, 1986). It is thus possible that the M1 sediments could be of Jurassic age, perhaps with some Early Cretaceous rocks at the top of the sequence.

In support of this conjecture is the discovery of coastal gabbro and lamprophyre dykes in West Greenland (Watt, 1969; Hansen, 1980) whose intrusion may be related to a period of crustal extension. The reported ages of the dykes range from Callovian (151 ± 7 Ma) to Barremian/Aptian (116 ± 4 Ma).

Structural development

Plates 4 to 7 show isopach maps of the four megasequences. Examination of the maps shows the development of three coalescing half graben separated by zones analogous to the transfer faults described by Gibbs (1984).

Depth converted sections along lines GL–71–59 and AGDF–09 are shown without vertical distortion in figs 3a and 4a. The development along these seismic lines is shown on successive approximately balanced sections in figs 3b to 3e and 4b to 4e. They show the calculated configuration along each line at the start of the development of each megasequence; 3b and 4b at the start of M4 time, 3c and 4c at the start of M3 time, 3d and 4d at the start of M2 time and 3e and 4e at the start of M1 time. Accurate balancing has not been done because movement in this area has not always been in the same direction and not always along the direction of the lines.

Megasequence 1 development (Plate 4)

At and just north of 63°N, a system of large faults developed, throwing down to the east. (The faults are labelled A on fig. 4 and Plate 4 and another seismic section through them is shown in Plate 3.) During M1 times, a throw of up to 2.5 km developed across these faults.

The faults can be seen in both plan (Plate 4) and section (fig. 4) to be listric and turn into NE–SW trending transfer faults (Plate 4). The system is terminated to the northeast by 'down to the southwest' faults, F, which can be seen on fig. 4 to be antithetic to faults A.

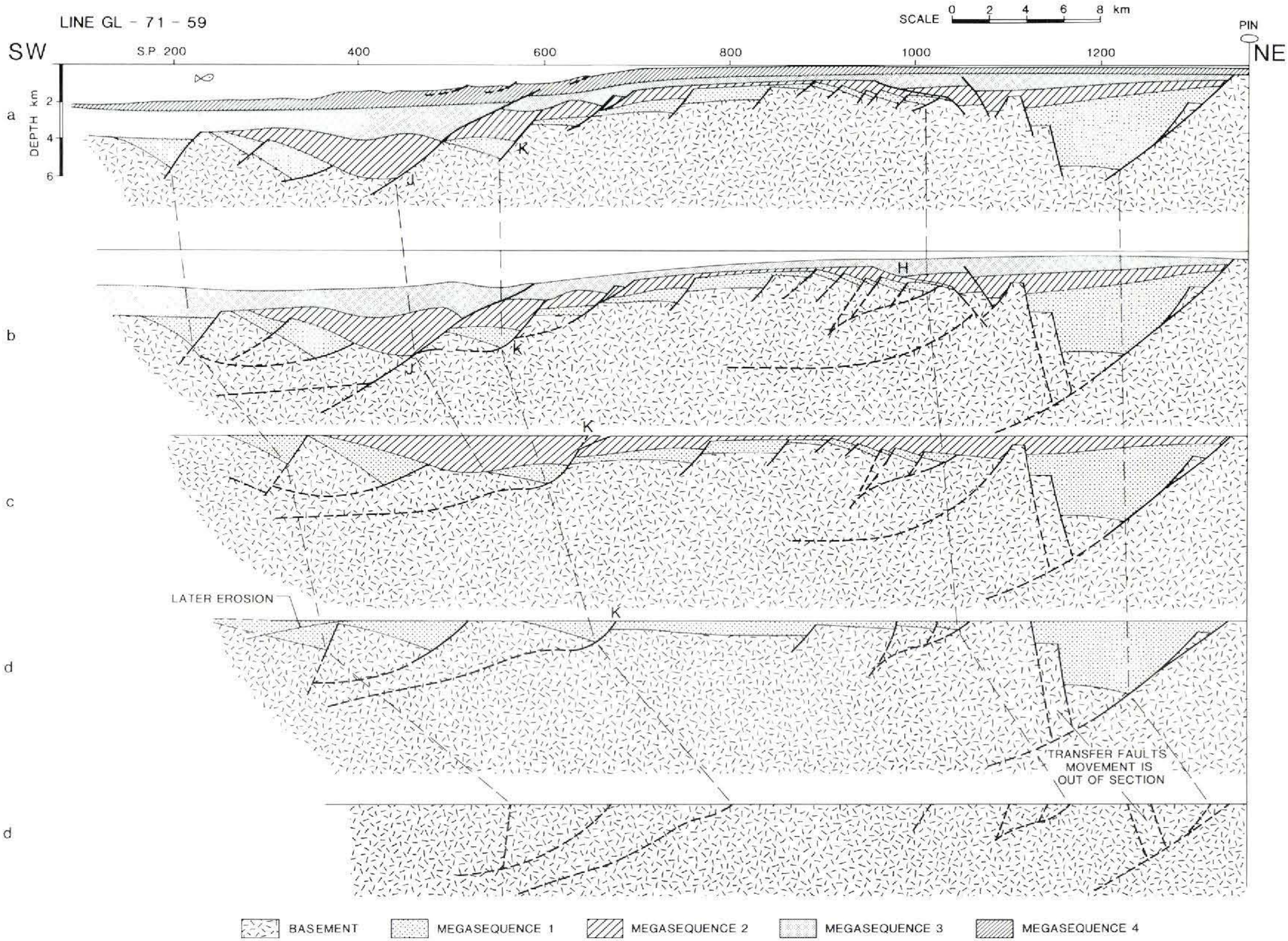
Further north, this 'down to the east' half-graben changes into a 'down to the west' one whose main bounding fault is at B on Plate 4. This second half-graben occupies the centre of the mapped area between about 63° 07′N and 63° 22′N. Plate 1 shows a seismic line through it.

Further north, near C on Plate 4, fault B changes direction abruptly from NW–SE to almost N–S. Smaller splay faults diverge from it farther southeast. A complex transfer zone runs WSW from this change in direction.

The formation of rift graben of this type has been discussed by Rosendahl (1987) using examples from East Africa. Families of overlapping half-graben develop, separated from one another by complex transfer zones and faults. Adjacent half-graben can develop with either the same or opposite polarity of extension.

In Rosendahl's (1987) nomenclature the three structures discussed above are 'blocks' and for convenience have been termed Blocks 1, 2 and 3 in order from south to north (Plates 4, 5).

Seismic line GL–71–59 (fig. 3) runs mostly through Block 3 and extends westwards under the present-day bathymetric continental rise. However, basins containing M1 sediments are shown extending to the west end of the line. There appears to be no major transition of crustal type along this line, such as would be expected at the boundary between continental and oceanic crust. It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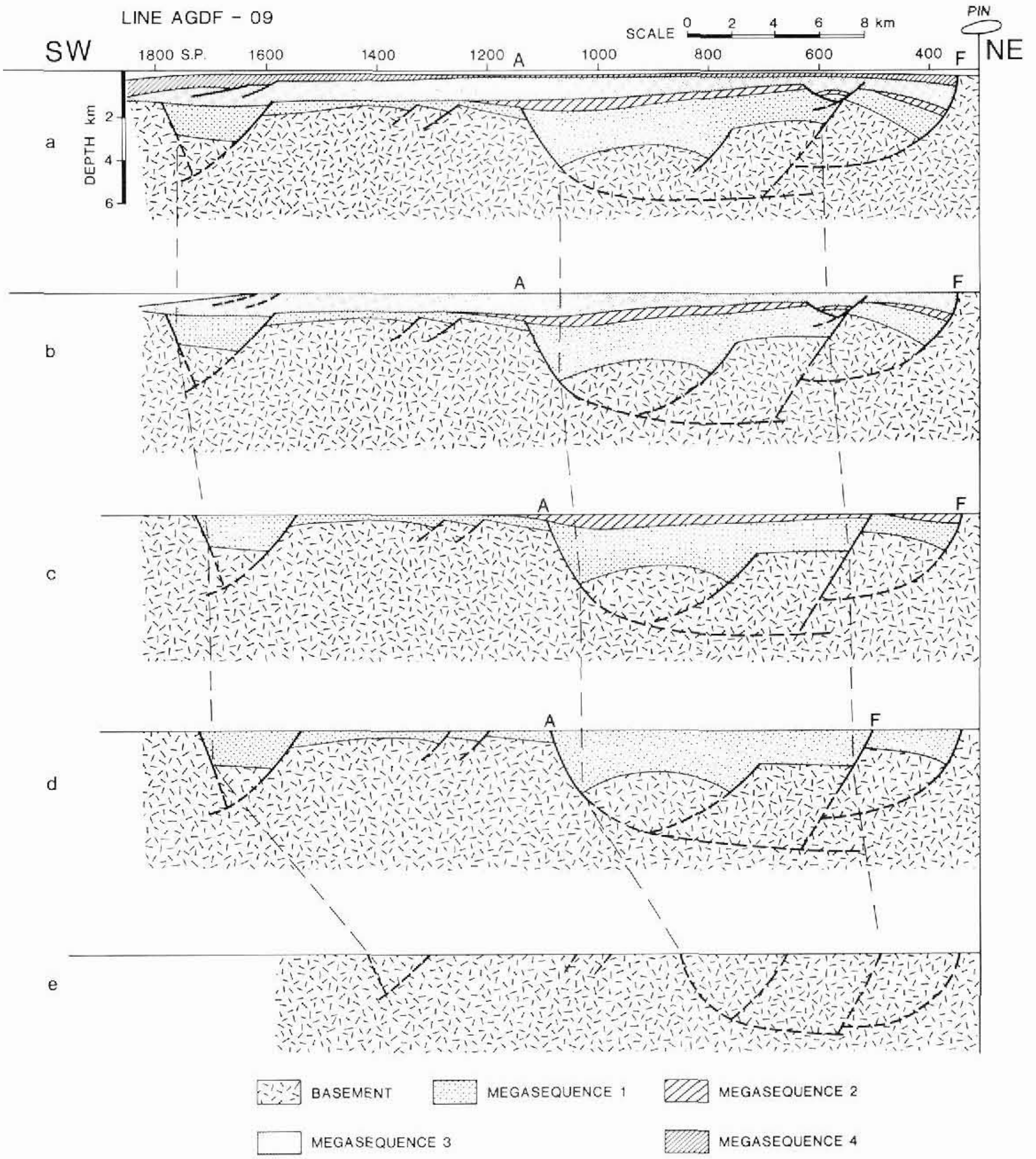

Fig. 4. Reconstruction of basin development along seismic line AGDF–09 for the same times as in fig. 3.

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Fig. 3. Reconstruction of basin development along seismic line GL 71–59. A depth converted interpretation of the line is shown in (a). Successive approximately balanced reconstructions are shown in: (b) at the start of Megasequence 4 time; (c) at the start of Megasequence 3 time; (d) at the start of Megasequence 2 time and; (e) at the start of Megasequence 1 time. Faults as interpreted on the seismic line are shown solid, those constructed by the balancing operations are shown dashed. Fault H moved out of section and does not balance.

seems reasonable to conclude that any Labrador Sea oceanic crust does not extend as far as the end of this seismic line, and that the present rapid increase in water depths at the edge of the continental shelf does not indicate a fundamental boundary in crustal type. There is no sign in the reconstruction in Plate 4 that any such deep water area existed in M1 times.

Megasequence 2 development (Plate 5)

In general terms, movement continued (or was reactivated) along much the same faults as during Megasequence 1 times. The area continued to develop as three blocks separated by transfer zones.

An exception is within Block 2 where movement on fault B seems to have decreased considerably, to the extent that the fault was no longer continuous and movement took place on NE–SW trending splays. Instead, most of the NE–SW extension occurred on fault D which was not active during M1 times (Plate 4). This change in conditions seems to have caused some space problems, for instance at E where a fault that was a 'down to the east' extension fault during M1 times reversed its movement and became a thrust fault during M2 times (Plate 5).

The eastwards throwing boundary faults of Block 1 and the westwards throwing system of Block 3 continued to be active, but there was still no sign of a deep-water basin at the start of M2 times (fig. 3d). By the end of M2 times, however, a distinct deepening to the west seems to have developed (fig. 3b). This lends weight to the identification of M2 as Upper Cretaceous. The oldest ocean floor spreading magnetic anomaly identified in the Labrador Sea is anomaly 32 (Srivastava *et al.*, 1981) which is of Campanian age. If M2 deposition started in Albian times as suggested above, no ocean basin would have existed to the west, but by the suggested time for the commencement of M3 deposition in the Paleocene, thermal subsidence towards the actively spreading ocean should have been well advanced.

During the reconstruction shown in fig. 3, the synclinal structure west of fault K in fig. 3c has been interpreted as a hanging wall syncline (Gibbs, 1984). This would require it to be developed over a ramp/flat structure in the detachment of fault K, and it is shown as having been caused this way.

Megasequence 3 development (Plate 6)

A major change in style occurred from M2 to M3 times. The 'down to the east' movement on the west bounding faults of Block 1 (faults A) almost ceased. However, movement continued on fault F which had formerly been antithetic to the fault A system. At this time the distinction between Blocks 1 and 2 became vague.

The change in structural style caused the development of a large roll-over structure with a crestal graben at G (fig. 4, Plates 6, 9).

The ramp formerly used by fault K (fig. 3) was used during M3 times by fault J (fig. 3b), a completely new movement. This cut updip dividing a formerly continuous basin, and downdip at a much steeper angle than the older faults around this area.

By the end of M3 time, a westerly regional dip, suggesting the existence of deep water, had developed over the western half of line GL–71–59 (fig. 3b).

Megasequence 4 development (Plate 7)

Tectonic activity became much less during this time. Only fault F and several faults along the present-day continental slope, including fault J, remained active. M4 is rather thin across most of Fiskenæs Banke, but thickens rapidly towards deep water (Plate 7). On line GL–71–59 (fig. 3) structures that can be interpreted as active slumping plus possible erosion by deep-water currents can be seen west of fault J, with the slumps detaching on slide planes within Megasequence 4 (fig. 3).

Present structural configuration (Plates 8, 9)

Isobath maps have been drawn on basement (Plate 8) and on the unconformity at the base of M3 (Plate 9).

The basement map (Plate 8) clearly shows the area divided into three blocks as marked on Plates 4 and 5.

In Block 1, depths in excess of 4.5 km are shown with basement shallowing steadily eastwards to an anticline at depths around 1.5 km before descending again to over 2 km below fault F. West of faults A, there is a dissected basement ridge bounded to the west by large faults. However, these faults are near the end of most seismic lines and their significance is not clear.

The basement ridge continues north and shallows in Block 2. From it, basement dips steadily eastwards, though heavily dissected by small faults. It reaches depths of over 5.5 km near point C, just under the transfer zone into Block 3. This general structure continues into Block 3, though the influence of the transfer zone has dissected the area into a mass of small compartments.

West of the basement high on line GL–71–59, basement depths in excess of 4 km are soon reached as water depths increase.

It is possible that it is the presence of the basement ridge that causes the shelf break to be where it is today, just to its west.

Plate 9 shows the present configuration of the unconformity at the base of Megasequence 3. The subcrops to that unconformity are also shown.

A structural low exists whose axis runs NW–SE through Block 2. East of this low the unconformity rises steadily to reach fault line F in Blocks 2 and 3, but in Block 1 it turns over at anticline G to dip into the fault.

West of the syncline, structural highs exist along the basement ridge. Within Block 2, the unconformity along the structural high is subcropped mostly by basement, but farther south a closed high containing a large volume of sediments from Megasequence 1 exists.

Petroleum potential

The problem of finding hydrocarbons in West Greenland has resolved itself into finding a source rock for liquid hydrocarbons plus testing a suitable configuration of reservoir and seal. Of the five wells drilled during the 1970s, only one, Kangâmiut 1, penetrated a reservoir lying under a seal.

Source rock potential

Schiener & Leythaeuser (1978) studied source rocks sampled at outcrop in the Disko–Nûgssuaq area. They concluded that the organic matter contained in the bulk of the Cretaceous source lithologies is predominantly gas prone. This is consistent with their being deposited in a deltaic environment (Henderson *et al.*, 1976).

Rolle (1985) examined the source rock potential of the five offshore wells. He concluded that the Ikermiut Formation contains a high amount of organic material which has a high potential for gas and a reasonable potential for oil.

Most of Rolle's analysis is based on samples of Paleocene age, which would be the equivalent of the lowest part of Megasequence 3 if the above correlation is valid. Assuming it to be so, then the only well to sample potential source rocks from Megasequence 2 (Upper Cretaceous) was Ikermiut 1, and Rolle shows it to be quite rich in TOC (about 3%).

Upper Cretaceous sediments are widespread offshore West Greenland (Henderson *et al.*, 1981). Only one sample from them which shows moderate potential for generating oil seems insufficient reason for concluding that the entire basin is dry.

In addition to the possibilities of Megasequence 2, Megasequence 1 has not yet been sampled by the drill, so its potential for containing source rock is completely unknown. Should it turn out to be the equivalent of the Lower Cretaceous Bjarni and Alexis Formations of the Labrador Shelf, it is unlikely to contain source rocks. Farther south, though, on the Newfoundland Shelf, a number of promising discoveries, including the giant Hibernia oil field, are sourced from the Mic Mac Formation of Late Jurassic age. Should such source rocks exist within Megasequence 1, then they would certainly be mature somewhere within the depth range 1 to 5 km between which Megasequence 1 has been shown to lie in the area of the present study.

Reservoirs and seals

The lithostratigraphy of the wells drilled to date on the West Greenland shelf has been summarised by Rolle (1985). He shows that most of the younger Tertiary section is predominantly sandy. While this would make an excellent reservoir, there appears to be no seal. The present study has also identified several sequences within Megasequence 3. The depositional environments of these sequences have not yet been studied, so it is possible that stratigraphic traps could be outlined.

Several of the wells encountered a shaly section, the Ikermiut Formation, lying immediately above the Bylot Unconformity. This would correspond to the lower parts of Megasequence 3, according to the correlation proposed above. These shales could make a good seal.

In the Disko–Nûgssuaq area, much of the Upper Cretaceous sequence is of deltaic facies, and would make an excellent reservoir (Ehman *et al.*, 1976). Kangâmiut 1 also encountered a thin Campanian sand lying immediately above basement.

The configuration of an Upper Cretaceous sand sealed by an overlying Lower Tertiary shale could make an excellent trap. The only one of the existing wells to test such a play was Kangâmiut 1, but there the thin (26 m) sand lay immediately above basement. The well penetrated no local source rock.

It must therefore be concluded that this play was inadequately tested by the five wells drilled to date on the West Greenland shelf.

On the basis of the tentative stratigraphic correlation presented in this paper, the most obvious seal to look for is in the lower part of Megasequence 3, which would correspond to the Paleocene shales encountered by Ikermiut 1, Kangâmiut 1 and Nukik 2. The identification of Megasequence 2 as Upper Cretaceous suggests that sandstones similar to those of the Disko–Nûgssuaq area (Ehman *et al.*, 1976) and in Kangâmiut 1 (Rolle, 1985) could exist to act as a reservoir. Megasequence 1 is, of course, of unknown lithology, so the existence in it of suitable reservoir rocks cannot be discounted. The most obvious play concept to test is again a closed high where sediments of Megasequences 1 and/or 2 lie under the unconformity at the base of Megasequence 3 and are sealed by shales there. If the above tentative stratigraphic correlation holds, the existence of this play has been demonstrated by at least one well, Kangâmiut 1. If it does not, then the play concept is still valid, for the sediments above and below the unconformity could be of any lithology.

Prospects within former Concession 26

To test for the existence of prospects of the type outlined above, an isobath map was drawn of the unconformity at the base of Megasequence 3 (Plate 9).

Four structural closures were found. Two are very small, on the crest of the roll-over anticline at G. This is disappointing, for the Hibernia field offshore eastern Canada exists in a similar roll-over configuration (Menely, 1987; Grant *et al.*, 1987), but of much larger size.

Two closures exist along the basement ridge at the western edge of the mapped area. The first is a large closure of around 24 km × 7 km. Its total volume is very large (around 30×10^9 m^3) but almost 95% of it consists of basement, which is likely to be of high grade metamorphic rocks in this area. Only some 2×10^9 m^3 of the structure consists of sediments of Megasequence 1 to which could perhaps be added some volume from a hypothetical weathered basement layer. These volumes, even given the existence of oil or gas as well as a favourable trapping configuration, would not be likely to contain amounts of hydrocarbons of interest in the near future.

Farther south along the same trend, however, is another interesting and perhaps more promising structure (Plate 9). Closure of over 100 km^2 appears to be present, and almost the whole of the closed structure contains sediments of Megasequence 1. The gross rock volume of this closure is around 11×10^9 m^3, so there could certainly be enough pore space to contain an oil field of over one billion barrels. As remarked above, the age and provenance of the M1 sediments is unknown, but the presence of source rock and reservoir cannot be discounted, and M1 certainly lies sufficiently deep farther east for any source rock to be mature.

On the present mapping, the closure of the structure has not been confirmed to the south, due to the quality of the seismic data there being too poor. Reprocessing might improve this situation, but failing that, new seismic data of better quality would need to be acquired.

Conclusions

The work reported on in this paper was in the nature of a pilot project to determine if more could be learned from the existing offshore West Greenland seismic data than has previously been published.

The following are the main conclusions of the study.

1. The area contains four seismo-stratigraphic megasequences, the oldest of which has not hitherto been reported from West Greenland.

2. The seismic data are of adequate quality to enable a re-evaluation of the area explored during the 1970s to be carried out, but may need to be reprocessed and supplemented for detailed prospect evaluation. Far more data need to be acquired to survey the whole West Greenland shelf adequately.

3. Only one of the five existing wells on the West Greenland shelf tested a structure capable of trapping hydrocarbons, and that in an area where source rocks capable of generating liquid hydrocarbons may not be present.

4. A structure sufficiently large to contain possibly economic quantities of hydrocarbons has been identified in an area which could contain source rocks.

5. The West Greenland shelf was not adequately evaluated by the oil industry when it terminated exploration there in the late 1970s.

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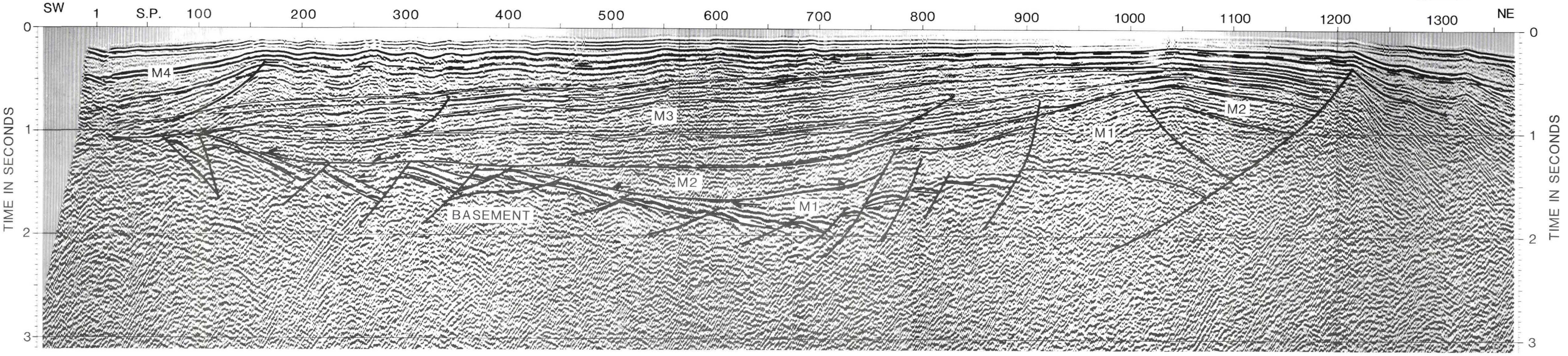
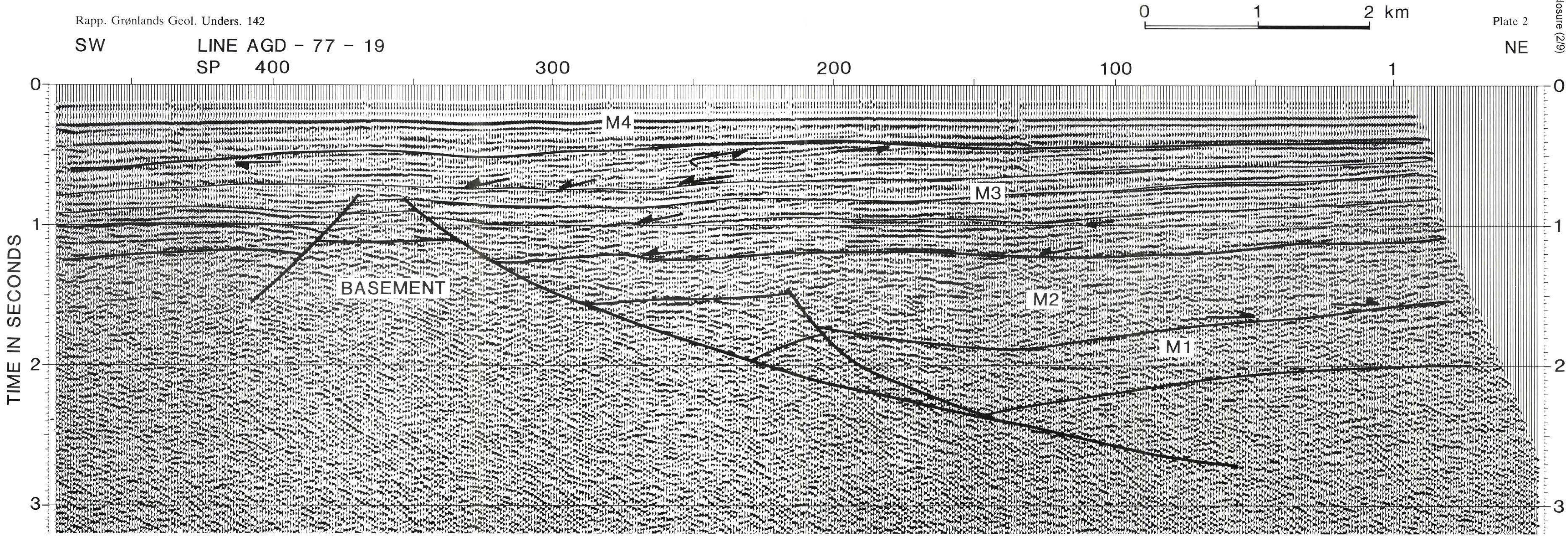
Plate 1

LINE AGD - 77 - 09

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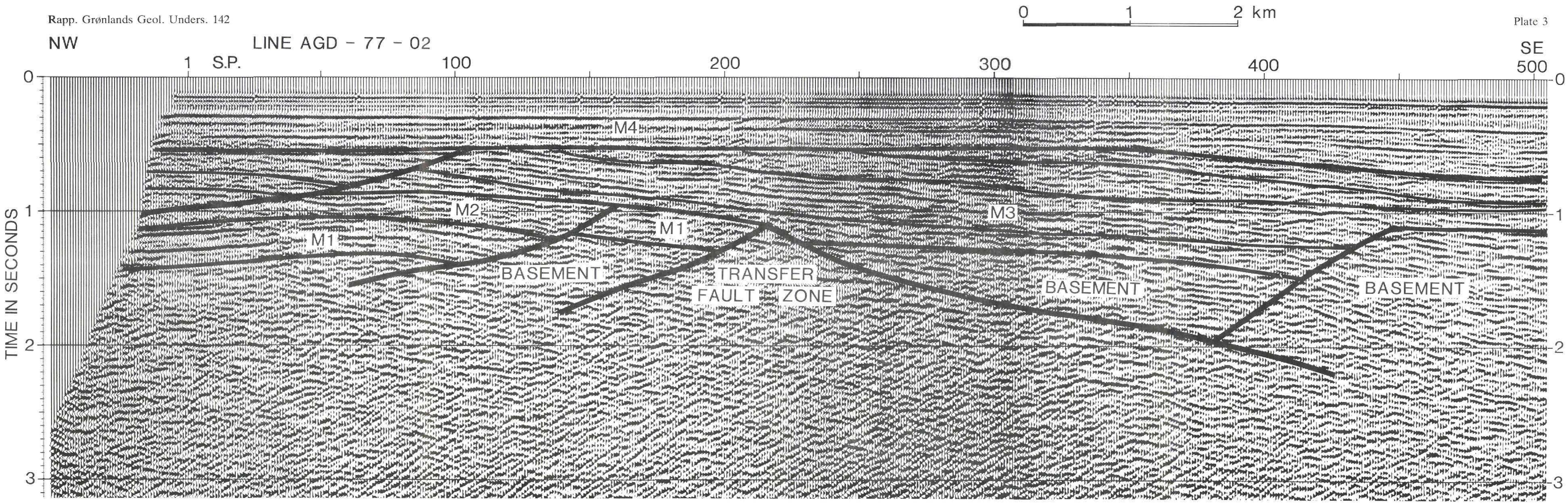
BASEMENT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LINE AGD - 77 - 02
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1 S.P.
100
200
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400
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0
1
2
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TIME IN SECONDS
M4
M2
M1
M1
M3
BASEMENT
TRANSFER
FAULT ZONE
BASEMENT
BASEMENT

Rapp. Grønlands Geol. Unders. 142

DANMARK
GRØNLAND **1 : 250000**

GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

Plate 4
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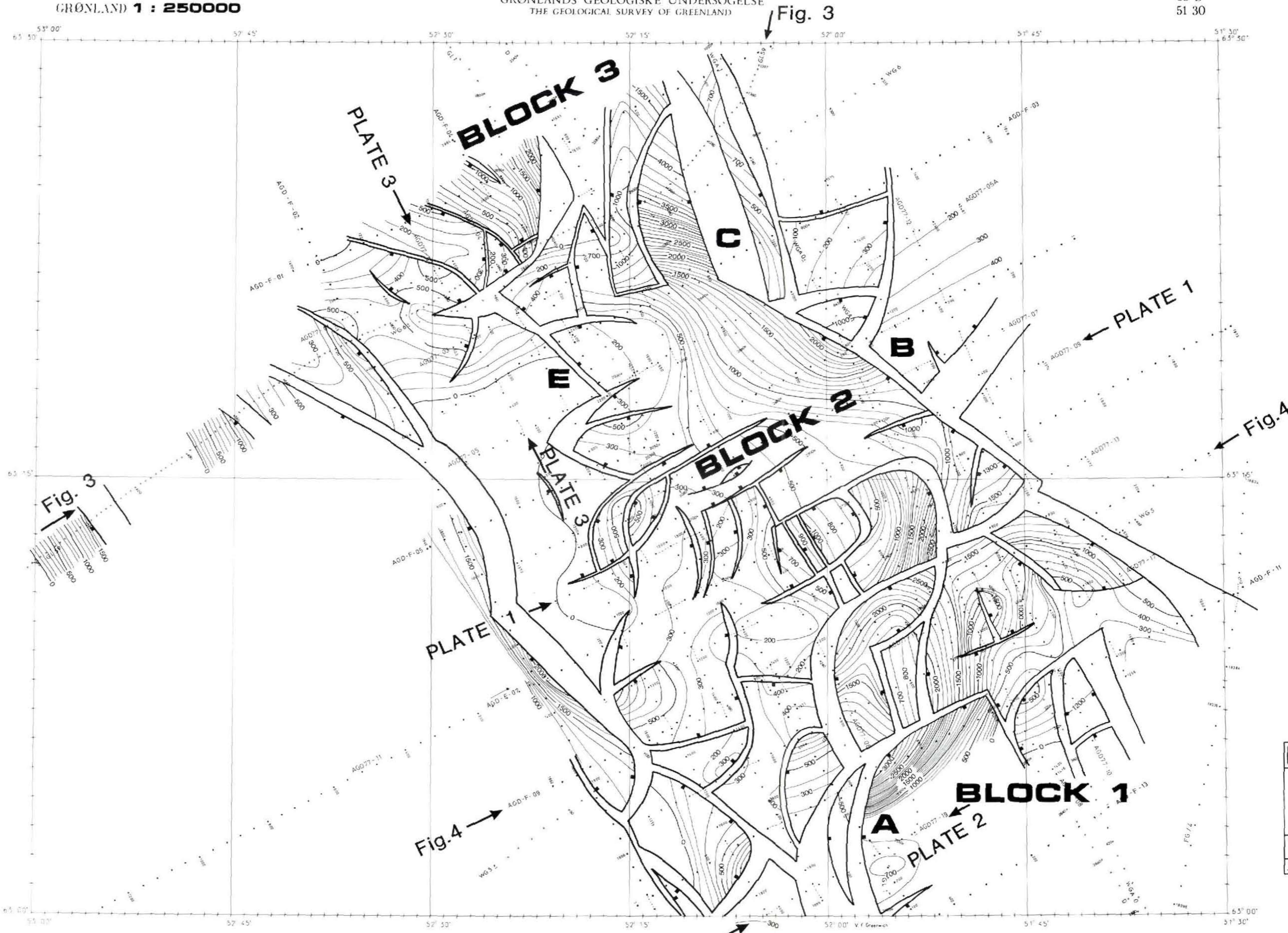
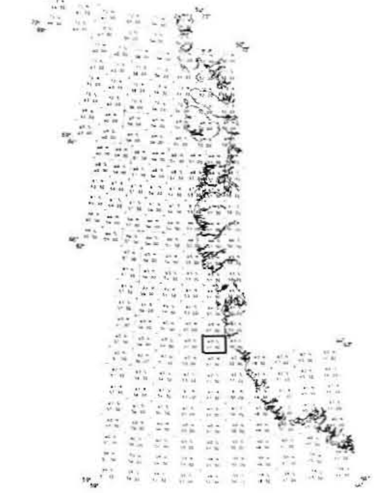
51 30





GRØNLANDS GEOLOGISKE UNDERSØGELSE

ISOPACHS IN METRES
OF
MEGASEQUENCE 1

J. CHALMERS	JAN. 88

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Produced by the Geological Survey of Greenland on the basis of material supplied by the Geodetic Institute and the Hydrographic Office, Copenhagen 1972.

Projection: Lambert's conical orthomorphic.
Ellipsoid: International. a 6 378 388 m. f 1/297.
Standard parallel: 64°30' N
Zone covered by projection: 63° N – 66° N
Scale at standard parallel: 1.0 × 10^{-1}

DANMARK
GRØNLAND 1 : 250000

GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

Plate 5
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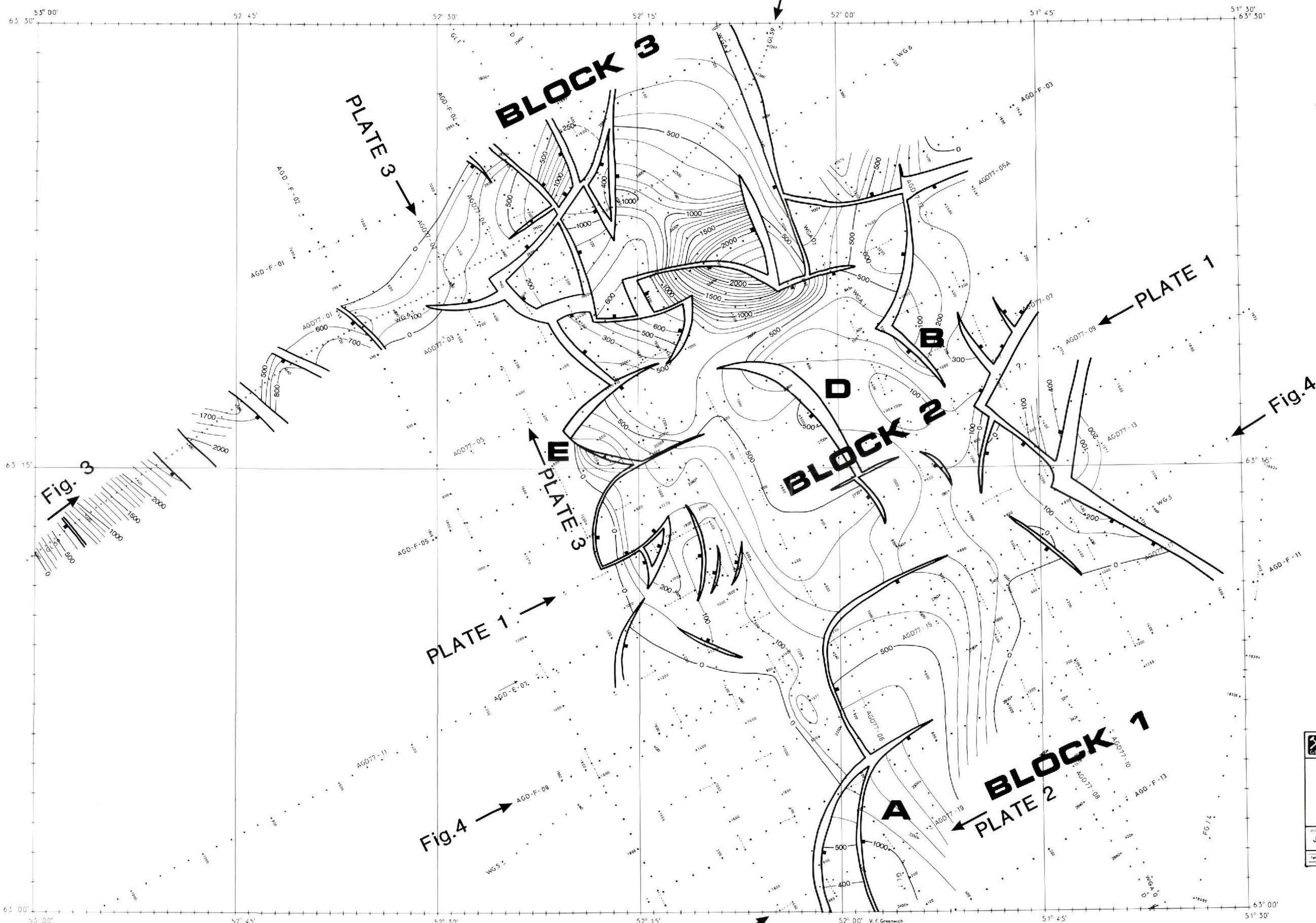

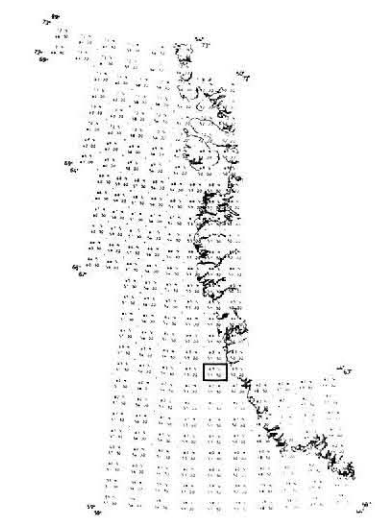

GRØNLANDS GEOLOGISKE UNDERSØGELSE

ISOPACHS IN METRES
OF
MEGASEQUENCE 2

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Ellipsoid: International, a: 6 378 388 m, f: 1/297.
Standard parallel: 64°30'N
Zone covered by projection: 63°N – 66°N
Scale at standard parallel: 1.0 × 10^-5

Plate 6

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GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

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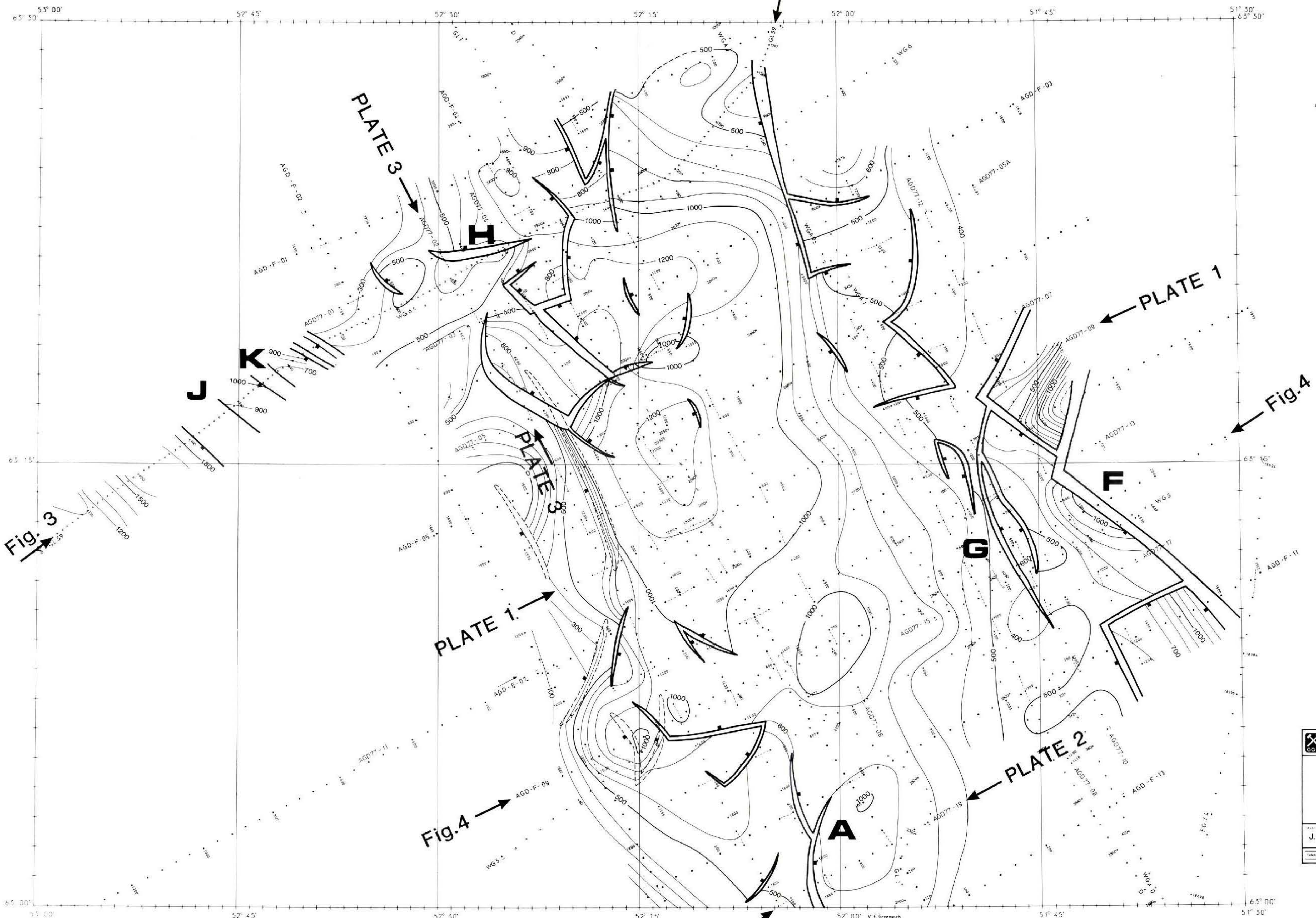

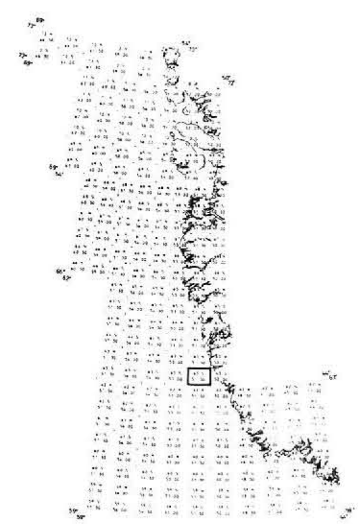

SLIDE FAILURES AT THE TOP OF THE SEQUENCE WITH DECOLLEMENTS WITHIN IT

1 : 250000

Produced by the Geological Survey of Greenland on the basis of material supplied by the Geodetic Institute and the Hydrographic Office, Copenhagen 1972.

Projection: Lambert's conical orthomorphic.
Ellipsoid: International, a 6 378 388 m f 1:297.
Standard parallel: 64°30'N
Zone covered by projection: 63°N – 66°N
Scale at standard parallel: 1.0 × 10⁻⁵

GRØNLANDS GEOLOGISKE UNDERSØGELSE	
ISOPACHS IN METRES OF MEGASEQUENCE 3	
J. CHALMERS	JAN. 88

G E U S
Report File no.
22479
Enclosure (7/9)

Plate 7
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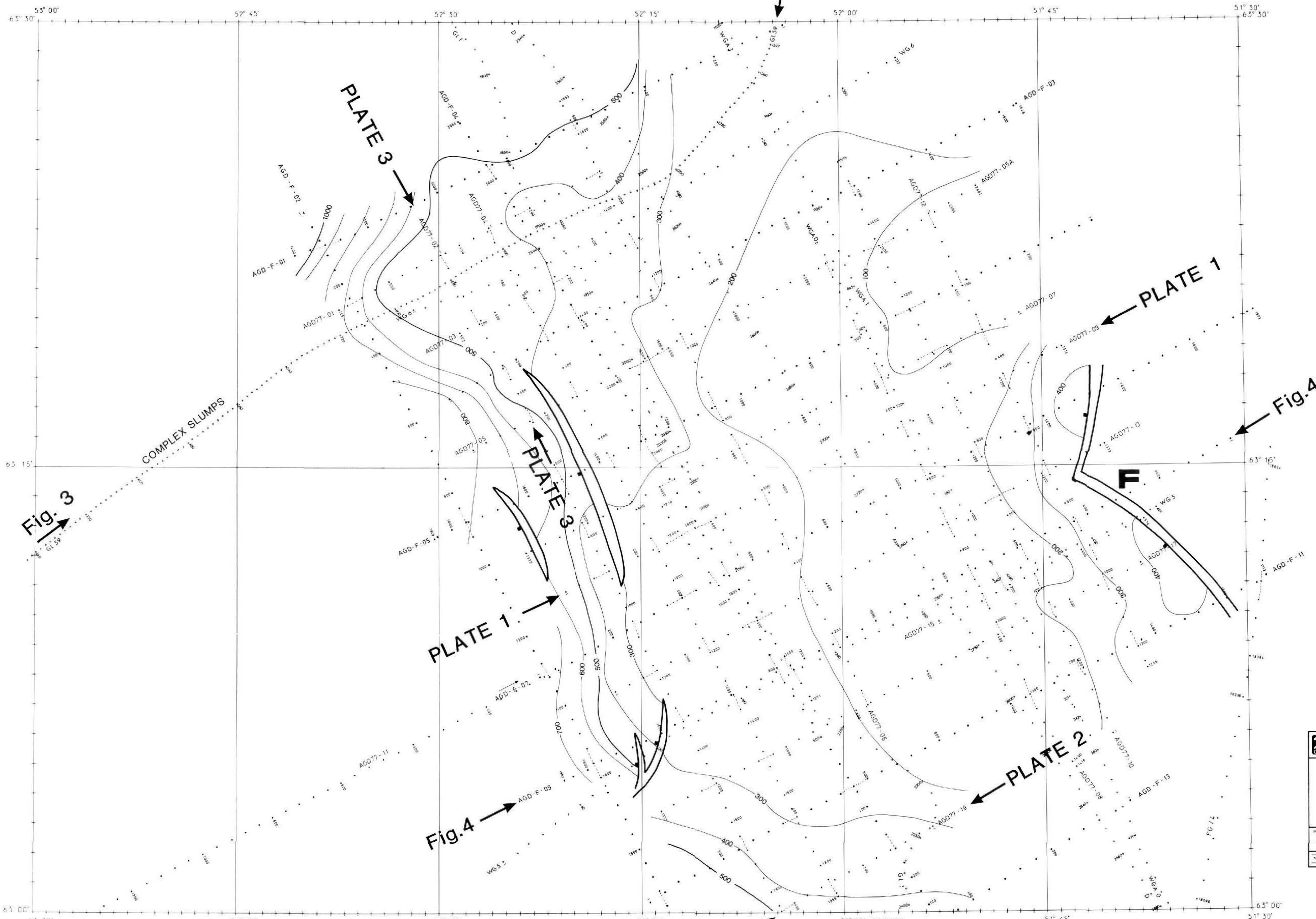
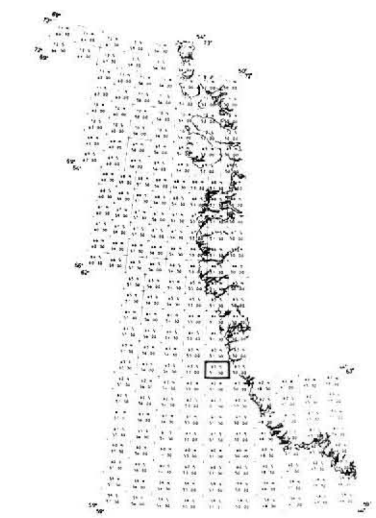
GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND





GRØNLANDS GEOLOGISKE UNDERSØGELSE
The Geological Survey of Greenland

ISOPACHS IN METRES
OF
MEGASEQUENCE 4

J. CHALMERS	JAN. 88

Produced by the Geological Survey of Greenland on the basis of material supplied by the Geodetic Institute and the Hydrographic Office, Copenhagen 1972.

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Projection: Lambert's conical orthomorphic.
Ellipsoid. International, a 6 378 388 m, f 1/297.
Standard parallel: 64°30'N
Zone covered by projection: 63° N – 66° N
Scale at standard parallel: 1.0×10^{-5}

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Enclosure (8/9)

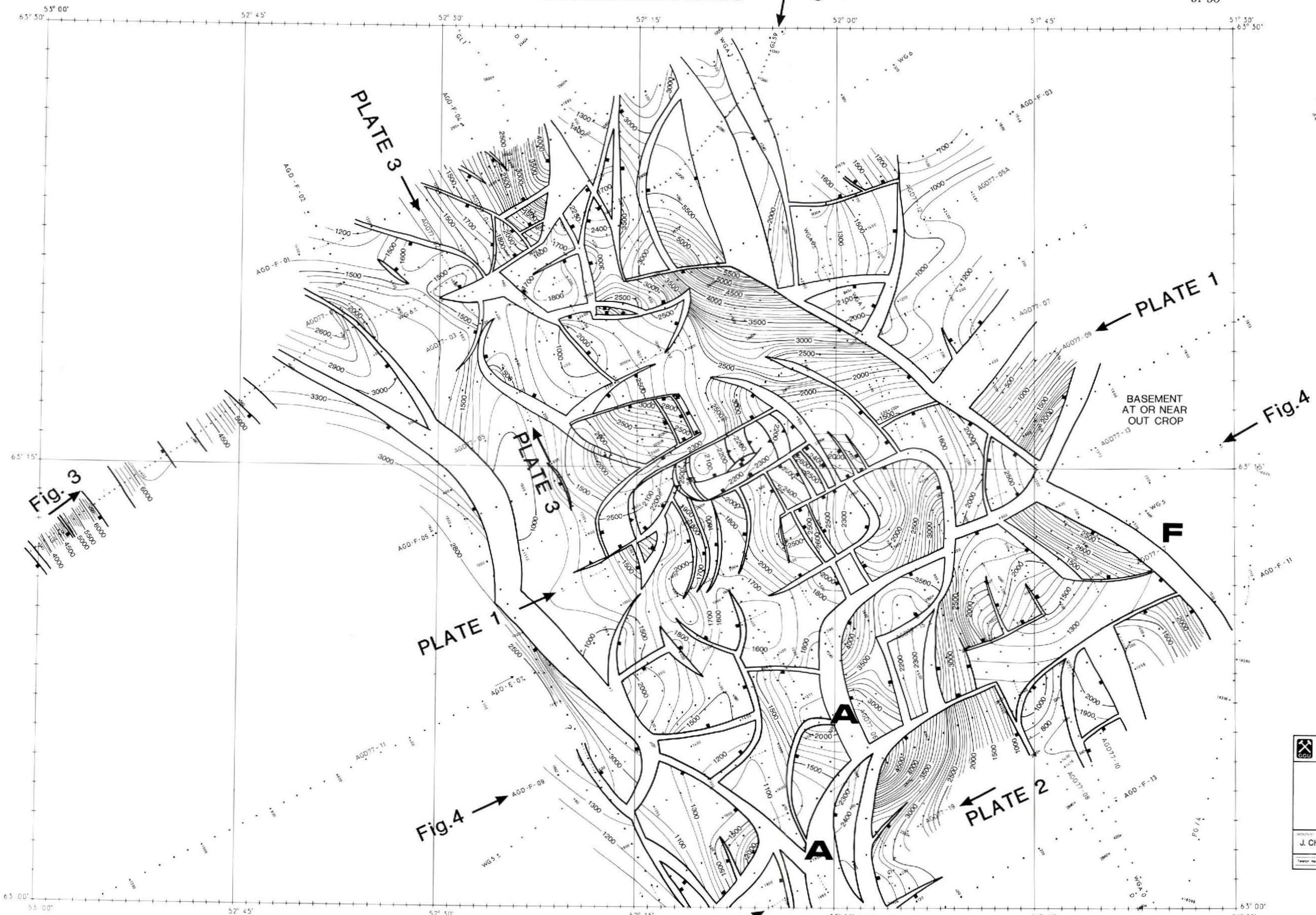
Rapp. Grønlands Geol. Unders. 142
DANMARK
GRØNLAND **1 : 250000**

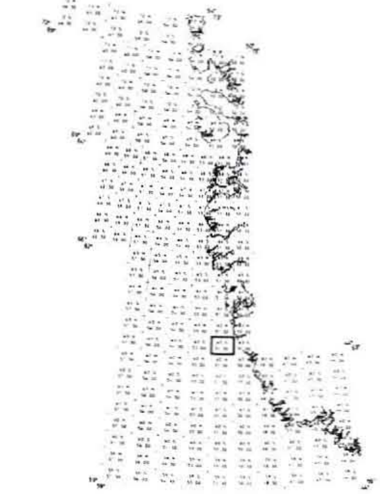
GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

Fig. 3

Plate 8

63 S
51 30





GRØNLANDS GEOLOGISKE UNDERSØGELSE The Geological Survey of Greenland · ØSTER VOLDGADE 10 · DK 1350 KØBENHAVN K · DANMARK			
DEPTHS IN METRES TO BASEMENT			
J. CHALMERS		JAN. 88	

Produced by the Geological Survey of Greenland on the basis of material supplied by the Geodetic Institute and the Hydrographic Office, Copenhagen 1972

PLATE 2

1 : 250000

Projection: Lambert's conical orthomorphic.
Ellipsoid: International, a 6 378 388 m, f 1/297.
Standard parallel: 64°30'N
Zone covered by projection: 63°N – 66°N
Scale at standard parallel: 1.0 × 10⁻⁴

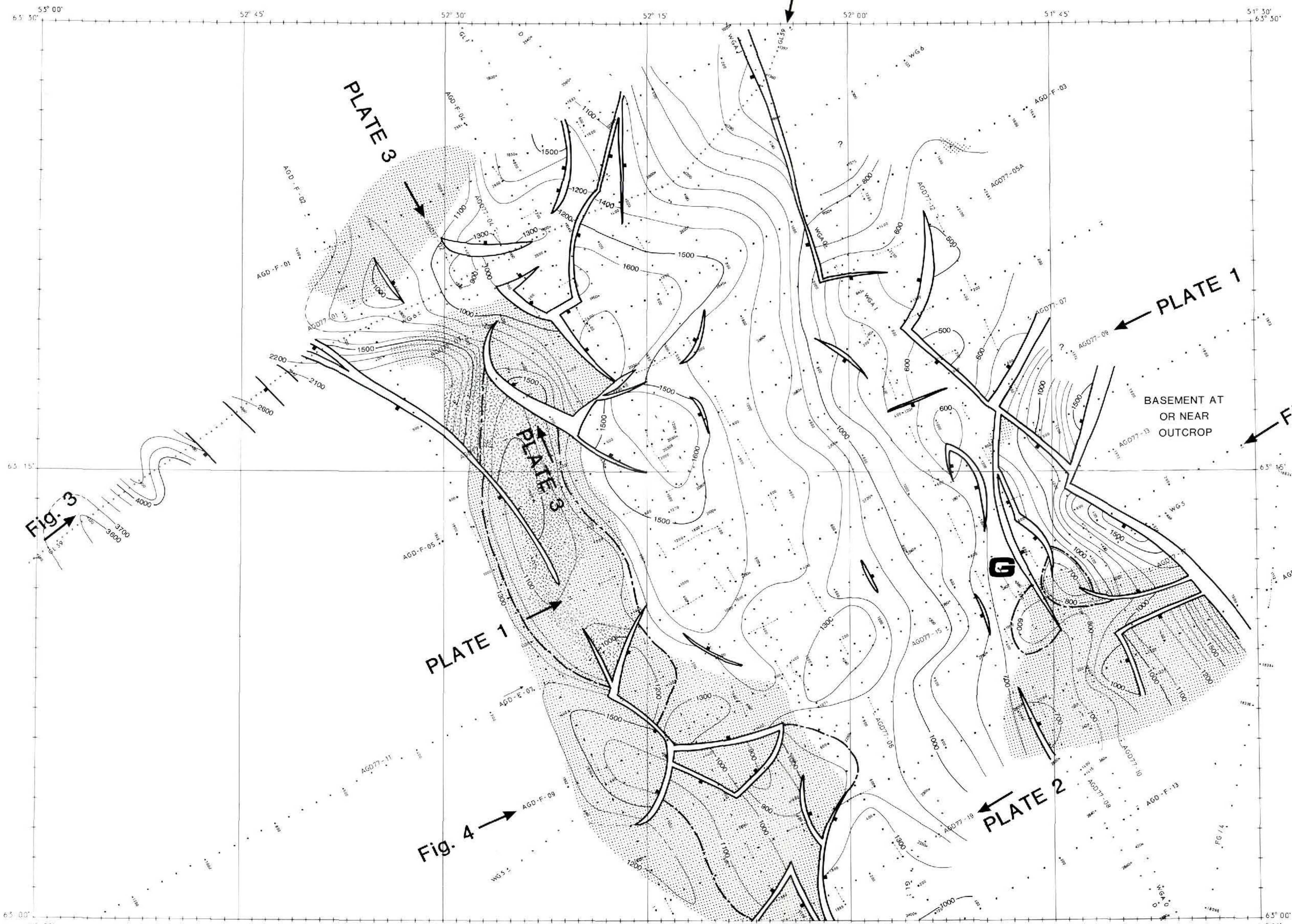
Rapp. Grønlands Geol. Unders. 142

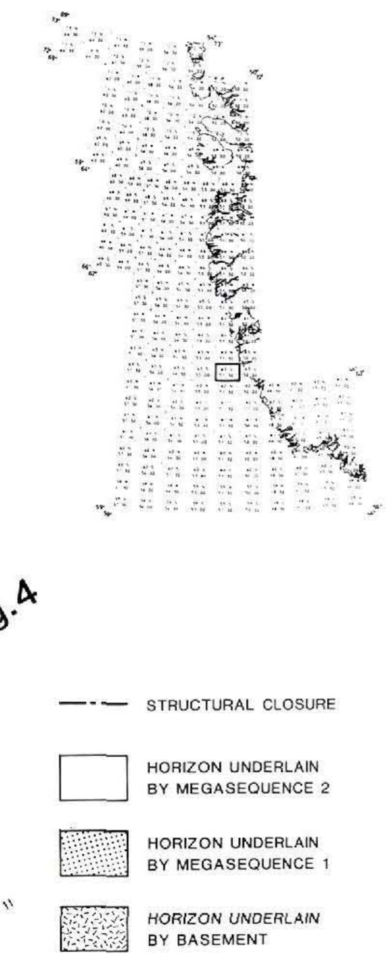
DANMARK
GRØNLAND **1 : 250000**

GRØNLANDS GEOLOGISKE UNDERSØGELSE
THE GEOLOGICAL SURVEY OF GREENLAND

Plate 9

63 S
51 30





GRØNLANDS GEOLOGISKE UNDERSØGELSE

DEPTH IN METRES
TO
BASE OF MEGASEQUENCE 3

J. CHALMERS	JAN. 88

1 : 250000

PLATE 2

Projection: Lambert's conical orthomorphic
Ellipsoid: International
Standard parallel: 64° 30' N
Zone covered by projection: 63° N – 66° N