Geology of the inner shelf west of North Cape, Norway

TORE O. VORREN, YNGVE KRISTOFFERSEN & KARIN ANDREASSEN

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An escarpment parallel to the coast off West Finnmark marks the boundary between the Scandinavian landmass of crystalline rocks and the overlying sedimentary succession offshore. Seaward-dipping sedimentary rocks subcrop at an erosional unconformity which in turn is overlain by horizontally stratified sediment layers. The seaward dip of the sedimentary rocks is probably due to Cenozoic uplift of the landmass. The uplift was predominantly flexural but there is indication of concomitant extensional faulting. The erosional unconformity is probably a polycyclic and polygenetic erosional surface initiated at the mid-Oligocene lowstand of the sea level. Three deltas up to 30 km wide, of supposed glaciomarine origin, are located at the escarpment. The deltas must have been deposited by continental ice-sheet before the last Late Weichselian readvance onto the shelf.

T. O. Vorren & K. Andreassen, University of Tromsø, Institute of Biology and Geology, P.O. Box 3085, Guleng, N-9001 Tromsø, Norway.
Y. Kristoffersen, University of Bergen, Seismological Observatory, Allégt. 41, N-5000 Bergen, Norway.

The aim of the study is to elucidate: (1) the nature of the boundary between the crystalline basement and the overlying sedimentary rocks, and its importance for the Cenozoic uplift of the landmass; (2) the origin and age of the upper regional unconformity of the shelf; and (3) nature and origin of late Cenozoic delta structures at the inner shelf.

Based on morphological evidence, Reusch (1901) inferred that an uplift of the Scandinavian landmass had taken place in relatively recent geologic time. In several papers O. and H. Holtedahl drew the attention to the marginal channels along the Norwegian coast (e.g. H. Holtedahl 1958, O. Holtedahl 1960). They advocated the idea that the channels were the loci of late Tertiary fault lines along which the present landmass had been uplifted. As pointed out by Holtedahl & Sellevoll (1971), the great thickness of sedimentary rocks close to the crystalline boundary on the shelf off Troms, particularly at Andfjorden, supports the idea of faulting in the area. Between 62°N and 68°N, Bugge et al. (1984) have found that early Mesozoic sediments onlap or rest unconformably upon the crystalline basement. We will discuss the nature of the boundary between the crystalline basement and the overlying sedimentary rocks in the North Cape area (Fig. 1).

Over most of the Norwegian continental shelf, except in the central North Sea area, there exists an upper regional unconformity (URU) separating variously dipping stratified sedimentary rock below from an overlying horizontal unit with a more complex and discontinuous seismic reflection character (Dekko 1975, Bugge & Rokoengen 1976, Lien 1976, Bugge et al. 1978, Rokoengen 1980, Rokoengen & Rønningsland 1983, Solheim & Kristoffersen 1984). We will discuss the origin of this upper regional unconformity in the study area.

In the northern North Sea, Rokoengen & Rønningsland (1983) have identified a deltaic unit of supposed Late Pliocene age just seaward of the crystalline rocks. West of North Cape we have mapped large deltaic structures in an analogous geological setting. The origin and age of these deltaic structures will be discussed.

Data

During the summers of 1982 and 1983 the University of Tromsø carried out shallow seismic profiling on the continental shelf off western Finnmark. An EG & G sparker was operated at 1 KJ and the signals were recorded on an analog EPC graphic recorder after a 70–500 Hz bandpass filtering. A 3.5 kHz hull-mounted penetration echo-sounder was operated in parallel with the sparker. Due to the weather conditions the profiles of 1982, lines 56, 78 and 79–82 (Fig. 1), are generally of poorer quality than the 1983 profiles, lines 3, 7, 15–26 (Fig. 1).

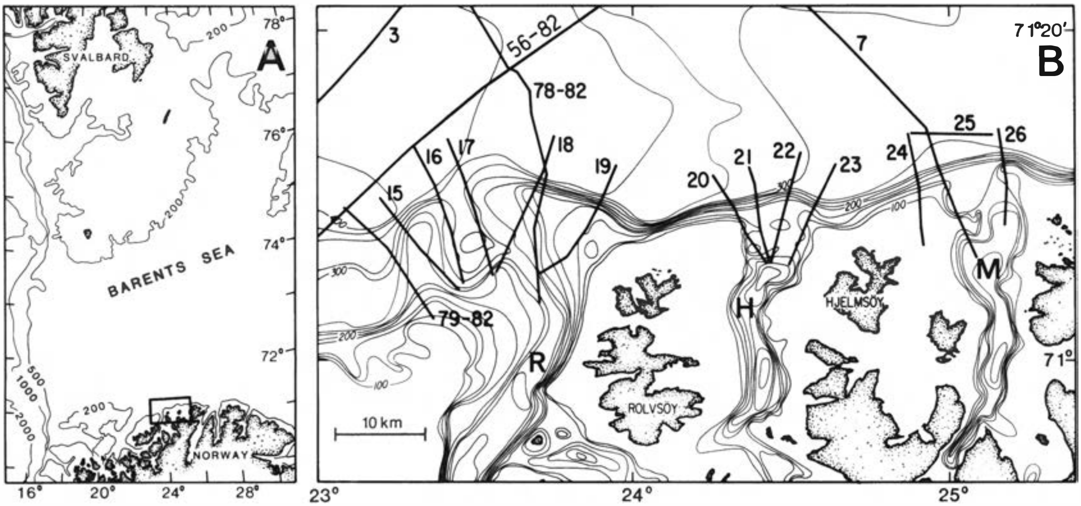

Fig. 1. A: Location map. B: Bathymetry and location of sparker profiles. R=Rolvsøy Trough, H=Hjelmsøy Trough, M=Måsøy Trough. Contour interval = 25 m.

The bathymetric map (Fig. 1) is based on soundings given on Norwegian sea charts 101, 102, 103 and 323 updated with depth values from the seismic profiles. A constant water velocity of 1500 m/s was used when calculating depths from the seismic profiles.

Morphology

Seven major morphological features can be recognized in the area shown in Fig. 1B:

- An even sea-bottom, 300–400 m deep, representing the inner shelf;
- A relatively steep escarpment about 200 m high leading to;
- A submarine/subaerial platform (−50 m to +50 m), the strandflat (Reusch 1894);
- Transverse troughs, 200–300 m deep, crossing the strandflat;
- Fan/deltas in front of the troughs. We give these informal names from west to east: the Rolvsøy delta, the Hjelmsøy delta and the Måsøy delta;
- A more or less irregular escarpment onshore leading from the strandflat to;
- A plateau-like surface (ca 300 m a.s.l.) assumed to be the remains of a more extended plateau-country (O. Holtedahl 1960) and referred to as the Paleic surface by Gjessing (1967).

Stratigraphy

Based on the sparker profiles, five major seismic units can be recognized (Figs. 2,3,4 and 5).

1. Basement comprising Caledonian metasedimentary rocks.
2. Sedimentary rocks dipping in a seaward direction. These rocks are part of the Tromsø-Finnmark Platform (Faleide et al. 1984) and are possibly of Carboniferous age (Rønnevik 1981).
3. An overlying complex unit of sediments with several, often discontinuous reflectors. The base of this unit is defined by an erosional unconformity (URU), equivalent to the upper regional unconformity in the western Barents Sea mapped by Solheim & Kristoffersen (1984).
4. Delta-deposits, which overlie the complex unit conformably in the profiles where the lower boundary can be clearly defined by reflector C/D (Fig. 3, profiles 15, 16 and 17).
5. A transparent unit, up to 200 m thick, with few internal reflectors. Its base is an erosional unconformity, T. The erosional nature of T is most clearly recognized in profiles 18, 19, 22 and 23 (Figs. 3 and 4).

The map of the seismic units (Fig. 6A) does not portray the occurrence of local sediment infill on top of the crystalline basement. Our data do not

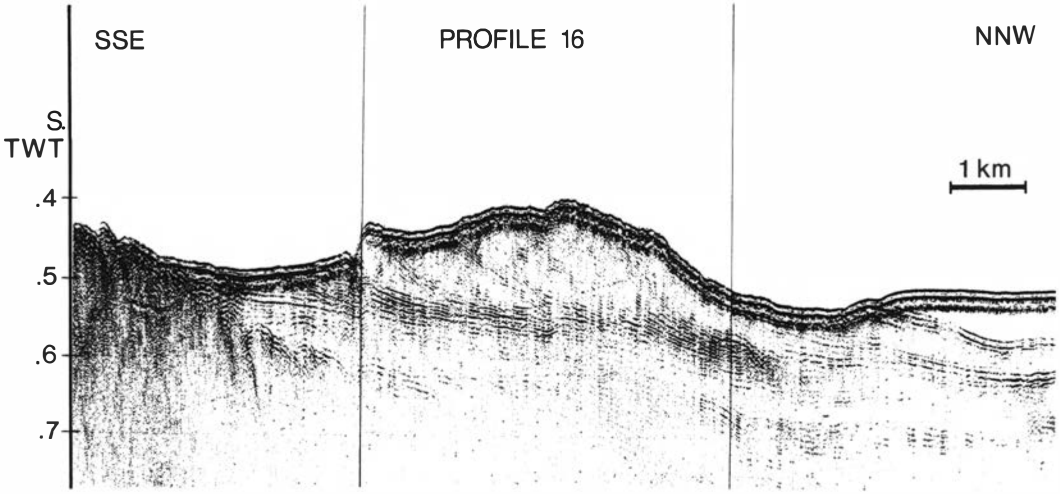

Fig. 2. Sparker record line 16 (Fig. 1). Interpreted section in Fig. 3.

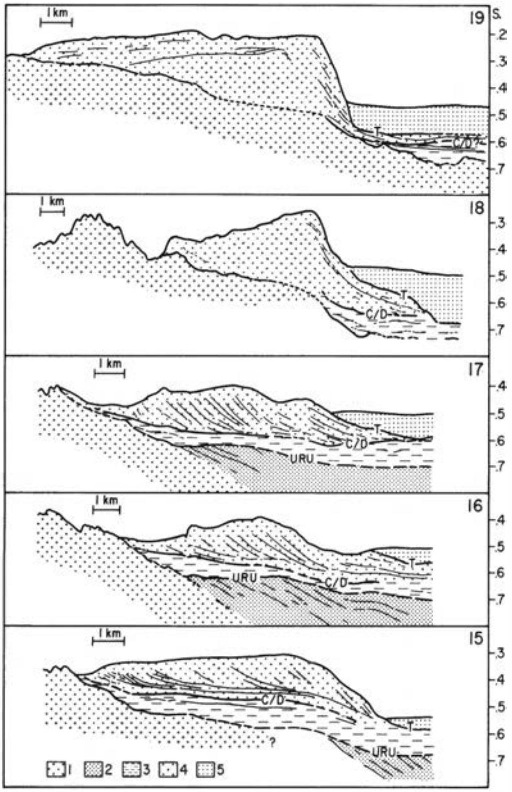

Fig. 3. Interpretation of sparker profiles across the Rolvsøy delta. Profile location in Fig. 1. 1: Crystalline basement; 2: Sedimentary rocks; 3: Complex unit; 4: Delta-unit; 5: Transparent unit. URU, C/D and T are reflectors discussed in the text.

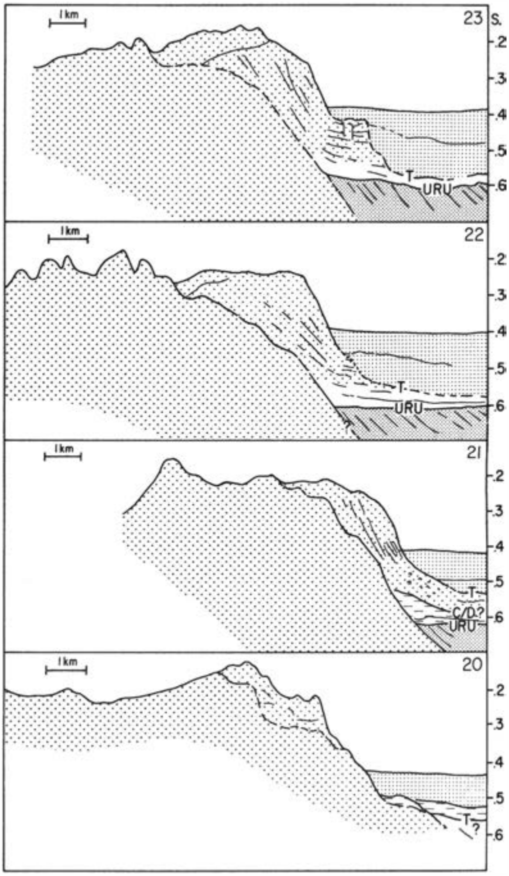

Fig. 4. Interpretation of sparker profiles across the Hjelmsøy delta. Profile location in Fig. 1. Legend in Fig. 3.

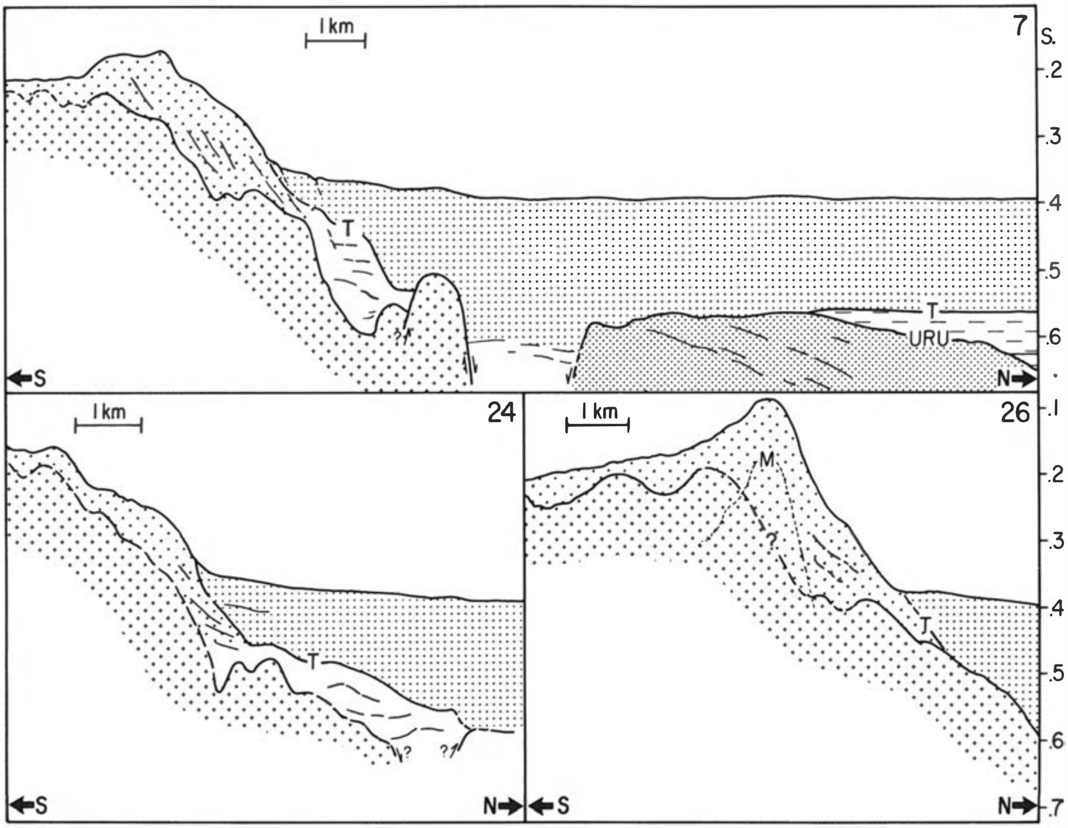

Fig. 5. Interpretation of sparker profiles across the Måsøy delta. Profile location in Fig. 1. Legend in Fig. 3.

permit the mapping of these deposits. The map shows that lithified sedimentary rocks are not exposed anywhere in the study area. Furthermore, the delta in front of the Rolvsøy Trough is by far the largest of the deltas. The transparent unit covers most of the inner shelf except for a small area in the west where the complex unit outcrops.

The thickness of sediments above URU (Fig. 6B) increases rapidly seaward to about 200–250 ms (corresponding to about 200–250 m assuming a velocity of 2000 m/s in the sediments). A maximum thickness of slightly more than 300 ms is observed in the Rolvsøy delta.

The boundary between the crystalline basement and the sedimentary rocks

The boundary between the crystalline basement and the sedimentary rocks is traversed by several of the sparker profiles and its location is more or less parallel to the coastal escarpment. In all profiles, where the boundary can be located, the sedimentary rocks lie conformably on basement. Using a velocity of 2000 m/s for the sediments above URU, the crystalline subsurface dips about 7° at the Hjelmsøy delta and less than 5° at the Rolvsøy delta. Locally, high-angle faulting has occurred in the vicinity of the boundary with downfaulting of a 2 km wide block (profile 7, Fig. 5). Irregularities in the basement which may be due to faulting are also observed in the adjacent profile 24 (Fig. 5).

Relating our observations to the nature of the uplift of the landmass, we conclude the following: The conformity of the basement and the sedimentary rocks and the consistent seaward dipping direction indicate that a flexure-like uplift of the landmass has occurred. However, the indicated faults (in profiles 7 and 24; Fig. 5) may possibly be of the same age as the upwarping.

According to Mørner (1980), the Fennoscandian Shield and the Barents Sea underwent substantial uplift at the Eocene/Oligocene and the Oligocene/Miocene boundaries. In addition he suggested a dramatic subsidence, about 0.9 – 0.8 MA ago. However, his evidence is circumstantial and some of his basic assumptions, e.g., the subsidence history of the Faroe-Iceland Ridge and its relation to the Barents Sea/Fennoscandian shield, are both highly debatable (see Bott et al. 1983).

Rønnevik (1981) and Faleide et al. (1984) have inferred that several tectonic phases have affected the Barents Sea region since the Carboniferous (supposed age of the tilted sedimentary rocks), viz. the Jurassic-Cretaceous Kimmerian phases and the Paleocene Laramide phase. However, these tectonic events did not seem to affect the Troms-Finnmark Platform (Faleide et al. 1984). Torske (1972) and Egeberg (1977) have argued that the uplift of western Scandinavia is linked to the opening of the Norwegian Sea, and thus is of Eocene age.

The Upper Regional Unconformity (URU)

The depth to the URU from the sea surface is about 600 to 750 ms (TWT), Fig. 6C. The URU has a fairly even surface, and slopes towards a shallow basin off the Rolvsøy Trough. The sediments directly overlying this unit are of different ages; in most profiles there is a sequence of the complex unit. In part of profile 7 (Fig. 5) all of this unit is eroded and the transparent unit rests directly upon the sedimentary rocks. In adjacent areas sedimentary rocks outcrop. Thus the URU must, in this area, be regarded as a polycyclic erosional surface.

Certain constraints can be placed on the maximum age for generation of the URU. About 100 km west of the study area, exploration drilling shows Paleocene and early Eocene sediments (Gloppen & Westre 1982, Westre 1984). Shallow drilling in the same area shows that late Pliocene or Pleistocene directly overlie the early Eocene sediments. In the apparent absence of mid-Oligocene to late Pliocene sediments on the inner part of the Barents shelf (Spencer et al. 1984), a likely candidate for the initiation of the URU in this area may be the mid-Oligocene sea level drop (Vail et al. 1977). Rønnevik (1981) and Faleide et al. (1984) have tentatively dated their reflector A as mid-Oligocene. This reflector subcrops a short distance east of the shelf edge towards Pliocene sediments (Rønnevik 1981). Accordingly, most of the Barents Sea is supposed to have been exposed during the late Oligocene and Miocene. If this is correct, URU may in its earlier phases have developed as a fluvial surface. The length of the aerial exposure is unknown. During the mid(?) Pliocene-Pleistocene the Barents shelf probably was covered by grounded glaciers several times (Solheim & Kristofferesen 1984). Then the earlier fluvial surface was modified by glacial processes.

The Deltas

Deposits with a more or less clearly visible foreset bedding (Figs. 2,3,4 and 5) occur in front of all the troughs, and indicate delta accumulation. Most noticeable is the Rolvsøy delta, which is about 30 km wide and 10 km from the proximal to the distal part (Fig. 6A). It has an average thickness of c. 150 ms, a maximum thickness slightly above 300 ms, and an estimated volume of 45 km^3. The Hjelmsøy and Måsøy deltas are smaller; respectively about 14 and 20 km wide; 4 and 6 km from the proximal to the distal part, and an average of 100 ms and 50 ms thickness. They both have an estimated volume of c. 6 km^3.

Assuming a velocity of 2000 m/s in the delta-sediments, the dips of the foresets are up to 10° (profile 19 ; Fig. 3) in the Rolvsøy delta, but mostly between 3 and 6°. In the Hjelmsøy delta the steepest slope is almost 14°.

In some of the profiles (19, 22 and 23; Figs. 3 and 4) an upper unit is recognized. The lower boundary of this and also the internal reflectors dip slightly landward. Possibly all or most of the 'delta-sediments' in profile 20 belong to this upper unit.

Origin

The location of the deltas in front of glacial troughs points to a glacigenic origin. The termini of the glaciers were probably situated at the thresholds of the troughs during the accumulation of the deltas. Although the two smaller deltas seem to have relatively steep foresets, the dips are generally less than the 15°–35° typically found in small sandy, gravelly ice-front deltas (e.g. Andersen 1968, Smith 1982), but they are larger than the less than 2° normally occurring in modern fluvial deltas (Elliot 1978). The reason for the dips being lower than in smaller glacioflu-

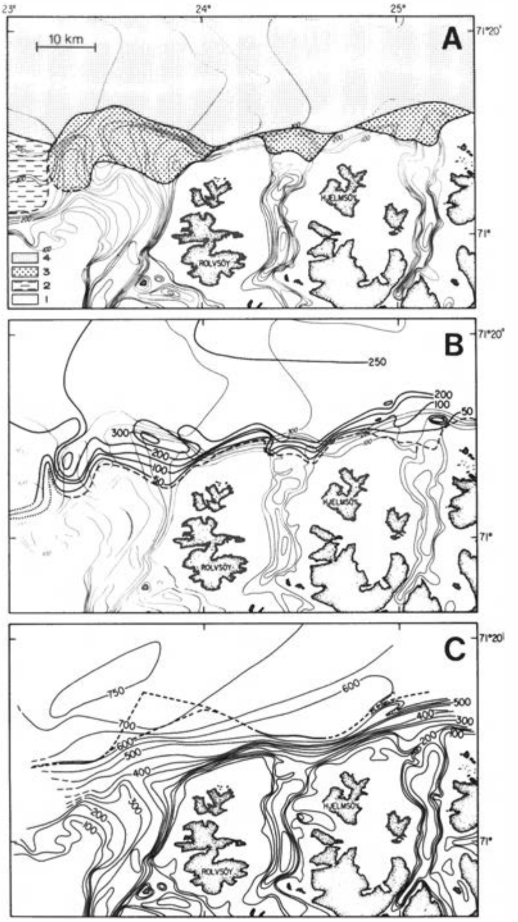

Fig. 6 A: Map of the sea floor geology. 1: Crystalline basement; 2: Complex unit; 3: Deltaic units, 4: Transparent unit.
B: Isopachs of the late Cenozoic sediments above the upper regional unconformity (URU). Contour interval 50 ms (two way travel time).
C: Isochrone map (two-way travel time from sea surface) of the upper regional unconformity (URU); contour interval 50 ms. Thick line marks the boundary between sedimentary and crystalline rocks at the subsurface; two alternatives are shown offshore the Rolvsøy Trough.

vial deltas is possibly that these delta-foresets comprise finer grained (silt?) sediments. Certainly the acoustic transparency indicates little material of coarser grain sizes than sand.

At least two post-depositional erosional events can be deduced from the seismic record; before and after the overlying younger transparent unit was deposited. Evidence for the first erosional phase is seen in profile 19 (Fig. 3) where the foresets are truncated against the transparent unit. In profiles 18, 22 and 23 (Figs. 3 and 4) an erosion of the pro-delta beds is observed. The last erosional phase is deduced from the lack of accumulation of the transparent unit in the outer low-lying depression in the delta at profile 16 (Fig. 3). These erosional episodes have caused the irregular surface and the truncation of the foresets. The irregular nature of the erosional features points to a glacial origin. Possibly the upper unit on the deltas was deposited as basal till/thrust slices during the episodes when glaciers advanced over the deltas. Similar features caused by glacial readvances over raised Late Pleistocene front deltas have been observed in several places (e.g. Andersen 1980).

Due to later erosion of the deltas the exact sea level during their deposition cannot be determined. However, foresets are registered at a minimum depth of c. 150 m below present sea level (e.g. profiles 19, 23 and 7; Figs. 3,4 and 5). This gives a maximum lowstand of the sea-level during deposition. There are other shallower parts of the delta, but they seem to comprise the superposed unit of till/thrust slices. If 150 m is close to the true value, most of this could be accounted for by glacio-eustatic regression, since this is a peripheral area where little vertical isostatic movement may have occurred.

The age of the delta deposits can only be determined relatively. They must be older than the last glacial readvance onto the shelf, which probably occurred in the Late Weichselian (Vorren & Kristoffersen 1986). They are also older than the thick, transparent unit of unknown age.

Conclusions

1. The Cenozoic uplift of the very northernmost Fennoscandian landmass seems to have occurred by flexuring possibly accompanied by some extensional faulting. The exact timing of the uplift is not yet clear, but an Eocene age is favoured.

2. The upper regional unconformity, URU, in the Barents Sea is polycyclic. It was probably initiated in mid-Oligocene concurrently with the formation of the seismic reflector A of Rønnevik (1981). The URU probably developed originally as a fluvial surface. During the Pliocene and Pleistocene it was remodelled by glacial action several times.

3. Three delta-structures on the inner part of the shelf are mapped. The deltas are situated in front of glacial troughs and are most likely of gla-

ciofluvial origin. The largest delta is about 30 km wide, 10 km in a longitudinal direction, up to 300 m thick, and comprises approximately 45 km^3 sediments. The deltas were probably deposited during a sea-level lowstand of a glacial period. Precise dating is not available, but their later history of glacial erosion and deposition indicates that they are older than the Late Weichselian.

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