Late Quaternary sedimentation in a glacial trough on the continental shelf off Troms, northern Norway

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Texture and mineralogy of 27 gravity cores and 20 grab samples from the Malangsdjupet area are described. In the western trough and on the slopes lies a firm pebbly mud (till ?) overlain by glaciomarine sediments and a 2–15 cm Holocene sand; in the depressions in the east there are 1–2 m of Holocene poorly sorted sand and mud. Mudrocks of Lower Cretaceous age were eroded just before deposition of the Skarpnes moraine (12,000–12,500 BP) and are the main source for the pebbly mud. Winnowing after withdrawal off the ice formed a gravel lag 14C dated to 11,900 ± 260 BP.

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The continental shelf off the coast of Troms has four transverse glacial troughs and one parallel to the coast (Holtedahl 1940, Andersen 1968) close to the boundary between crystalline Precambrian and Mesozoic sedimentary rocks (Fig. 1).

Generally, the deep troughs contain muddy sediments while the banks between are covered with a coarse lag deposit winnowed from the underlying till (Holtedahl & Bjerkli 1975).

The present investigation describes the superficial (0–2.73 m) sediments of the Malangsdjupet trough (Fig. 2). The purpose of the work is to reconstruct Weichselian and Holocene sedimentary environments. The chronostratigraphy referred to is according to Mangerud & Berglund (1978), who place the boundary between Middle and Late Weichselian at 20,000 years BP.

Malangsdjupet is located on sedimentary rocks, known only through their seismic velocities (Sellevoll 1969, Rokoengen & Bugge 1976, Sundvor 1976). The boundary with the crystalline Precambrian basement occurs at its eastern end. The Precambrian rocks are mainly granites and gneisses, while metasediments further east are the predominant Caledonian rock type (Holtedahl & Dons 1960) (Fig. 1).

On the basis of sparker investigations, the thickness of the Quaternary sediments has been estimated and divided into four separate units (Bugge & Rokoengen 1976) (Figs. 3A, B). A ridge close to the shelf edge and one in the middle of Malangsdjupet were previously recognized by their bathymetric features as glacial marginal deposits (Egga moraines I, II) and a Weichselian age was suggested (Andersen 1968). Bugge & Rokoengen (1976) recognised an ‘Inner glacial unit’ and this unit is referred to as Egga III in this paper.

Terminal deposits of Late Weichselian age (Skarpnes moraine, Tromsø–Lyngen moraine, Fig. 1) are located 30–40 km east of the area (Andersen 1968). Between the Skarpnes moraine and the eastern part of Malangsdjupet is a bathymetric high between Senja and Kvaløya which has been suggested as a terminal moraine (Island I) or as a rock threshold (Andersen 1968).

Sampling
The location and type of samples are plotted in Fig. 2. The grab samples and the N-gravity cores were collected in 1970 and 1972 by NTNFK (now Institutt for Kontinentalundersøkelser, IKU). Oljedirektoratet sampled the O-gravity cores in 1974 for geochemical hydrocarbon investigations. The T-cores were sampled by the Universitetet i Tromsø, autumn 1977 and summer 1978.

Analytical procedures
The cores were split with an osmotic knife and stratigraphical features noted. Colour, determined moist, is according to Munsell Soil
Color chart 1975. The undrained shear strength and sensitivity were measured by the fall cone test.

Samples were grain-size analysed, using whole phi-intervals, by wet-sieving of material <16 mm and pipette analysis of <0.063 mm according to standard procedures (Folk 1968). The data was processed and the statistical parameters $M_2$ and $\sigma_1$ (Folk & Ward 1957) computed using a computer programme modified from Myhre (1974).

Mineralogical investigations of the clay and
silt fraction were carried out using a Philips x-ray diffractometer (XRD) with a Ni-filtered Cu\textsubscript{Kα} radiation. The x-ray slides were prepared by vacuum filtering through millipore filters, a procedure which causes little separation of the mineral grains (Stokke & Carson 1973).

Clay was run on XRD at 1° 2θ/min and slow scan at 0.25° 2θ/min over the 3.58Å kaolinite/3.54Å chlorite peaks.

Identification of the clay minerals was carried out according to Caroll (1970) and Biscaye (1964). Semiquantitative measurements of the major clay minerals were calculated by determining the peak area by planimeter and applying the weighted factors suggested by Biscaye (1965) and Gjems (1967), where illite is treated as an internal standard and the 7Å peak times 0.5, the area of the 10–14Å mixed-layer times 0.33, and the 17Å peak times 0.25. The kaolinite/chlorite ratio was calculated by measuring the areas of the 3.54Å chlorite and 3.58Å kaolinite on the slow scan diffractograms and apportioning the ratio to the 7Å peak area (Biscaye 1964).

The silt was split by pipette method into three fractions 2–4 μ, 4–20μ, 20–63 μ for mineralogic comparison of the four lithofacies. The fractions 4–20μ and 20–63 μ were crushed in a McCrome wet mill for ten minutes before filtering. Semiquantitative measurements of the silt fractions were carried out by multiplying peak height by the width at half peak height (Gibbs 1961). The obtained values are only considered as relative values between the lithofacies. The phyllosilicates 10Å and 7Å are combined as one group using a correction factor of 0.5 for the 7Å peak.

The sand fraction in a few selected samples was mounted in an epofix resin and thin sectioned. The petrographic composition of the sedimentary rocks in the gravel were investigated by XRD and microscope.

The weight percent CaCO\textsubscript{3} was determined by solution with 2N HCl and weighing.

### Bathymetry and hydrology

The bathymetry of the area was first worked out by O. Holte dah (1940). Malangsdjupet, a broad submarine channel across the continental shelf, comprises two large depressions separated by a 10 km wide ridge at 300–325 m depth. It is an extension of Malangsfjorden (Fig. 2). The continental slope to the west of Malangsdjupet is steep, averaging 35°; just 5 km west of the shelf edge the depth is 1800–1900 m. Bathymetric measurements are old and inaccurate.
Fig. 3. Thickness of the Quaternary deposits in the Malangsdjupet area. A – estimated by sparker profiling, B – the interpreted units. From Bugge & Rokoengen (1976).

(Rokoengen & Bugge 1976) and echosounding while sampling in 1977 indicated a more hummocky bottom than shown at Fig. 2. This was also observed on the sparker profiles recorded by IKU in 1976 (K. Rokoengen, pers. comm. 1978). The lack of detailed bathymetric maps prevented a more detailed study of the geomorphology and made an interpretation of the depositional environment more difficult.

The eastern area which is located on crystalline rocks has a very irregular bottom (Rokoengen & Bugge 1976), while the banks, Sveinsgrunnen and Malangsgrunnen, have a smooth surface. However, several minor ridges and depressions have been observed on the banks (Holtedahl 1940, Andersen 1968).

The northeast flowing Norwegian Coastal Current and the Norwegian Current further west are the most important hydrographic factors in this area. Current, salinity and temperature measurements carried out in 1972–1975 by Vassdrags- og Havnelaboratoriet at Norges Tekniske Høgskole (VHL reports 1973, 1974, 1975, 1976), are available for the eastern part of Malangsgrunnen (Fig. 2).

The direction of the bottom currents (5 m above the bottom) is variable and strongly influenced by tidal changes and wave generated currents. The maximum speed of the bottom currents at station M3 is 50–70 cm/sec in a southerly direction and at stations M1 and M2 40–50 cm/sec towards the north-east.

Salinity is low, c. 34%. Water temperature is 8–10°C in summer and slightly below 5°C in late spring.

Only the innermost part of the fjords freeze during winter due to the tidal currents (mean tidal range is c. 1.80 m) which transport large amounts of relatively warm sea-water into the fjords. Sea-ice is therefore rare in the outer coastal areas.

Sediment description and stratigraphy

The main lithologic units are schematically illustrated in Figs. 4, 5. Based on sediment texture, Malangsdjupet and the neighbouring banks can be divided into three different depositional areas (Fig. 2).

The western part of Malangsdjupet and its lower slopes with a thin sand layer over glacial sediments.

The eastern part of Malangsdjupet with non-glacial sediments in the depressions.

The shallow areas (200 m), the shelf edge and the continental slope down to at least 500 m depth with coarse sediments.

Area A

Three lithostratigraphic units have been recognized: a firm pebbly mud, a soft clayey silt
Quaternary sedimentation on the shelf

Fig. 4. Lithostratigraphy in the gravity cores obtained from the deeper parts of Malangsdjupet. Note the variation in thickness of the glaciomarine clayey silt covering the pebbly mud (till?) in the western part of Malangsdjupet. Detailed stratigraphy of 08, Fig. 6, 7; T10, Fig. 8, 9 and 014, Fig. 10, 11.

Fig. 5. Grain size distribution of grab samples and the top of the gravity cores from Malangsdjupet; also, the slopes towards the surrounding bank and from the continental slope.
CORE O 8

<table>
<thead>
<tr>
<th>SCALE IN CM</th>
<th>LITHOFACIES</th>
<th>CORE DESCRIPTION</th>
<th>COLOUR</th>
<th>SHEAR STRENGTH</th>
<th>WATER CONTENT</th>
<th>% SEDIMENTARY ROCKS</th>
<th>WEIGHT %CaCO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>SAND</td>
<td>HIGH CONTENT OF BIOGENOUS DEBRIS GRAVEL OCCURS ~Y Bioturbation</td>
<td>5Y ¼</td>
<td>3.8</td>
<td>4.8</td>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>50</td>
<td>CLAYEY SILT WITH PEBBLES</td>
<td>HOMOGENEOUS UNIT</td>
<td>5Y ½</td>
<td>4.8</td>
<td>4.8</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>100</td>
<td>PEBBLY MUD %</td>
<td>LAMINATED</td>
<td>25Y N4</td>
<td>2.2</td>
<td>2.1</td>
<td>75</td>
<td>7</td>
</tr>
</tbody>
</table>

Fig. 6. Stratigraphy in core O8, area A, Location Fig. 2, 4. The three main lithofacies are very similar throughout area A. However, the shear strength of the pebbly mud is lower (~1.75 t/m²) further west. The thickness of the clayey silt show large variations. In T-4-1, sampled at the same location as O8 (Fig. 4), the clayey silt is 2.38 m. ¹⁴C dating of in situ mollusks in the clayey silt gave 12,000 ± 240 BP (Table 1).

with pebbles, and an upper thin sandlayer with a gravel lag. Details are given in Figs. 6, 7.
Core T 10 has a somewhat different stratigraphy and will be described separately.

The pebbly mud. — A dark, structureless and firm mud with variable, but generally low pebble content (Fig. 12A) is found in the lower part of eight cores along the centre of the western part of the trough. The poor sorting (Fig. 13) and the angular and striated pebbles suggest a glacial origin either as till or glaciomarine sediments. However, grain-size distribution of glaciomarine sediments close to an ice margin or below a floating ice shelf may be similar to tills (Chriss & Frakes 1970). The slight overconsolidation

![Graph](image-url)

Fig. 7. Grain size distribution (probability scale) of samples from the three main lithofacies in core O8.
Table 1. $^{14}$C radiocarbon dates (years before 1950).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Depth core</th>
<th>Material dated</th>
<th>Weight</th>
<th>Lab. ref.</th>
<th>Age (B.P.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 8/7</td>
<td>1,0 -1,15 m</td>
<td>Mollusk frag.</td>
<td>3,4 g</td>
<td>T 2499</td>
<td>38550 ± 4070</td>
</tr>
<tr>
<td>0 - 13/9</td>
<td>0,20 -0,22 m</td>
<td>Astarte sp.</td>
<td>8,8 g</td>
<td>T 2500</td>
<td>11130 ± 190</td>
</tr>
<tr>
<td>0 - 13/9B</td>
<td>0,22-0,24 m</td>
<td>Chlamys islandica</td>
<td>5,7 g</td>
<td>T 2718</td>
<td>11900 ± 260</td>
</tr>
<tr>
<td>0 - 14/6</td>
<td>1,77-1,79 m</td>
<td>Waldheimia cranium, Arca pectunculoides &amp; moll. frag.</td>
<td>6,5 g</td>
<td>T 2501</td>
<td>9610 ± 170</td>
</tr>
<tr>
<td>0 - 15/5</td>
<td>0,40-0,45 m</td>
<td>Foramin. sand</td>
<td>110,0 g</td>
<td>T 2716</td>
<td>5260 ± 80</td>
</tr>
<tr>
<td>0 - 17/7</td>
<td>0,73-0,78 m</td>
<td>Foramin. sand</td>
<td>28,7 g</td>
<td>T 2717</td>
<td>6730 ± 150</td>
</tr>
<tr>
<td>T - 4 - 1</td>
<td>1,45-1,95 m</td>
<td>Nuculana sp.</td>
<td>3,9 g</td>
<td>T 3168</td>
<td>12000 ± 240</td>
</tr>
</tbody>
</table>

(shear strength 1.25 – 4.5 t/m²) and the crushed or worn foraminifera and small mollusk fragments suggest an origin as till containing re-sedimented marine and/or glaciomarine sediments.

However, the overconsolidation shows the highest values in the shallowest part of area A (core 08, 09, 010) and indicates a possible proximal glaciomarine deposition for the pebbly mud west of 08, rather than till. It can therefore be concluded that the depositional environment for the pebbly mud is uncertain, but a mixture of proximal glaciomarine deposits and tills for the area A seems most likely.

$^{14}$C dating of mollusk fragments from the pebbly mud gave 38,550 ± 4070 BP (T 2499, Table 1) and suggests incorporation of interstitial sediments. From the northern part of Kvaløya, mollusk fragments incorporated in till were $^{14}$C dated to 40,600 ± 2780 BP (Vorren 1979). Normal marine sedimentation could therefore have taken place in Malangsdjupet and these sediments could have been reworked by later glacial advances.

Clayey silt with pebbles. – The boundary with the pebbly mud can easily be determined by the colour difference and change in shear strength. Bioturbation structures and a thin gravel lag are located at the distinct boundary with the overlying sand (Figs. 6, 7).

The clayey silt is soft (shear strength 0.20 – 0.90 t/m²), poorly sorted, often laminated in the lower part, and has a low content of angular outsized (maximum 12 cm) clasts (Figs. 12A, 13).

The fossil content is low. *Nuculana sp.* was found in situ in two cores. Both well preserved and worn foraminifera occur, indicating a mixture of in situ and reworked assemblages.

The relatively low consolidation, well preserved lamination and undisturbed mollusks preclude the possibility of transport by grounded ice. However, the large, angular clasts indicate sediment contribution from a floating ice shelf or icebergs in addition to the major part derived from suspension. $^{14}$C-dating of paired *Nuculana sp.* in core T 23 gave 12,000 ± 240 BP.

The sand layer. – The olive coloured, 2–15 cm sand layer (Fig. 4A) contains scattered pebbles and is rich in foraminifera, small mollusks, ostracodes, and sponge spicules. The fossils are abraded and were transported prior to deposi-
### CORE T 10

<table>
<thead>
<tr>
<th>Litho-facies</th>
<th>Core Description</th>
<th>Colour</th>
<th>Shear Strength</th>
<th>Water Content</th>
<th>% Sedimentary Rocks</th>
<th>Weight %CaCO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy</td>
<td>High content of fossil debris and pebbles bioturbation</td>
<td>5Y 4/3</td>
<td>3.5</td>
<td>20%</td>
<td>40%</td>
<td>10</td>
</tr>
<tr>
<td>Claysilt</td>
<td>X/pebbles are rare</td>
<td>5Y 4/1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pebby mud</td>
<td>Homogeneous unit</td>
<td>5Y 3/1</td>
<td>1.5</td>
<td>25%</td>
<td>50%</td>
<td>20</td>
</tr>
<tr>
<td>Homogeneous unit</td>
<td>X/pebbles are common</td>
<td>5Y 3/1</td>
<td>1.8</td>
<td>75%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laminated</td>
<td>Sand</td>
<td>5Y 4/1</td>
<td>3.7</td>
<td>10%</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>Gravel</td>
<td>5Y 2/2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>Laminated</td>
<td>5Y 4/1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Homogeneous unit</td>
<td>5Y 3/1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20</td>
</tr>
</tbody>
</table>

Fig. 8. Stratigraphy of core T10, area A. Location Fig. 2,4. Note the low shear strength of the pebbly mud compared to this unit in core 08. The sand and gravel layer (81–86 cm) consist mainly of soft, dark mudrocks of lower Cretaceous age.

...tion. The carbonate fraction is therefore included in the grain-size analyses (Fig. 12A, 13).

The gravel lag in core 013 contains Astarte sp. in living position and a large fragment of Chlamys islandica. They gave ^14C-ages of 11,130 ± 190 BP (T 2500, Table I) and 11,900 ± 260 BP (T 2718, Table I).

Core T 10. – This was sampled at 413 m depth on the lower part of the eastern slope, near the sedimentary/crystalline rock boundary (Figs. 1 and 2) and the Egga III moraine (Fig. 3B).

Further west in the inner depression, Holocene sediments comprise the entire core (area B). However, in core T 10 (Fig. 8, 9), rock fragments occur at the top of a sandy layer rich in biogenous debris above a thin gravel lag and a clayey silt with pebbles. These lithofacies are interpreted as equivalent to the one generally found in the upper part of the cores in area A.

The core is very poor in fossils below the sand layer at the top of the core. Only small fragments of mollusks occur and foraminifera are rare.

The three layers of pebbly mud have only a slight overconsolidation and none in the upper, and the undisturbed lamination and sandlayer...
suggest a glaciomarine origin for the pebbly mud in T 10. The high content of angular to sub-rounded soft mudrocks in the sand and gravel at 81–86 cm depth indicate that they are of local origin. In this area erosion remnants of sedimentary rock, possibly piercing through the Quaternary deposits, have been detected by seismic profiling (K. Rokoengen, pers. comm. 1978). A possible interpretation of the pebbly mud in T 10 is therefore that the glacier was grounded on these erosion remnants just east of the location, giving proximal glaciomarine deposits with a high percentage of homogeneous sedimentary mudrocks.

**Area B**

In the eastern depressions a distinct upper sand layer or gravel lag was not observed, but a coarsening upward sequence is found throughout the area except for core N 54. Sediments containing ice-rafted clasts were not detected.

Core 019 (Fig. 10, 11), which is representative of area B, consists of mud with sand lenses in the basal part, passing upwards into a more homogeneous, occasionally bioturbated sand near the top. Abraded, transported calcareous fossils are common in the sand.

Three ¹⁴C dates from area B (T2501, T2716, T2717, Table I) gave Holocene ages and indicate an average sedimentation rate of 8–18 cm/1000 Y.

**Area C**

The bank sediments have previously been described as coarse sediments formed by winnowing of till (Andersen 1968, Holtedahl & Bjerkli 1975).

Photographs of the bottom on the banks show gravel to boulders with a patchy sand cover between (Lien & Myhre 1977). The thickness of the coarse lag at Malangsgrunnen and Sveinsgrunnen is not known, but is probably rather thin (Rokoengen et al. 1977).

Within Malangsdujet the heavily winnowed area (Figs. 2, 5) extends down to at least 200 m, indicated by the difficulty of obtaining gravity cores above this level. The border with area A must be considered as transitional because of the slight winnowing and little Holocene deposition also in area A.

However, in Fig. 2 the shelf edge and continental slope down to 500 m are included in area C because of the high content of gravel and the difficulty of obtaining cores. Photographs of the bottom here also show that exposed gravel to boulders are common (Lien & Myhre 1977).

**Mineralogy and provenance**

The main sources for the minerogenic part of the Quaternary deposits in Malangsdujet are: unmetamorphosed sedimentary rocks on the continental shelf and crystalline Precambrian and Caledonian rocks from further east (Fig. 1).

The sediments were split into four lithofacies for mineralogic comparison:

- Holocene sand layer in area A
- Poorly sorted sand and mud. Holocene accumulation sediments in area B
- Volcanic rocks
- Gravel and sand with pebbles and boulders

**Fig. 9.** Grain size distribution (probability scale) of samples from the three main lithofacies in core T10.
Clayey silt with pebbles in area A
Pebbly mud in area A
Only a brief investigation of the winnowed sediments in area C was carried out, and the sand fractions were not systematically investigated due to the low sand content in the clayey silt and the simple mineralogy of the sand in the Holocene sediments.

Fig. 10. Stratigraphy of Holocene sediments of core 014, area B. Location, Figs. 2, 4. The upper homogeneous unit has a high content of fossil debris compared to the lower unit.
Gravel

The sediments in area A and C contain gravel.

The samples in area C are winnowed sediments and contain only crystalline rocks except for a few siderite nodules. Gneisses and granites are common rock types, but metasediments, e.g. garnet micaschist and calcareous arenites, also occur. Dredging on the banks has also shown that sedimentary rocks are rare in the coarse fraction (O. Holtedahl 1940, H. Holtedahl pers. comm. 1976).

In area A sedimentary rocks are more common. A systematic counting of the 2–4 mm fraction from samples of selected cores showed that mudrocks are common in the pebbly mud and less common in the clayey silt above (Table 2). Dark mudrocks are the sole sedimentary rock in T 10 except for three siderite fragments, while light mudrocks occur in the western part of area A (Table 2).

No attempt was made to distinguish between the different coarse crystalline Precambrian rocks and Caledonian metasediments in the 2–4 mm fraction, but from a brief investigation of the larger clasts there is evidently a large majority of granites and gneisses, especially in the gravel lag of the top sand layers.
Table 2. Mineralogy of the 2-4 mm fraction in selected samples.

| Lithologic unit | Sample | % Sedimentary rocks | | % Crystalline rocks | Number counted |
|-----------------|--------|---------------------|---------------------|---------------------|--|------------------|
|                 |        | Dark mudrocks       | Light mudrocks      | Carbonates          |                |
| Gravel lag      | 0-8/14 | 100                 | 44                  |                     |                |
|                 | 0-6/1  | 8                   | 30                  | 1                   | 61              | 220             |
|                 | 0-9/1  |                     |                     | 100                 | 125             |
|                 | 0-10/3 | 1                   | 1                   | 98                  | 88              |
| Clayey silt     | 0-8/13 | 5                   | 2                   | 93                  | 90              |
| with pebbles    | 0-10/7 | 10                  |                     | 90                  | 31              |
|                 | 0-9/3  | 4                   |                     | 96                  | 25              |
| Pebbly mud      | 0-6/3  | 10                  | 62                  | 1                   | 27              | 170             |
|                 | 0-9/4  | 56                  | 14                  |                     | 30              | 286             |
|                 | 0-10/8 | 48                  | 21                  |                     | 31              | 188             |
|                 | 0-8/7  | 52                  | 4                   | 1                   | 44              | 282             |
| Core T 10       | T 10/1 | 5                   |                     |                      | 95              | 130             |
|                 | T 10/3 | 77                  |                     |                      | 23              | 141             |
|                 | T 10/4 | 88                  |                     |                      | 12              | 58              |
|                 | T 10/7 | 83                  |                     |                      | 17              | 126             |
|                 | T 10/8 | 66                  | 2                   |                      | 32              | 158             |

The easy disintegration of the soft, fine-grained mudrocks into rock fragments which splits further to separate mineral grains of silt and clay size causes a high content of mudrocks in the sand fractions coarser than 0.25 mm, while gravel fractions coarser than 4 mm show an increase in hard crystalline rocks.

XRD analyses of the sedimentary rocks show a pronounced mineralogic difference between the dark and light mudrocks. Illite is the main clay mineral in the dark mudrocks, with kaolinite, chlorite, vermiculite, and 10–14Å mixed layer in smaller amounts, while smectite and smectite/illite is the major clay mineral in the light mudrocks. Non-phyllosilicates are quartz and plagioclase in both rocks types. Thin section studies of the dark mudrocks also revealed clastic biotite, often chloritized, and muscovite.

In order to find the approximate age of the two rock groups, four fragments of each rock type were investigated for palynomorphs by T. Bjerke, Universitetet i Oslo. The results indicate a Lower Cretaceous age (Albian–Aptian) for the dark mudrocks. Upper Cretaceous and reworked Lower Cretaceous palynomorphs occur in the light mudrocks.

Assuming this age relation is correct the distribution of mudrock clasts confirm the seismic interpretation of the oldest Mesozoic rocks occurring in the east near the boundary with the crystalline basement and younger towards the west (Sundvor 1976, Rokoengen & Bugge 1976). It is also in accordance with the suggested glacial erosion.

Silt

There are two main groups: pebbly mud and clayey silt with only traces of calcite; the top sand layer and the Holocene accumulation sediments in the eastern part with calcite as a major mineral (Fig. 15). The carbonate content of bulk samples was analysed separately to determine the difference in total weight percent of CaCO₃ between the lithofacies (Fig. 6, 8, 10). According to these values there are two to five times more carbonate in the Holocene sandy sediments than in the glacial units, which is caused by the increase of fossils, especially foraminifers. But the 5–10 weight % CaCO₃ in the pebbly mud and clayey silt was only detected by XRD as traces of calcite and aragonite. The Holocene sediments have minor amounts of aragonite but it is only a small percent of the CaCO₃ content. However, the source of the carbonate is not only from biogenous debris because calcareous
metasediments and siderite fragments were detected in the gravel and sand.

Except for the calcite content there are only small differences between the four lithofacies. The amount of phyllosilicates decreases rapidly with increasing grain size, while feldspar and quartz increases. The major feldspar is plagioclase (3.25 Å) in all fractions and lithofacies with only small amounts of potash feldspar (3.19 Å). All the lithofacies contain amphibole and this mineral was not detected in the sedimentary rocks and is probably derived from the crystalline rocks where amphibole is a common mineral (Landmark 1973).

**Clay mineralogy**

Besides the major clay minerals (Fig. 14), vermiculite and traces of smectite were detected in all samples. The 10–14 Å mixed layer is mainly smectite/illite. Larger amounts (5–15%) of smectite were found in the westernmost cores (06, T 25), in which light mudrocks are common.

The non-phyllosilicates are plagioclase, amphibole, and traces of quartz. Calcite was only detected in the Holocene lithofacies.

Except for smectite found in core 06, T 25 no regional differences were detected within any of the lithofacies. This can be explained by a homogeneous source like the pebbly mud for the sediments deposited above it. No large depletion of kaolinite was detected above the pebbly mud. This should be expected if the source for the clay was only the crystalline rocks which contain no kaolinite. XRD investigation of the clay fraction of 11 samples of Late Weichselian sediments...
Depositional environments

From the present investigation of the surficial sediments in the Malangsdjupet area five lithofacies may be distinguished.

- Sand layer above Late Weichselian sediments (area A)
- Poorly sorted sand and mud (area B)
- Lag deposits (area C, A)
- Clayey silt with pebbles (area A)
- Pebbley mud (area A)

The age of the pebbly mud (till ?)

The Egga I in Malangsdjupet has a distinct glacial morphology and was classified as a marine, morainic outwash fan (Andersen 1968:14). Seismic records indicate till-like sediments in the Egga moraines and only east of Egga II are there bedded sediments of varying thickness over the till (Bugge et al. 1974) Fig. 3A, B.

No morphological description has so far been given of the form of the Egga II in Malangsdjupet. The Egga II is 7-13 km broad with a gentle slope on the proximal side, a very gentle slope on the distal side, and has a maximum thickness of 80 m (Bugge & Rokoengen 1976). This smooth, broad surface does not resemble other well described submarine terminal deposits like the Ra in southern Norway or the Egga I in Malangsdjupet. Vorren & Elvsborg (1979) described this as a marginal moraine complex rather than a single terminal moraine.

The age correlation of the Egga moraines in Malangsdjupet found by seismic profiling is uncertain, but 13,300 BP, 12,000 – 12,200 BP, and 11,000 – 12,000 BP is suggested for Egga I, II, III respectively (Rokoengen et al. 1977). No data from the seismic investigations and sampling indicated an age older than the Weichselian maximum for the Egga moraines (Rokoengen et al. 1977). Andersen (1968) summarized the arguments favouring the view that the Egga I moraine was deposited during the Weichsel maximum.

However, K.D. Vorren (1978), on the base of$^{14}$C datings of lacustrine sediments at Andøya, suggests that the ice never extended northwest of Andøya during the Weichselian maximum. And the age suggested for the Skarpnes moraine (12,000–12,500 BP) by Andersen (1968) conflicts...
with the ages indicated by Rokoengen et al. 1977. Vorren & Elvsborg (1979) concluded that the ages obtained for the Egga II, III by Rokoengen et al. (1977) was probably from younger sediments deposited on top of the marginal moraines.

Reviewing the stratigraphy of the cores in Malangsdjupet from the top of the Egga II to the Egga I, there are small lateral variations. But the pebbly mud is less overconsolidated west of 08 and the glaciomarine clayey silt overlying the pebbly mud is thin or lacking in the middle of the trough. $^{14}$C dating of in situ mollusks in the clayey silt in the core T-4-1 (location as 08) gave $12,000 \pm 240$ BP (Table 1), which indicates a rapid deposition of the glaciomarine sediment, because $^{14}$C dating of the gravel lag gave only a slightly younger age, $11,900 \pm 260$ BP (Table 1). This suggests an age of the pebbly mud not much older than $12,000 \pm 240$ BP. However, this is contradictory to the age of the Skarpnes moraine, $12,000$–$12,500$ BP (Andersen 1968), but in accordance with Rokoengen et al (1977). The mineralogy of the pebbly mud shows sedimentary rocks from the shelf to be the main source and an erosion of the shelf shortly prior to the Skarpnes moraine is indicated by the $^{14}$C datings. How far the ice extended out in Malangsdjupet during deposition of the pebbly mud is uncertain, but the shear strength values found in 08, 09, 010 point to a grounded ice at least as far as Egga II.

**Glaciomarine deposition**

Because many glacial morphologic features are preserved on Malangsgrunnen and Sveinsgrunnen, the transgression following the glacial retreat has been interpreted as having occurred rapidly (Holtedahl 1940, Andersen 1968). A rapid transgression fits well with the suggested age of the final retreat of the ice from the shelf because relative sea level during Bölling was above the present in this area (Andersen 1968, Vorren 1978).

In the deeper part of Malangsdjupet the retreat was followed by accumulation of soft clayey silt with scattered clasts. The sediments are derived from three sources:

- Winnowed sediments in the shallow areas
- Outwash in front of the retreating glacier
- Sediments dropped from floating icebergs or an ice shelf

The mineralogy of the clay and silt fraction is rather similar in the pebbly mud and the clayey silt and the mud of the glaciomarine deposits could be derived by winnowing of the pebbly mud. The mineralogic composition of the tills on the banks is unknown, but seismic profiling across the banks indicates rocks of the same age as along Malangsdjupet (Rokoengen & Bugge 1976), and points to a common source rock for the tills in Malangsdjupet and on the banks.

The occurrence of pebbly mud with a high content of dark mudrocks of lower Cretaceous age in core T 10 close to the boundary between Precambrian crystalline rocks and the Mesozoic rocks indicates erosion of sedimentary rocks during deposition of Egga III. The sparse sediment cover above this upper pebbly mud in core T 10 suggests that when the ice finally retreated to the crystalline rocks little sediment was transported out in front of the glacier to reach Malangsdjupet. This fits also with the clay mineral data which show no large depletion of kaolinite in the glaciomarine sediment even in the area close to the crystalline basement with no source containing kaolinite.

The transition from fine grained glaciomarine sediments to gravel and sand of Late Weichselian age implies a great increase in current velocities throughout the basin. Malangsdjupet is so deep that isostatic changes or currents generated by waves are of negligible importance. The high energy environment was therefore due to strong marine currents.

The $^{14}$C-date obtained in the gravel lag ($11,900 \pm 260$ BP) is within the period 12,500–11,000 BP, which Mangerud (1977), by comparing Late Weichselian mollusks in coastal areas in western Norway and from the fjords of Troms, suggested for a northward movement of the oceanic Polar Front from western Norway to a position south of Troms. However, investigations of Late Weichselian mollusks in the Nordvestbanken – Fugløybanken area indicate the influence of warm Atlantic water (Vorren et al. 1978). Therefore an oceanic Polar Front running parallel and closed to the coast with a highly oscillating boundary seems more likely.

The increase in current velocities early in Late Weichselian is thus explained by a variable oceanic Polar Front located at the shelf outside Troms. A similar explanation was given for the change to a high energy environment during the Subatlantic on the Spitsbergen bank (Bjørlykke et al. 1978).
The southward migration of the oceanic Polar Front during 11,000–10,000 BP (Ruddiman 1977, Mangerud 1977) may be traced by homogeneous, fine-grained sediments found in the lower part of the cores in area B, Figs. 10, 11. Floating icebergs probably contributed to the sediments in Malangsdjupet as late as the withdrawal of the glaciers from the Tromsø–Lyngen moraine about 10,000 BP (Andersen 1968), because all the icebergs calving in Malangsfjorden had to drift out between Senja and Kvaløya.

However, in core 014 in area B no ice-rafted pebbles are found below the mollusk layer dated to 9610 ± 170 BP. Also in all the other cores in area B non-biogeneous particles >1 mm are lacking. This is interpreted as a definite end of glacial influence on the sedimentation in Malangsdjupet.

**Holocene sedimentation**

During the early Holocene, fine-grained sediments were deposited in area B; and the coarsening upward found in this area indicates increased current velocities during Holocene.

Coarsening up in Holocene sediments has also been reported outside western Norway (Holtedahl et al. 1974, Elverhøi pers. comm. 1978) and the northwestern part of the Barents Sea (Bjørlykke et al. 1978).

The increase in current velocity during the Holocene must have been caused by changes in the marine currents along the coast as wave currents only reach down to c. 200 m (Kulm et al. 1975). The coarsening-up unit detected in Holocene sediments at 160–350 m depth outside western Norway has been explained by the onset of the Norwegian Coastal Current during early Holocene (Elverhøi, pers. comm. 1978), when the oceanic Polar Front moved north to the Svalbard area.

The currents transporting fine sand and silt in Malangsdjupet are considered to have been generated by the Norwegian Coastal Current moving northeastwards along the coast, controlling the sedimentation during Holocene and preventing final deposition of sediment in area A. Only in the deep area B has accumulation prevailed during Holocene with a sedimentation rate of 8–18 cm/1000y.

On the banks of area C, where large scale winnowing formed a thick gravel lag, probably prior to 11,000 BP, only sand consisting of quartz and skeletal debris is accumulating at present. However, photographs of the bottom from this area show commonly exposed gravel to boulders (Lien & Myhre 1977). Current measurements (VHL reports 1973, 1974, 1975, 1976) indicate movements of sand and finer gravel in the present environment. The patchy sand cover is considered to be undergoing erosion, transport, and deposition at present.

On the shelf edge and slope of area C winnowing is not induced by waves, but is most likely caused by the Norwegian Coastal Current as in area A.

Transport from the banks into Malangsdjupet is difficult to prove because of the few samples from the slopes above area B. But the coarsest sediments are located close to the slopes and indicate transport, especially along the small trenches running towards the eastern part of area B.

**Conclusion**

The corer penetrated into a firm pebbly mud (till?) in the middle of the western part of Malangsdjupet, while the glaciomarine cover exceeded the core length towards the slopes from the banks. The increasing thickness of the glaciomarine cover towards the banks is due to the large amount of suspended sediments derived by winnowing shortly after withdrawal of the glacier. Little sediment was transported out onto the shelf after withdrawal of the glacier to the mainland.

A discussion of the age of the pebbly mud led to the following tentative conclusion: The ice extended out in Malangsdjupet as far as Egga II, shortly prior to the deposition of the Skarpnes moraine (12,000–12,500 BP) and deposited the pebbly mud; the ice then retreated rapidly to the small Egga III and further to the Skarpnes moraine.

The winnowing started prior to 11,900 ± 260 BP and is related to the northward movement of the oceanic Polar Front to a position close to the coast of Troms. Winnowing has been most severe on the banks, shelf edge, and slope, but only the deepest parts of Malangsdjupet have accumulated more than 2–15 cm during the Holocene.

In the depressions where 1–2 m of Holocene sediments have accumulated, a coarsening upward has developed. The increasing current velocities during early Holocene are explained by
the onset of the Norwegian Coastal Current which controls the present day hydrodynamic pattern. Current measurements on the banks by VHL show that sand and finer gravel are only temporarily stable in the present day environment.

Soft, dark mudrocks of Lower Cretaceous age are the major contributor to the mineralogy of the pebbly mud, but the content of light, Upper Cretaceous mudrocks increases towards the shelf edge. Only in the coarser gravel fractions are crystalline Precambrian and Caledonian rocks most common.

The glaciomarine and Holocene sediments have a mineral assemblage in the clay and silt fractions similar to the pebbly mud except for the large amount of biogenous debris added to the Holocene sediments. The pebbly mud is interpreted as the main source for the post-till sediments.

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