Glaciotectonic deformation structures in unconsolidated sediments at Os, south of Bergen

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Sønstegaard, E.: Glaciotectonic deformation structures in unconsolidated sediments at Os, south of Bergen. *Norsk Geologisk Tidsskrift*, Vol. 59, pp. 223–228. Oslo 1979. ISSN 0029-196X.

Studies of a section in western Norway of glaciomarine sediments emphasize the extremely local character of glaciotectonic fold structures, sharply delimited from the undisturbed sediments some few metres away. Silt and fine sand are shown to have been deposited close by the glacier front.

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Marine, ice marginal deposits in Norway commonly consist of stratified sand and gravel, whereas the most fine-grained material, silt and clay, occupies a more distal position in relation to the ice front. The Preboreal glaciofluvial marginal deposits at Romerike, eastern Norway, for example, demonstrate this type of grain-size distribution (Holtedahl 1924). Fine-grained sediments can also occur, however, in the more proximal parts of the marginal deposits, as has been described from Herdla (Aarseth & Mangerud 1974) and from Sarpsborg (Feyling-Hanssen 1964: 105). The following description of a section at Myrvollen, Os, shows that silt can be deposited right up to the ice front, in a relatively open, marine environment.

Stratigraphy

The studied locality (Fig. 1) occurs 2 km north of Osøyri, about 1.5 km inside the margin of the Herdla Moraine (Aarseth & Mangerud 1974). Above the marine limit, which is about 60 m a.s.l., there is mainly bare bedrock with a thin, discontinuous cover of soil, mainly weathering products and raw humus. The areas below 40–45 m a.s.l. are covered by glaciomarine sand and silt, and postglacial marine and lacustrine sediments (Fig. 1). There are series of gullies, all of which open out into the lake Banktjørn, eroded into the glaciomarine silt (Sønstegaard & Mangerud 1977).

A number of sections were cut into the glaciomarine silt, but only one, in which some particularly interesting structures occur, is described here. The section (Fig. 2) can be divided into a western part, where the sediments lie undisturbed (Fig. 4), and an eastern part where the lowermost beds are strongly folded (Fig. 3). The glaciofluvial gravel in the western area has no clear stratification (Fig. 4). The exact thickness of this unit is unknown, but is probably about 1 m.

1.5–2 m of laminated, glaciomarine sand and silt lie conformably on the gravel (Figs. 2, 4 and 5). This boundary is very sharp, and the lamination is caused by grain-size variation from coarse sand to clayey silt. These sediments clearly drape over the underlying deposits, and were deposited largely from suspension. Some of the sandy laminae, however, thicken into, or are confined to depressions, suggesting traction transport of at least some of the sand along the bottom.

There are several reasons as to why the laminated silt is glaciomarine:

The sediment never occurs higher than the marine limit.

The sediment contains many marine microfossils, and was deposited while there was yet open tundra vegetation on the land (Sønstegaard & Mangerud 1977).

The sediments were folded by the glacier while they were accumulating.

Lamination is common in glaciomarine sediments in western Norway, but not in non-glacial, marine sediments. The lamination, probably not yearly varves, is likely to have been caused by variation in mud content in the load of the glacial streams.

There is a gradual upwards transition from the laminated silt into a massive unit, about 1 m thick, of clayey silt (Figs. 2, 4 and 5). Pollen

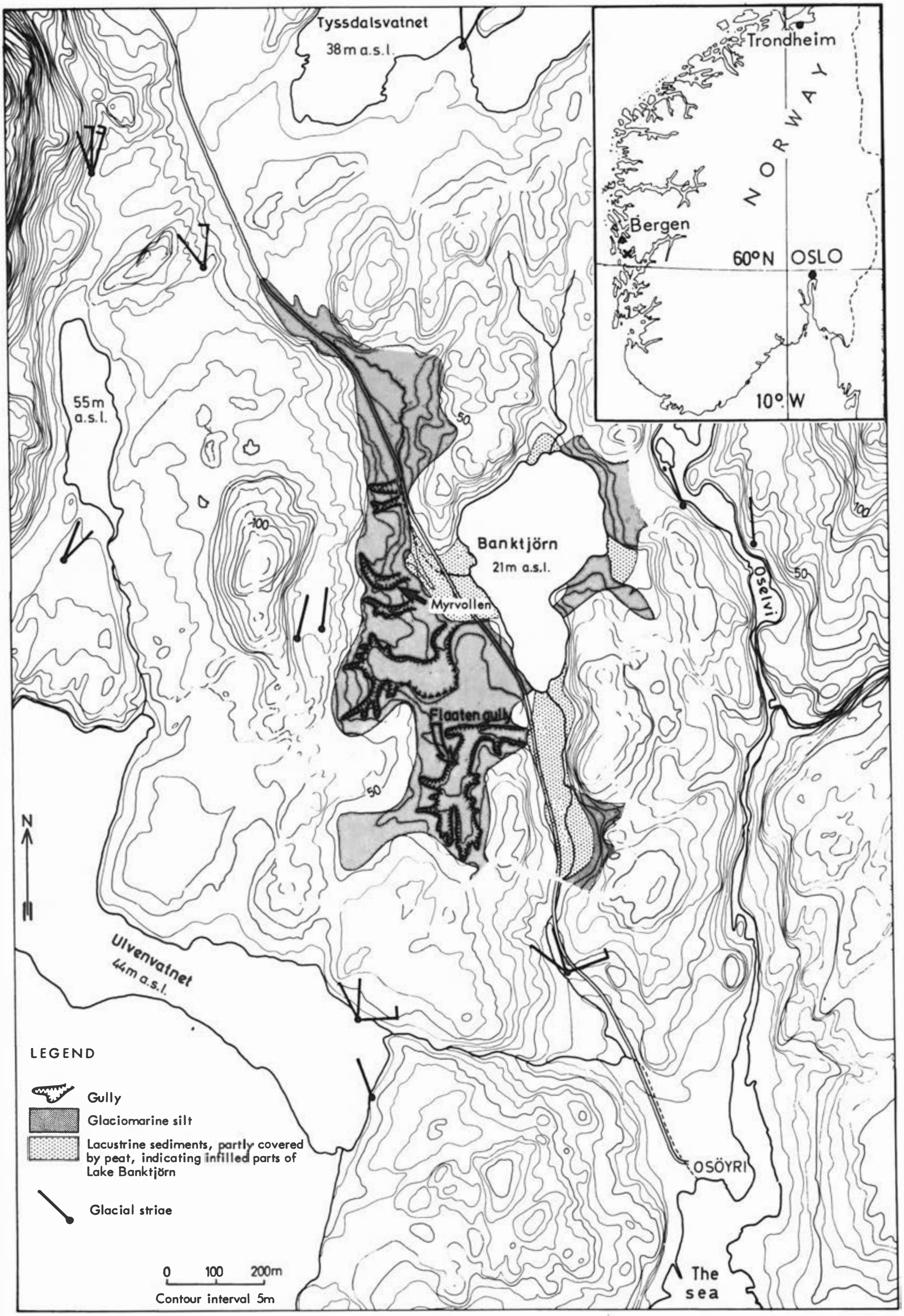

Fig. 1. Map of the area north of Osøyri, mainly after Sønstegaard & Mangerud (1977, fig. 2). Os is approximately located by a cross on the insert map.

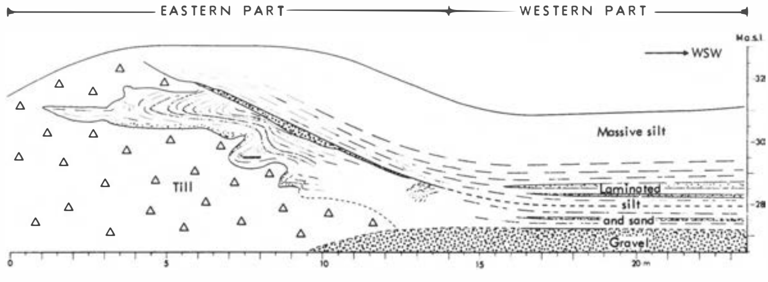

Fig. 2. Sketch showing the stratigraphy and structures in the Myrvollen section.

analyses in similar sediments from Banktjørn (Sønstegaard & Mangerud 1977) show a marked increase in arboreal pollen, particularly *Betula,* at the level where lamination disappears. This massive silt is interpreted as postglacial, marine silt.

The stratigraphy described above is representative for the areas around Banktjørn where the silt is developed.

In the eastern part of the section there occur, in addition, unsorted sediments which are interpreted as till (Figs. 2 and 3). The texture (Fig. 5) suggests that the source material was fine-grained, glaciomarine sediments. The till, which is up to 5–6 m thick, can be traced laterally (southwards) for some 15–20 m from the section; it is probably a small, terminal moraine, but cannot be correlated with other marginal deposits.

Deformation structures

In the eastern area the deposits are divided into an undisturbed upper and a strongly deformed lower part, separated by a marked angular discordance which dips at 22° towards WSW (Figs. 2, 3 and 6). Westwards the discordance gradually flattens out and disappears (by abscissa 14 m, Fig. 2). Because of continuous avalanching of the unconsolidated sediments, it was extremely difficult to follow the discordance in detail westwards, but it appeared to wedge out into a thin sand lamina at about 70 cm above the boundary with the underlying glacio-fluvial material. Although the exact stratigraphic position of the discordance is somewhat uncertain, it clearly occurs within the glaciomarine silt, and probably at the level suggested in Figs. 2 and 4.

Along most of the plane of discordance there lies a layer of sand and gravel up to 30 cm thick. Conformable on this lies the laminated

Fig. 3. The eastern part of the section. The spade marks the till/silt boundary at approximately 5 m (compare Fig. 2). The lamination of the sediments above the discordance (stippled) is better seen on Fig. 6.

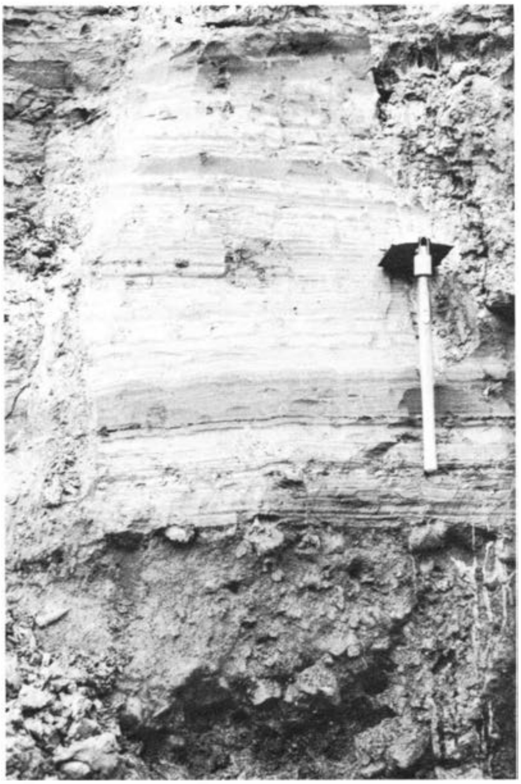

Fig. 4. Laminated glaciomarine silt and sand above coarser glaciofluvial material, and massive silt on the top. From the western part of the section. The blade of the spade shows the approximal position of the discordance.

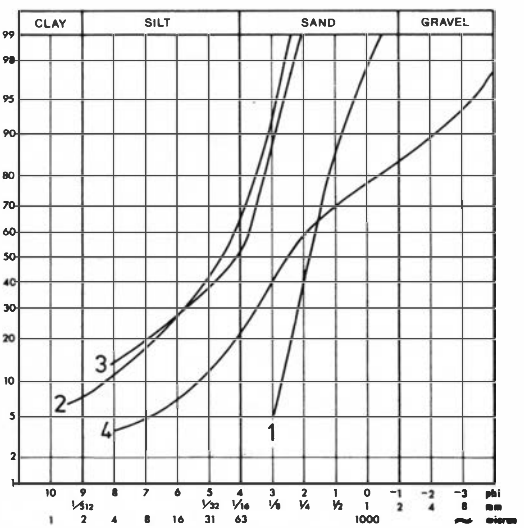

Fig. 5. Grain size distribution curves. Sample 1: Glaciomarine sand. Sample 2: Glaciomarine silt. Sample 3: Massive silt. Sample 4: Till.

glaciomarine silt in which individual laminae are persistent over at least several metres.

The strongly folded sediments under the discordance consist of beds of laminated sand and silt which obviously are laterally equivalent to the undisturbed sediments under the plane of discordance. In the western area, therefore, the interval of folding can be placed at the level immediately below the discordance.

The impressive deformation below the discordance consists of overturned and recumbent folds which decrease in their scale westwards, and which have a series of small folds and faults superimposed on them (Fig. 6). The faults dip eastwards and normal faults are more numerous than reverse faults. Fold axes have a N–S orientation (Fig. 7).

Interpretation of the deformation structures

The deformation must have taken place immediately before the creation of the erosional discordance which lies some 70 cm up in the glaciomarine silt of the western area (Fig. 2), i.e. relatively early during the period of glaciomarine sedimentation.

The stratigraphic position of the till is somewhat uncertain. It may have been deposited originally as a lodgement till prior to the deposition of the glaciomarine silt and later folded together with the lower part of the silt. However, the till is absent in the western part of the section, and this rather suggests that it was deposited at the same time as the folding took place. The high silt content in the till is consistent with this suggestion.

The orientation of the fold axes, together with the other structures, demonstrates that the direction of movement during deformation was towards the west, i.e. in a direction up the valley floor. Flow movements due simply to gravity, therefore, which may cause similar fold structures (e.g. Boulton 1972, pl. 10), cannot be the explanation here. Larger glaciotectonic structures of frozen sediments described from Denmark (Gry 1940) much resemble these at Myrvollen. The latter were, however, formed at about 30 m below sea level and accordingly in an unfrozen state.

The texture of the till indicates a local glacier advance, and the structures show that the sec-

Fig. 6. The discordance (stippled) with laminated sediments above, and a series of small, normal faults in the upper part of a large fold below.

tion lies right at the outer edge of this advance. The deposition of the obviously ice-pushed till, that was partly injected into the glaciomarine sediments, caused the upheaval and folding of these sediments. The till cannot, therefore, be interpreted as flow till but is more likely to be a submarine terminal moraine, formed by the lateral pressure of the ice towards the west.

There is a discrepancy between the western direction of ice movement deduced from the tectonics and that of the youngest glacial striae

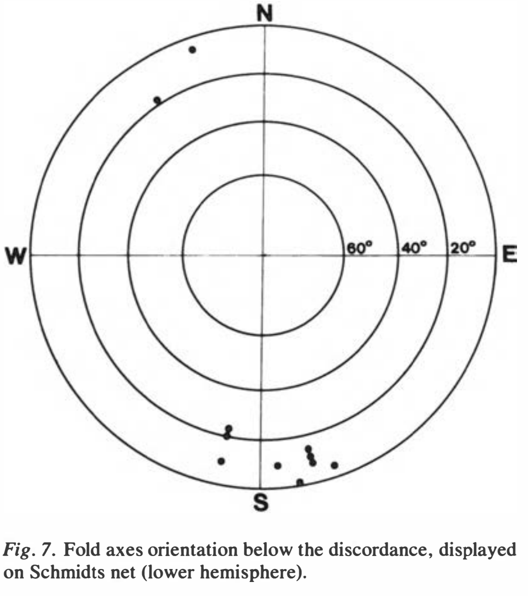

Fig. 7. Fold axes orientation below the discordance, displayed on Schmidts net (lower hemisphere).

in the region, being towards south (Fig. 1). This may be explained by

a slightly older age of the striae than the tectonization,

the influence of the local topography, or, most probably

diverging ice movements at the snout of the glacier.

The sedimentological and tectonic history of the eastern and western part of the section may then be summarized as follows. After the ice melted during the transition Younger Dryas/Preboreal chronozones, glaciofluvial material was first deposited, followed by fine-grained, laminated glaciomarine sediments in both the eastern and the western parts. During an early stage of this sedimentation phase the glacier front readvanced, perhaps only by a few metres, causing the folding of the glaciomarine sediments in the eastern part of the section, at the same time as the till was emplaced. Immediately afterwards there was erosion and development of the discordance on the ice-pushed ridge.

In the western part of the section there was, during this time, continual sedimentation of glaciomarine silt and sand. The folding in the eastern part of the section had apparently no influence on the sedimentation here.

Two main conclusions can be drawn:

The glaciomarine sediment, mainly laminated silt and fine sand, was deposited right up against the glacier front.

The effect of a small readvance of a glacier, with the development of significant glaciotectonic folding, can be completely local, and without trace only a few metres away from the ice.

Acknowledgements. – Dr. Jan Mangerud has given valuable help through discussions in the field and by critical reading of the manuscript. Miss Ellen Irgens and Mr. Masaoki Adachi drew the figures, and the manuscript was translated into English by Dr. R. J. Steel. To all these persons I offer my sincere thanks.

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