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& Svein Østmo:
Quaternary geology of Jæren
and adjacent areas,
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BJØRN G. ANDERSEN, OLE P. WANGEN & SVEIN R. ØSTMO

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Jæren in southwestern Norway is covered with a sheet of Late Weichselian glacial deposits which in places overlies rather thick units of older glacial and marine deposits. Younger Late Weichselian and Holocene marine sediments, eolian sand and peat cover parts of the Late Weichselian sheet. The distribution of the surficial deposits was mapped, and numerous analyses of grain size, fabric, clast roundness and pebble counts were used to characterize the depositional environments. On the basis of lithostratigraphical, biostratigraphical and chronostratigraphical studies, including datings by different methods, a stratigraphical model is presented for the Late Weichselian and older deposits. The model is preliminary, since the dating and correlation of deposits older than 25 000 - 30 000 years B.P. remain uncertain. All units in the model are mentioned in stratigraphical order:

Karmøy stadial tills are of Early Weichselian age. The coast was ice-covered at that time. *Bø/Nygaard interstadial* marine deposits of late Early Weichselian or early Middle Weichselian age overlie the Karmøy stadial deposits. The fossil fauna and flora suggest that the interstadial was cool, and the sea level was not much higher than today. *Jæren stadial* tills and glacio-marine deposits are most likely of Middle Weichselian age. The ice front was located at the coast which could have been completely ice-covered during phases of the stadial. *Sandnes interstadial* marine deposits are probably of late Middle Weichselian age. The fossil flora and fauna together with the lithology suggest that the climate varied between cool Boreal and Arctic. *Stavanger stadial* tills cover most of Jæren and Karmøy. They are of Late Weichselian age and include both a gravelly and a clayey member. In the literature from before 1960 the clayey member was called the Skagerrak till, and it was supposed to be of pre-Weichselian age.

In situ sub-till marine deposits, which are correlated with the Sandnes interstadial, lie up to 200 m above sea level at Jæren. They must have been deposited during a considerable marine transgression, supposedly caused by isostatical depression of the land, during the Middle Weichselian, possibly of the order of 200 m. However, another possibility is that the isostatic depression was less than 200 m and that the high-level marine deposits have in part been tectonically uplifted. Broad submarine ridges on the North Sea floor to the west of Jæren have been interpreted as end moraines, and end moraines from five glacial phases, between 13,500 years old and 12,500 years old, are recognised on Jæren and adjacent mountain areas. Beach ridges and shore-lines between 6 m and 26 m above sea level were mapped. Most of them represent either a Late Weichselian or a Holocene (Tapes) shore complex.

Bjorn G. Andersen, Departement of Geology, University of Oslo, Postbox 1047, 0316 Oslo 3, Norway.

Ole P. Wangen, Veglaboratoriet, Gaustadalléen 25, 0371 Oslo 3, Norway.

Svein R. Østmo, Norsk Hydro a.s., Oil and Gas Div. Drammensvn. 264, Oslo, Postbox 200, 1321 Stabekk, Norway.

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Introduction

The result presented in this paper were obtained in connection with our mapping of Quaternary deposits for the Norwegian Geological Survey and during stratigraphical studies for the IGCP-project 24. The mapping was carried out mainly within the area of 1:250,000 map-sheet Stavanger. Detailed Quaternary maps of this area at a scale of 1:50,000 will be published soon.

A considerable part of the results of our work has been presented earlier in the theses of Østmo (1971) and Wangen (1968), in several lectures by Andersen, in Andersen (1979) and in Andersen et al. (1981, 1983). To some extent the results of reconnaissance studies in adjacent areas are also incorporated in this presentation, including studies in the Egersund—Bjerkreim area carried out by Th. Hellvik.

Geographical setting

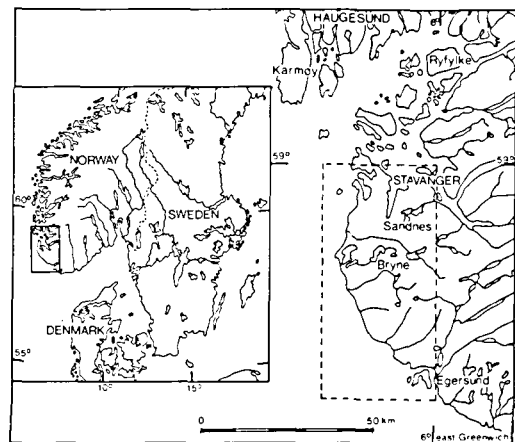


Fig. 1. The location of the Stavanger map-area (dashed frame) and adjacent areas.

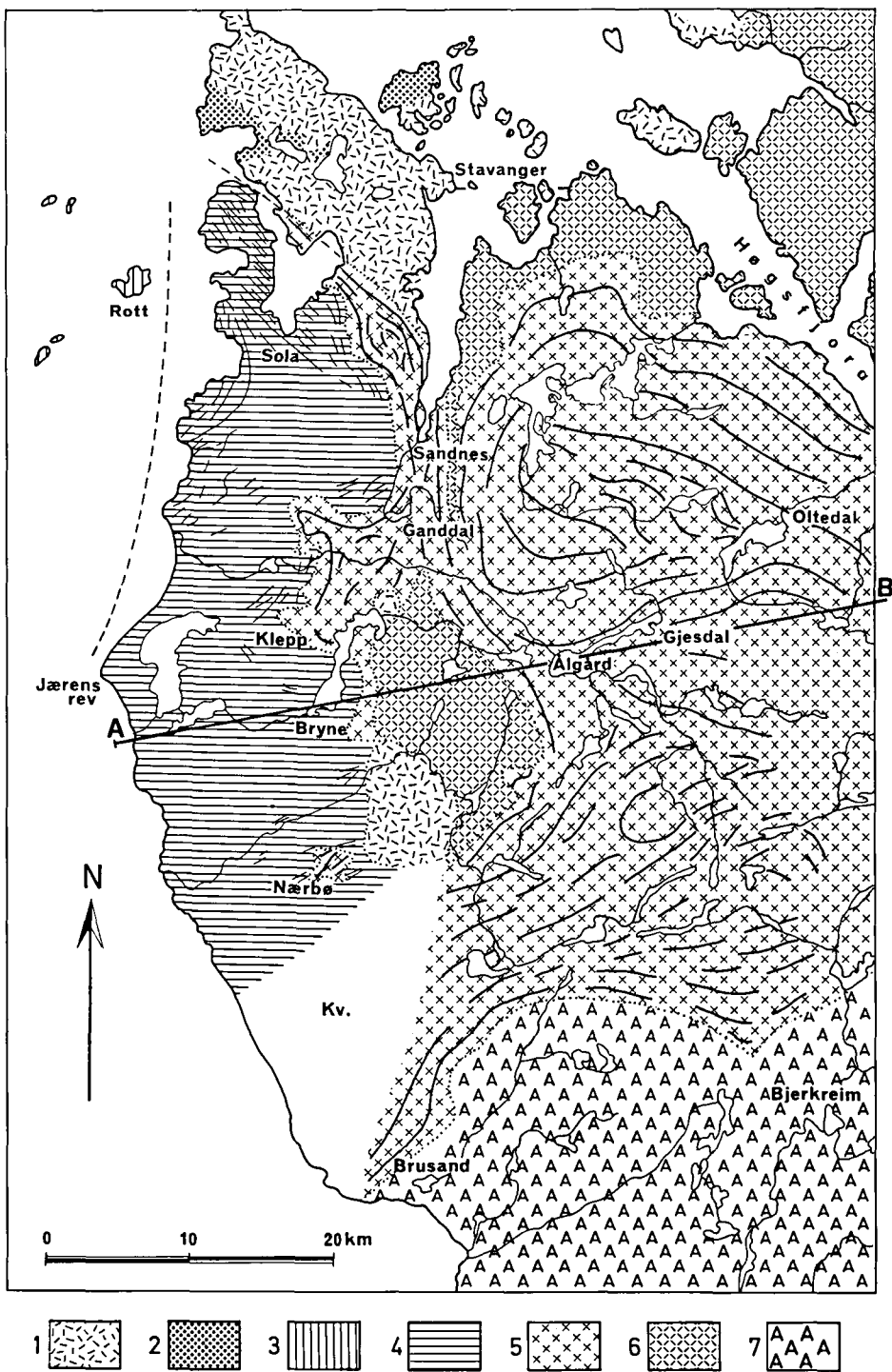


Fig. 2. Bedrock map of the area (from T. Birkeland, pers.comm. 1970). (1) Phyllite, (2) Paragneiss, (3) Greenschist, (4) Mica gneiss, (5) Anatectite (mainly gneisses and granites), (6) Porphyry granite, (7) Anorthosite.
 Kv: Quaternary, bedrock not exposed.
 A-B: Location of the profile presented in Fig. 3.

The Stavanger map-area (DFig. 1) comprises the Jæren coastal plain and the mountainous area to the east of Jæren. Most of Jæren is covered by Quaternary sediments which in places have a considerable thickness, whereas bedrock is usually exposed in the highland to the east.

The present climate is cool-oceanic with a mean annual temperature of 7.6°C, and the mean temperatures for the warmest and the coldest month are 14.9°C and 0.8°C, respectively (Brun 1967). The mean annual precipitation is about 1100 mm on Jæren and about 2000 mm in the highland areas (pers.comm. from Værvarslinga på Vestlandet). Scattered small wooded areas exist on Jæren, mainly of birch and planted pine, while in the highland valleys the trees are predominately birch.

The bedrock within the Stavanger map-area consists mainly of Precambrian gneisses and granites (anatectites) in the eastern part, anorthosite and other basic rocks in the southern part, and phyllites, mica schists and mica gneisses in the western part. According to O. Holte-dahl (1960) the last-mentioned rocks are of Cambro-Silurian age, though Birkeland (1970) considered them to be Precambrian. A phyllite unit in the northwestern part of Jæren was Rb-Sr dated at 540 ± 100 m.y., and a tectonic wedge of banded gneiss within the phyllite has an age of 994 ± 30 m.y., according to Roddick et al. (1981).

The highest mountain summits lie approximately on a planation surface that slopes gently towards the west (Fig. 3). To the east of Jæren this surface corresponds with the exhumed Precambrian peneplain, which forms extensive upland areas in Ryfylke, immediately to the east of the Stavanger map-area (Andersen 1954). Jæren is evidently a younger surface eroded into the old plain. Several workers believed that Jæren is a part of the coastal plain or 'Standflat' formed by different shore processes (Reusch 1895, Nansen 1922). In contrast Ahlmann (1919) stressed that the bedrock in Jæren is rather weak and he believed that the coastal plain was formed by subaerial erosion, while Feyling-Hanssen (1966) suggested that a fault line follows the eastern border of Jæren and that the area has been downfaulted. Our observations are insufficient to draw definite conclusions on the origin of the Jæren coastal plain, but it seems possible that each of the above-mentioned processes could have contributed to the form of the present-day landscape.

Quaternary deposits, historical review

The sheet of Quaternary deposits on Jæren has been studied by many scientists, and only some of the most important observations and conclusions can be mentioned in this review.

A gravelly till lies at the surface in most areas, but in parts of southern Jæren a clayey till is exposed. Far-travelled erratics from the Oslofjord and Baltic regions together with crushed marine shells were observed in the clayey till. Helland (1885) therefore suggested that it was deposited by a Skagerrak glacier which moved from the Skagerrak area in a northerly direction towards Jæren. Later, Bjørlykke (1908) and Grimnes (1910) studied and mapped both the gravelly till and the clayey Skagerrak till. At some localities the gravelly till lies on top of the clayey till. Therefore it was generally assumed that the two tills were deposited during two different glaciations, the gravelly till by a glacier which moved westwards from the mountains in Ryfylke. In 1874 a drilling was carried out at Grødeland on southern Jæren. There, a clayey Skagerrak till was observed on top of 76 m sand and gravel which rest on 13 m gravelly clay. Bjørlykke (1908) considered the gravelly clay to be a till from an older glaciation and suggested that there are deposits from three glaciations on Jæren. This view was accepted by most scientists who studied the Quaternary deposits on Jæren.

Stratified marine deposits were found below the mentioned tills at several localities, such as Sandnes, Madla, Foss-Eigeland, Reve and Grødeland. Arctic and Boreo-arctic shell faunas were observed in most of the deposits, but at Reve Bjørlykke found a *Cardium edule* fauna which he considered to be interglacial.

In 1964 both Andersen and Feyling-Hanssen presented evidence suggesting that the clay within the 'Skagerrak till' was derived from marine clays which lay on Jæren, and that the far travelled erratics were ice-rafted and had been dropped into the clay. They suggested that both the gravelly and the clayey tills were deposited by a glacier that flowed in a westerly direction from the eastern mountains during the Late Weichselian. This suggestion was also supported by observations on Karmøy (Ringen 1964), and by other observations on Jæren (Feyling-Hanssen 1966, 1971, 1974, Wangen 1968, Østmo 1971, Andersen et al. 1981).

Most of the sub-till marine deposits were

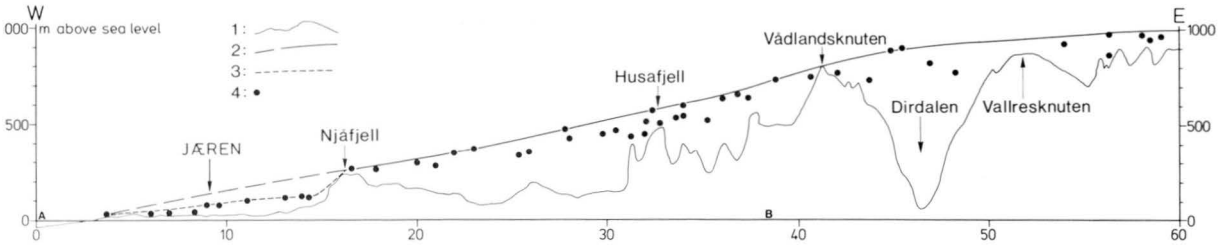


Fig. 3. East-west profile of the land surface between Jæren and Ryfylke (see Fig. 2). (1) Observed surface. (2) Reconstructed old surface (the Precambrian peneplain). (3) Reconstructed young erosion surface (coastal plain). (4) Altitude of the highest-lying summit within narrow belts on both sides of the profile.

supposed to represent a Sandnes interstadial of Middle Weichselian age, but some of them could represent older Weichselian interstadials and stadials (Feyling-Hanssen 1974, Østmo 1971, Andersen et al. 1981), and deposits at Reve and Grødeland could be of Eemian age.

Late Weichselian end moraines on Jæren have been described in particular by Wangen (1968), Østmo (1971), and Klemsdal (1969). They all indicated that remains of the Lista end moraine lie along the shore of southern Jæren. Moraines observed by Østmo and Wangen are shown in Plate 1, see the discussion in a following chapter.

The Late Weichselian and Holocene shore features have been studied by many scientists (Holmboe 1901, Øyen 1903, Bjørlykke 1908, Reusch 1907, Danielsen 1912, Hansen 1913, Holmsen 1922 and Fægri 1939–1940). They

observed that the highest-lying Late Weichselian shore levels rise from about 6 m - 8 m on southern Jæren to 22 m - 26 m on northern Jæren. The *Tapes* level, which represents the warmest Holocene phases, rises from about 6 m - 8 m to 8 m - 10 m between southern and northern Jæren.

Thomsen (19829) constructed a shore-level displacement diagram for northern Jæren on the basis of diatom analyses, pollen analyses and radiocarbon dates of sediments from several lakes. The most striking feature in this diagram is the transgression near the Alleröd – Younger Dryas transition.

Holmboe (1901) and Fægri (1939-1940) recorded *Tapes* transgressions, and the warm-water *Tapes* fauna was studied in particular by Øyen (1903), Bjørlykke (1908) and Danielsen (1912) (see Table 2).



Fig. 4. A typical Jæren landscape near Nærbø. The rise towards Høg-Jæren lies in the background. The boulders in all of the walls come from a very bouldery Late Weichselian till which covers most of Jæren.

Peat deposits in bogs were described by Holmboe (1901, 1903), Holmsen (1922) and by Fægri (1939-1940). On the basis of pollen analyses Fægri outlined the Late Weichselian and Holocene vegetation and climate. Later, Chanda (1965) restudied the Brøndmyra bog profile and presented a new revised diagram which included several radiocarbon dates. In a study of cores from lakes on northern Jæren Thomsen (1982) found a zonation similar to the one presented by Chanda (see Fig. 27).

Morphostratigraphy (end moraines)

The Stavanger map-sheet (Fig. 1) also covers parts of the North Sea to the south and west of Jæren, but no mapping of the sediments on the sea floor was attempted. Rough information about the sediments is presented on the fishery charts, and the sea-floor topography is known through echo-soundings carried out by the Norwegian Hydrographic Service (NSKV). The unpublished results (in 1974) of these soundings were used to draw the isobaths of parts of Plate 1. On the basis of the mentioned information, some general conclusions were drawn about the formation of several submarine features. This has also been done for parts of the North Sea floor adjacent to the Stavanger map-sheet, in order to give a more complete picture of the morainal sequence.

The North Sea moraines of early Late Weichselian age

A series of nearly parallel, low ridges lie in a broad zone to the south of the Norwegian Channel. A hummocky topography with closed depressions exists in connection with parts of the zone. Many depressions resemble kettle holes and the topography resembles that of end moraine zones. In contrast to this topography, there are plains on the sea floor to the south of the zone. Not all of the closed depressions need necessarily be kettle holes; nor need all of the ridges be end moraines. Some of the small depressions could be pockmarks and some of the shallowest depressions could be lagune depressions formed by shore activities, and the smallest ridges could be beach ridges or current ridges (sand waves). However, the large size and the shape of many ridges together

with the general morphology including several deep depressions, indicate that this is a morainic topography which, to a considerable extent, has been modified by marine wave abrasion as the sediments passed through the shore zone. The fishery charts show that the sea floor in many of the areas with the most typical morainic topography is partly covered with stones. These stones are not derived from local bedrock outcrops, since the bedrock lies below a thick section of Quaternary sediments. Some of the stones are undoubtedly ice rafted, but the patterns of the stony sea floor indicate that this is probably not the case for most of them.

Some of the main ridges which were interpreted as end moraines are shown on Plate 1, and they are briefly described in the following. Review maps of suggested end moraines in the North Sea area were presented by Andersen (1979, 1981); they are to a considerable extent based on our observations.

The Monkeybanke moraines

Pratje (1951) suggested that the broad ridge at Monkeybanke to the south of Lille Fiskebanke is an end moraine, and he indicated that it could be of Warthian age. However, Valentin (1958) suggested that the Weichselian Maximum ice border was located to the south of Monkeybanke and continued across Doggerbanke to England.

The Lille Fiskebanke moraines

The southernmost 'sharp' ridge on the floor of the North Sea is the one which crosses Lille Fiskebanke. Since this ridge is aligned with the oldest Weichselian end-moraine ridge on Jutland in Denmark, the two ridges very likely correspond. Therefore, the Lille Fiskebanke moraine could represent the oldest Weichselian end moraine, see Figs. 1-7 in Andersen (1981). A plain to the south of the moraine, about 40 m above sea level, grades into lower-lying plains, and they were all interpreted to be outwash plains modified by wave abrasion.

The Ytterbanke and the Egersundbanke moraines

To the north of Lille Fiskebanke, there are two parallel, long main ridges near Ytterbanke, and two main ridges near Egersundbanke. These ridges are considered to be end moraines, or remnants of end moraines that have been more or less reworked by wave abrasion. Smaller ridges which are not marked on the map in

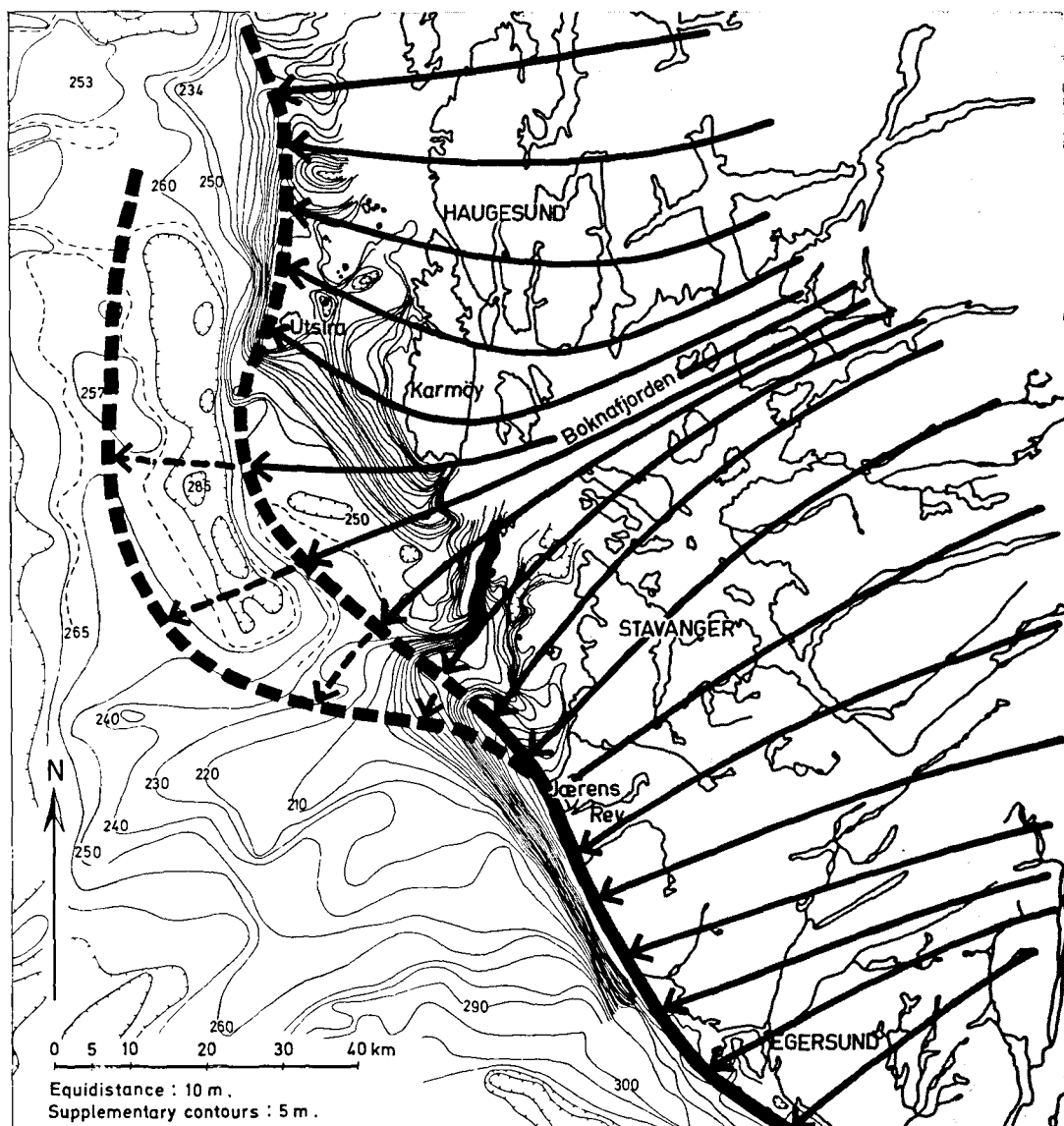


Fig. 5. Southwestern Norway during the Lista glacial phase.

Plate 1 also exist, and they could be of morainic origin, but they could as well be beach ridges, tidal sand banks or large sand waves.

Moraines on Jæren and adjacent mountain districts

The deep Norwegian Channel lies between the North Sea end moraines and the coast of Norway. Most probably the ice front retreated very quickly across this channel and halted at the

edge of the shallow shelf off the Norwegian coast where the large Lista moraine is located. This end moraine lies along the outermost coast at Lista and can be traced as a submarine ridge on the shallow shelf towards Jæren (Andersen 1960, Klemsdal 1969). Earlier, Bjørlykke (1908) indicated that the hills and ridges along the coast of Jæren could be remnants of an end moraine, and Grimnes (1910) considered them to be an end moraine, while Hansen (1913, p. 113) thought that they were more likely rem-



Fig. 6. Remnants of the Lista ice-marginal deposits at Horr, looking NNW. The hills in the background represent proximal remnants of the moraine. Notice the break at the foot of the hills, about 8 m above sea-level. The break represents the highest-lying marine shore-line (ML).

nants of a median moraine or drumlin deposited by the Skagerrak glacier.

Klemsdal (1969) described the end moraine on Jæren in more detail. He correlated the moraine with the Lista moraine, since he was able to trace the submarine ridge almost continuously from Jæren to Lista. Klemsdal suggested that the end moraine continued across a submarine threshold between Jæren and Karmøy, to the north of Jæren. However, no corresponding end moraine has been found on Karmøy. Therefore, the Lista moraine more likely continues along one or both of the submarine ridges to the southwest of Karmøy, as indicated by Østmo (1971) (Fig. 5). The two ridges are aligned towards the area to the west of Sotra Island where the large ridge shown on the sparker profile in Plate 1 is located, and Flodén and Sellevoll (1972) indicated that the ridge on this profile could be an end moraine corresponding with the Lista moraine. The Lista moraine, between Reve and Brusand on Jæren, forms no continuous distinctive ridge. Two small islands, both called Rauna (bouldery islands) which lie at Brusand and Obrestad represent the bouldery crest of the ridge. The other segments of the moraine are low hills and ridges with a direction parallel to the coast, i.e. at right angles to the direction of the ice flow. Wave abrasion along the hills and ridges has formed steep cliffs behind the shore zone, itself strewn with large erratics (Fig. 6) which are the remains of the distal parts of the moraine. The surviving hills

and ridges are just remnants of the proximal part of the end moraine. At several places the original moraine has been completely levelled by marine abrasion, and in a few places the levelled parts have been covered with Holocene sand, for instance near Orre.

Most parts of the shore zone between Reve and Brusand however, are covered with large quantities of big erratics, and this zone lies in striking contrast to the shore zones to the north of Reve and to the south of Brusand where there are few erratics and much sand.

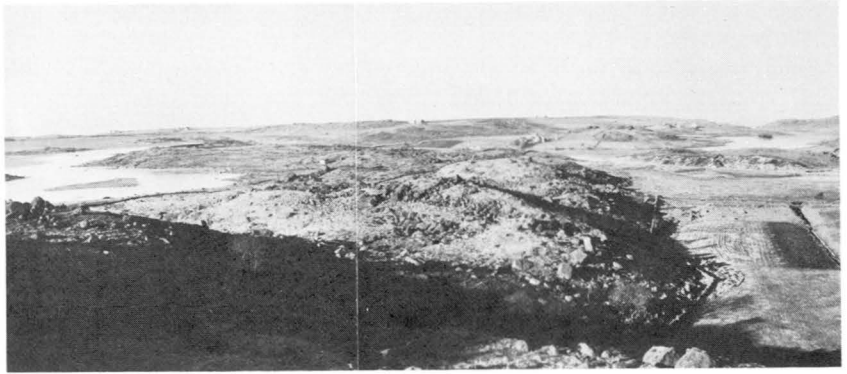
No accurate dating has been carried out of the Lista moraine. However, at Brøndmyr near Reve, about 5 km from the end moraine on the proximal side, there is a bog with Oldest Dryas deposits at the base. They were radiocarbon dated at $13\,000 \pm 4\,500$ years B.P. (T.-149A) and $13\,150 \pm 300$ years B.P. (T.-149B), Chanda (1965). A corresponding age was obtained for the base of the organic deposits in lakes on northern Jæren (Thomsen 1982). Hence the Lista event is most likely older than 13 000 radiocarbon years B.P., and an age somewhere between 13 000 and 13 500 ^{14}C years B.P. seems most likely. This agrees well with suggestions made by Andersen (1960), Klemsdal (1969) and Østmo (1971).

The Mosevann - Lutsi moraines (Plate 1).

Scattered end moraines have been found on Jæren and in several of the valleys which lead eastward from Jæren to the mountains. Most of the moraines are small and indistinctive, and they may have been deposited in association with stagnant ice. Therefore, they do not necessarily correspond with climatic fluctuations. No distinctive marginal moraines have been seen in the mountains between the valleys, which makes correlation of the moraines difficult. However, most of the end moraines fit into a pattern of four moraine zones.

No precise dating of the moraines have been carried out, but they must be older than about 12 200 years B.P. (see p. 10) and younger than the Lista moraines (13 000 - 13 500 years B.P.). This indicates that the moraines were most likely deposited during the relatively warm Bølling chronozone (13 000 - 12 000 years B.P.), and most of Jæren and the districts between Jæren and Lysefjord were probably deglaciated in that period.

Fig. 7. The Mosevann moraine at lake Storamos, looking north with the lake to the left.



The Mosevann moraines

Several moraine ridges on Høg-Jæren represent the Mosevann moraines. They lie about 250 m above sea level to the west of lake Storamos (Fig. 7) and were first identified and described by Grimnes (1910). The ridges are 5 m to 20 m high and form a 4 to 5 km long arc. They consist of till rich in gravel and boulders, and of a faintly stratified bouldery gravel. An area with a typical hummocky dead-ice topography (see p. 24) with hills and ridges of gravelly till and boulder-rich glaciofluvial gravel, lies on the proximal side of the moraines. On the distal side, to the west of the end moraine, there is predominantly a thin cover of boulder-rich till on top of a clayey till. The Mosevann Moraines and the hummocky zone have a rather distinctive southern limit along a long East-West oriented moraine ridge at Flåta. This moraine was most likely deposited during a late phase of the Mosevann glacial phase, between a stagnant glacier on the Mosevann plateau and a moving (surging?) glacier in the lowland to the south of the plateau.

The Kartavoll moraines

A sharp ridge, about 19 m high and 1 km long, lies across the valley floor at Kartavoll near the eastern end of lake Storamos. The alignment of the ridge is transverse to the former ice-flow direction. Gravelly till and numerous large erratics cover the surface of the ridge which has a steep proximal (east) side and a more gentle distal side. A small lateral moraine ridge on the valley side to the east of Kartavoll probably corresponds with the Kartavoll ridge.

Other moraine ridges which are probably end moraines corresponding with the Kartavoll moraine have been found in three valleys to the

north of Kartavoll. They lie at Tjalandsvann, in the northern end of Taksdalsvann and at Foss-Eigeland.

The Bue moraines

Marginal moraines in four valleys have been correlated with the Bue moraine (Plate 1). The moraines will be described in order from south to north.

About 8 km to the east of the Kartavoll end moraine, lake Røyslandsvannet is divided into two parts by a distinctive ridge which rises about 5 km above the water level. The ridge crosses the floor of the valley and grades into an about 100 m long lateral moraine on the southern side of the valley. Within the next valley north of Røyslandsvann, a similar ridge divides Kydlandsvann. This ridge rises 15 m above the water level and has a typical curved shape, with the concave side facing east.

Two parallel north-south oriented end-moraine ridges lie near the northern side of the valley to the east of Myravann, 2 km south of Ædlandsvann. At Espeland in the Bråstein Valley, between Bråsteinsvann and Sviland, several morainic hills and kettle holes lie in a zone across floor of the valley. A gently inclined lateral-moraine ridge on the eastern side of the valley leads down towards the zone, which must represent deposition at a stagnant ice front. Large terraces with sand and gravel which lie in contact with this zone, on the distal side, were deposited in a small ice-dammed lake in front of the glacier (Fig. 22).

The Lutsi moraines

End moraines and ice-front deltas that are correlated with a Lutsi Moraine have been found

at four localities which will be described in the order from north to south:

A distinctive ridge about 12 m high separates the lake Lutsivann from the lake Dybingen, about 6 km east of Sandnes (Plate 1). The ridge is curved with the concave side facing towards the northeast, and it has a flat summit. An exposed section through the ridge reveals a deltaic structure with topset beds and south-dipping foreset beds of sand and gravel with some boulders. There are more boulders, and the sorting is poorer near the ice-contact (northeast) side of the ridge which is interpreted as a small ice-front delta. A sharp moraine ridge of mainly large boulders is located at the foot of the valley side to the south of Augeland Farm, about 4 km west of lake Tengedalsvann. The direction of glacial striation is here towards the south, at right angle to the moraine ridge, which is considered to be an end moraine. Lake Svihusvann is dammed at its southern end by a low ridge. Gravel with boulders is exposed at the surface of this ridge.

A broad curved end-moraine ridge crosses the valley floor at the southern end of the lake Oltedalsvann (Fig. 8). The ridge is up to 30 m high and consists of a very bouldery till. Both the shape and the location of the ridge indicate that it is an end moraine deposited by a glacier which flowed in a southerly direction.

The Lysefjord moraines

Distinctive marginal moraines in the fjords immediately to the east of the mapped area represent the Lysefjord moraines (Andersen 1954, Anundsen 1972), see Pl. 1. Some of the largest Lysefjord moraine ridges lie at the mouth of Lysefjord about 5 km to the east of the eastern border of the Stavanger map-area. Andersen (1960) was able to trace corresponding marginal moraines eastward across the mountain districts of southern Norway to the well known Ra end moraines in eastern Norway, which have been radiocarbon-dated at 11 000 to 10 500 years B.P. (Andersen 1979, Sørensen 1979).

The senior writer (unpublished) found shells of mainly *Mytilus edulis* in flat-lying beds of marine silt and clay below about 8 m of outwash sand and gravel in an outwash delta near the mouth of Lysefjord. The delta plain, 38 m - 40 m a.s.l., lies in contact with the Lysefjord end moraine which is located about 1200 metres from the fossil locality. Both the delta plain and the outwash correspond with the moraine. A

radiocarbon date at $12\,200 \pm 150$ years B.P. (T-2467) of the *Mytilus* shells show that the ice front had retreated to the mouth of Lysefjord as early as in late Bølling time, and the Lysefjord moraine must be younger than Bølling.

The Ryfylke moraines

About 20 km to the east of the Lysefjord moraines in Ryfylke, there are the ridges of the *Trollgaren moraines*. These ridges are very sharp, but generally small (Andersen 1954). Anundsen (1972) traced moraine ridges corresponding with the Trollgaren moraines into the mountain districts of northern Ryfylke. He found a series of marginal moraines a short distance to the east of the Trollgaren moraines too. They were called the Blåfjell moraines. Even to the east of the Blåfjell moraines there are some small marginal moraines, according to Anundsen (1972). Therefore, in Ryfylke, there is evidence of three marginal moraine phases which are younger than the Lysefjord moraines. They have not been dated, but they are most likely of late Younger Dryas and/or Preboreal age. Moraines that probably correspond with the Ryfylke moraines have been found in many areas along the coast of Norway. Numerous radiocarbon dates of these moraines indicate that the ages of most of them are, respectively, $10\,000 \pm 200$ to $9\,900 \pm 200$ years B.P., $9\,600 \pm 200$ years B.P. and $9\,300 \pm 200$ years B.P. (Andersen 1980, 1981).

Direction of ice flow

It was generally assumed that the Weichselian glaciers covered Jæren and flowed in a westerly direction on southern Jæren and a southwesterly direction on northern Jæren. Both the direction of glacial striation and the transport of erratics proved this assumption. In addition, most scientists thought that the glacier during the Saalian Glaciation followed the deep Norwegian Channel along the south coast of Norway and transported a clayey till from the North Sea on to Jæren. This till covers a considerable part of southern Jæren and it was called the 'Skagerrak till'. Scattered far-transported erratics from the Oslofjord area and the Baltic region were found in the 'Skagerrak till', but no glacial striation from the postulated 'Skagerrak Glacier' was ever found on Jæren.

Our fieldwork aimed at finding the direction of the former glacier flow by means of glacial

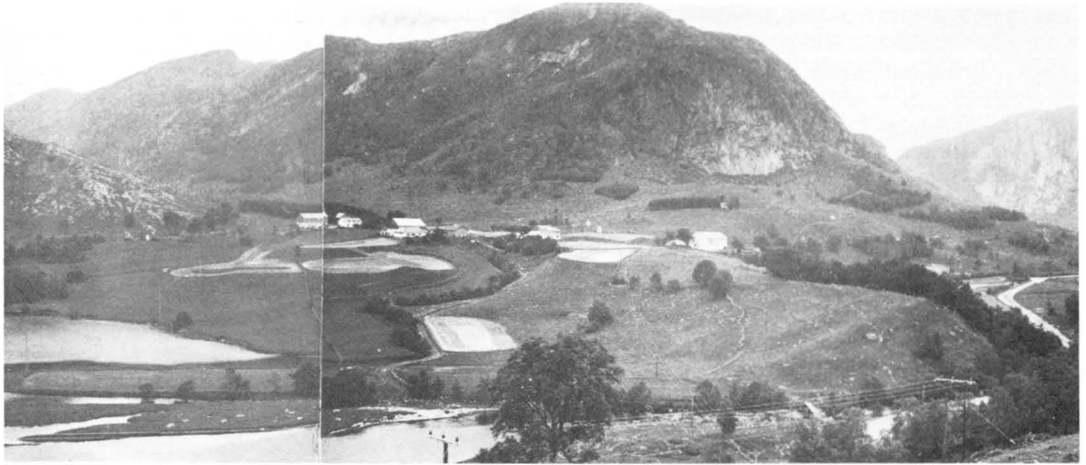


Fig. 8. The end moraine at the southern end of lake Oltedalsvann, looking east from the western part of the moraine ridge.

striation, glacially sculptured rock surfaces, till fabric analyses and pebble counts. Particular attention was given to finding evidence for the postulated 'Skagerrak glacier'. Since considerable parts of Southern Jæren have a cover of 'Skagerrak till', it ought to be possible to find striations and sculpturing from the corresponding glacier flow towards the north. In addition, fabric analysis and pebble counts within the 'Skagerrak till' should indicate this flow direction.

Glacial striation

Well preserved glacially striated and sculptured rock surfaces exist, particularly on the anorthosite which underlies the Skagerrak till on southernmost Jæren. (Plate 3). However, all the observed features were formed by glaciers that flowed in a westerly (southwesterly) direction. The striation on a rock surface that underlies the old Foss-Eigeland (Figgjo gravel) delta (Fig. 28) has the same westerly direction. This striation is older than the Late Weichselian maximum. Despite a careful search, no evidence was found of a northerly flow direction.

The only northerly oriented striations described from the coast near Jæren were found on the island of Utsira, west of Karmøy, Figs. 1 and 5. This striation was generally believed to have been formed by the 'Skagerrak glacier' during the Saalian glaciation (Holtedahl 1953, p. 596). Undås (1948) observed a striation direction towards 295° - 320° on western Utsira and towards 345° - 325° on eastern Utsira. The till

and the erratics on Utsira were so little weathered that Undås assumed that the 'Skagerrak glacier' covered Utsira and Jæren during the Weichselian Glaciation. The observations made by Undås correspond well with observations carried out by the writers during a reconnaissance study at Utsira. Both the sediments and the surfaces of erratics and exposed bedrock were as little weathered as they are in adjacent areas which were undoubtedly covered by the Weichselian glaciers. On the southwestern part of Karmøy the writers observed a very fresh glacial striation and roches moutonnees oriented towards 285° - 310° . The striation is, without doubt, of Weichselian age, and it seems likely that it was formed by the same glacier as the striations on Utsira. In that case both striations were most probably formed on the northern flank of a large Ryfylke glacier that occupied Boknafjord, as indicated by Andersen (1964), see Fig. 5. Glacial striation in a northerly direction was recently observed by the senior writer at Nygaard and Bø on northeastern Karmøy. The striation occurs in connection with a till of the Karmøy stadial (p. 51), and it was correlated with phases of this stadial. Striations in westerly and southwesterly directions were correlated with other phases of the Karmøy stadial. The striations most likely represent relatively local ice-flow directions, and the northerly oriented striation was probably formed on the northern flank of a Ryfylke glacier. In an area to the east of Karmøy a set of old striations in a northwesterly direction was observed by Anundsen (1977).

Till fabric analyses and pebble counts

Altogether 30 till-fabric analyses and 41 pebbles counts carried out within the 'Skagerrak till' on Jæren clearly show that this till was deposited by a glacier which flowed in a westerly direction, parallel with the direction of the glacial striation in the same area (see Plates 3 and 6) and the discussions in the following chapters. All of our observations therefore show that the 'Skagerrak till' was not deposited by a northerly flowing 'Skagerrak glacier'. Both the gravelly and the clayey tills, which form the upper till sheet on Jæren, were deposited by a glacier which flowed in a westerly direction from the mountain districts which lie to the east of Jæren. The dates (p. 38) of shell fragments from the till suggest that this happened after the Middle Weichselian, i.e. in Late Weichselian time.

At locality no. 2 (Plate 4) on Eigerøy to the south of Jæren, Garnes (1976) found a south-southwest and a south-southeast pebble orientation in an old and a younger till bed respectively. Both beds overlie marine sediments supposed to be of Middle Weichselian age. The writers have found no evidence of a corresponding south-southeast glacial flow-direction on southern Jæren. Therefore, this direction at Eigerøy is most likely of more local origin.

The direction of the glacial striations and the pebble orientations observed by the writers within the tills are plotted on Plate 3. They are at right-angles to the coastline on southern Jæren, and towards southwest on northern Jæren. Evidently the Ryfylke glacier that occupied Boknafjord must have been very dominant and forced the ice in a southwesterly direction on northern Jæren (Fig. 5). Along parts of Gandafjord, the striation direction is even towards the south. Crossing striations were found at several localities to the east of northern Jæren. There, the youngest sets are oriented towards the south. Some of the striations in these areas even point in a south-southeasterly direction. Many of the south and south-southeast oriented striations must have been formed very late when the movement of the glacier was much influenced by the local topography. However, they indicate also that the Ryfylke glacier in Boknafjord forced the ice towards the south during relatively late phases of glaciation.

The direction of the glacial flow at right-angles to the coastline on southern Jæren and southeast of Jæren corresponds well with the

general inclination of the land surface. In addition, this direction is at about right-angles to the Lista end moraine, which is almost parallel with the coastline. Some of the observed till fabrics in southern Jæren, where the coastline is north-south oriented, show a more north-westerly pebble orientation. This is the case in the gravelly till at Refsland (Plate 3, no. 22), and in the lowermost part of the clayey till at Stavnheim (Plate 3, no. 15). The preferred pebble orientation in the upper part of the till at Stavnheim is virtually due west. This indicates that the glacier on southern Jæren moved towards the west-northwest in an early phase and towards the west in a later phase, which very likely corresponds with the Lista moraines.

The deposits

Methods and general results

Fabric analyses

Altogether 70 fabric analyses were carried out. During the early phases of our studies the analyses were used mainly to find the flow direction of the glacier which deposited the very clayey till, the so-called 'Skagerrak till'. However, soon the analyses were extended to most types of glacial deposits, and they proved most useful in characterizing the deposits.

Fabric analyses have been described and discussed in numerous publications, particularly in the ones dealing with the lodgement till. The analyses show that the long axis (*a*-axis) of rock fragments in a lodgement till generally has a preferred orientation parallel to the ice-flow direction, and a preferred plunge against the ice-flow direction. In addition, most of the middle axes (*b*-axes) of flat stones are horizontal or fairly horizontal (*c*-axes nearly vertical or plunging steeply in the ice-flow direction).

For most of the fabric analyses which were carried out on Jæren, rock fragments between 1 cm and 10 cm long were used. No fragments exposed on vertical surfaces were sampled, to avoid overrepresentation of fragments oriented at right-angles to the surfaces. A test analysis on two vertical ditch-walls which crossed each other at right-angles clearly showed that the possibility for such an overrepresentation is real, when only rock fragments exposed on the walls are sampled.

All of our analyses were carried out at least 1 m below the top surface, which is below the

most active, frost-disturbed zone. Three oriented samples of clayey tills were analyzed in the laboratory, using the standard technique for grains smaller than 1 cm (Karlström 1952).

Rock fragments with their long axis (a-axis) at least twice as long as the intermediate axis were used for the fabric analysis, and notes were made about the shape of most of the sampled fragments. Our notes showed that the most elongated fragments are generally best oriented parallel with the ice-flow direction. Since all of the sampled fragments are well elongated the orientation picture frequently became clear even with a few fragments sampled. Generally only 30 to 50 fragments were sampled, but as many as 100 fragments were sampled in some cases when the orientation picture was less clear. Some analyses were not completed, generally because the available number of acceptable rock fragments was too low.

Andrews et al. (1979, p 521) tested the fabric method by measuring different numbers (N) of stones. Applying statistical treatment to the results they arrived at the following conclusion: "with N = 25 the main characteristics of the sample distribution are present, and that increasing N to say 100 does not reduce or increase the spread of data. Increasing N will result, however, in a smaller standard error". Harris (1969) presented a graph showing the relation between number of pebbles measured and the observed frequency in the 'modal class' needed to give a significant orientation strength.

A selected number of the most characteristic rose diagrams and Schmidt nets are presented in Figs 9 and 10. The rest of the 70 diagrams are filed at N.G.U. All analyses with significant orientation strength have been specially marked. Analyses where no significant orientation strength was obtained cannot be accepted as good indicators of specific transport directions. However, many of these analyses too are of considerable interest since they can characterize the environment during deposition.

All plunge-angles were measured to the nearest 10°, and angles less than 4°-5° were considered horizontal. Angle steeper than 60° were considered vertical. No contouring was carried out on the Schmidt nets since each analysis was based on relatively few measurements.

GENERAL RESULTS

The results of the fabric analyses show some general trends which to some extent are related

to the origin and lithology of the deposits. The analyzed deposits were divided into 7 groups.

(I) Glaciomarine clays.

Relatively few rock fragments were found in the well exposed supposedly autochthonous glaciomarine clays. Therefore only one analysis was carried out in such clays, and that was in the lower part of the *Portlandia (Yoldia) arctica* clay (Zone I) in the Graveren clay pit at Sandnes (loc. 305). All together 40 acceptable stones were measured in this clay, and the orientation pattern obtained corresponds well with the results of reconnaissance observations made in other glaciomarine clays on Jæren. Many rock fragments with steeply plunging a-axes and a random horizontal orientation pattern of the a-axes seem to be typical. The high number of steeply plunging a-axes may seem surprising since it is well known that elongated pebbles drop through the water and reach the floor generally with nearly horizontal a-axes. In a test which we carried out using 200 selected pebbles of various shapes, but all with a-axes about twice as long as the b-axes, more than 95% reached the floor with nearly horizontal a-axes (less than 15° angle). Therefore, the many pebbles with steep a-axes in glaciomarine clays most likely received their orientation after they reached the sea floor. They could have been tilted when they sank into the soft clay, or when the clay was compacted, or they could have been tilted when icebergs ploughed into the clay.

(II and III) Very clayey subglacial till.

Marine molluscs and foraminifera found in the very clayey tills show that they are in part redeposited marine clays, and in many cases they could equally well be classified as tectonized glaciomarine clays. The fabrics of these sediments vary considerably. Most of them showed excellent preferred pebble orientation, good pebble imbrication, no, or maximum 2, clasts with vertically oriented a-axes, and many with horizontal b-axes. However, some of the fabrics are almost identical to the fabric observed in the glaciomarine clay, for instance, loc. nr. 81 and 46 in Fig. 9.

(IV) Subglacial till with 15% to 5% clay.

Most of the tills within group IV are very hard and compact and they are most likely lodgement tills. The pebble orientation in the tills of this group is usually very good, and most

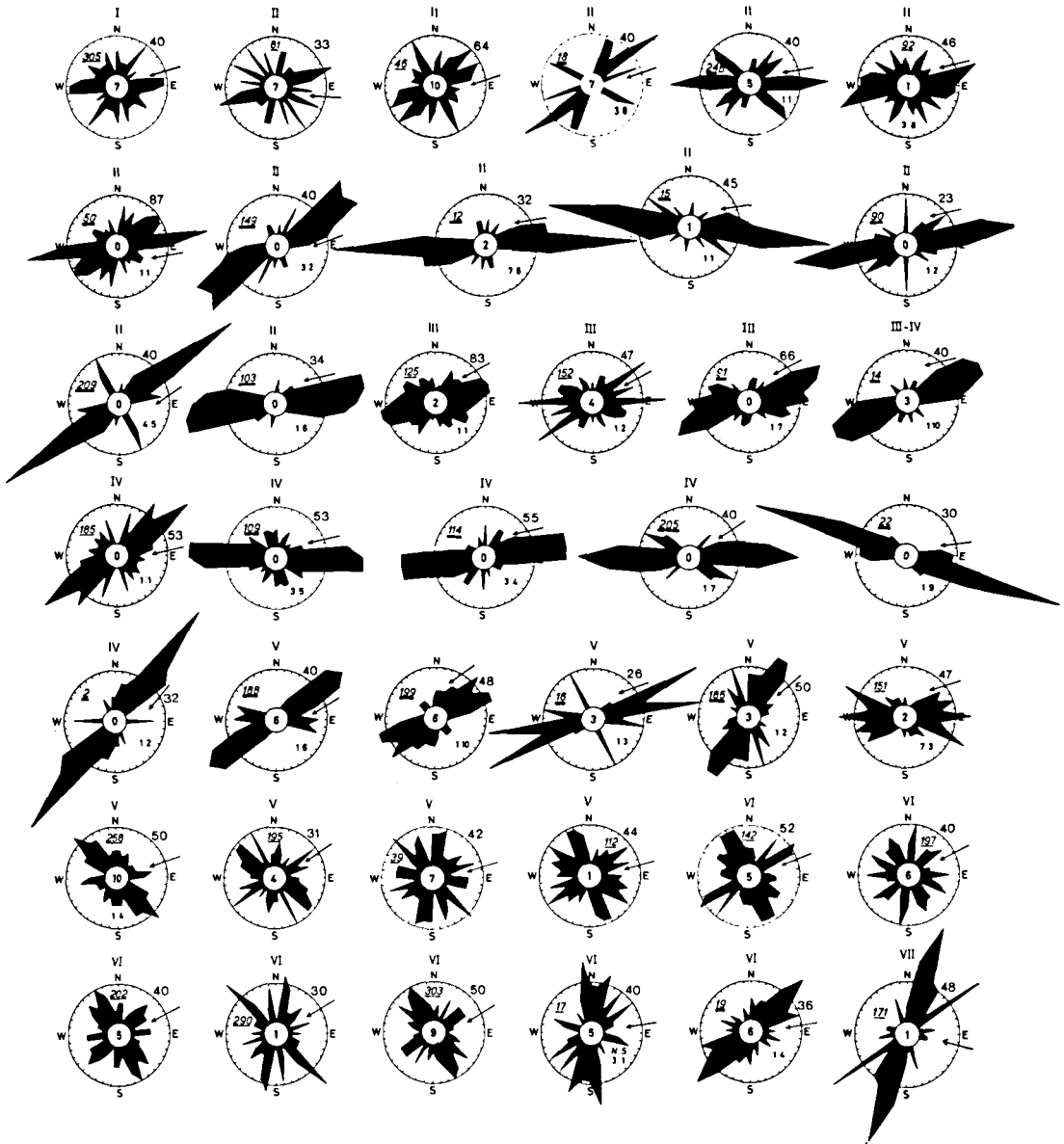


Fig. 9. Fabrics of tills, glaciomarine and glaciofluvial deposits. I: Glaciomarine clay. II, III, IV: Clayey subglacial tills with respectively more than 30% clay, between 30% and 15% clay and between 15% and 5% clay. V: Gravelly subglacial till, with less than 5% clay. VI: Gravelly supraglacial (ablation) till. VII: Glaciofluvial gravel. The locality number is underlined and refers to a number in Pl. 4. The heavy line under the locality number indicate that the significance level was reached. The number in the center shows how many long axis plunge more than 60°. The figure at the outer circle represents the number of analyzed clasts. The ratios (1:3 etc.) are those between westerly and easterly plunging long axes. The small arrows represent the general trend of glacial striation at or near the locality. Clasts with a long axis of more than 20 mm long were measured, except for analysis nr. 15 which is a 'microanalysis'.

analyses lie well within the significant orientation strength. Other characteristics of the fabrics are: they have in general (1) no, or very few vertical or steeply inclined a-axes, (2) a preferred plunge of the a-axes against the ice-flow

direction, (3) most b-axes of flat pebbles are nearly horizontal (c-axes nearly vertical), (4) a small peak of transverse a-axes of pebbles which commonly have steeply inclined b-axes.

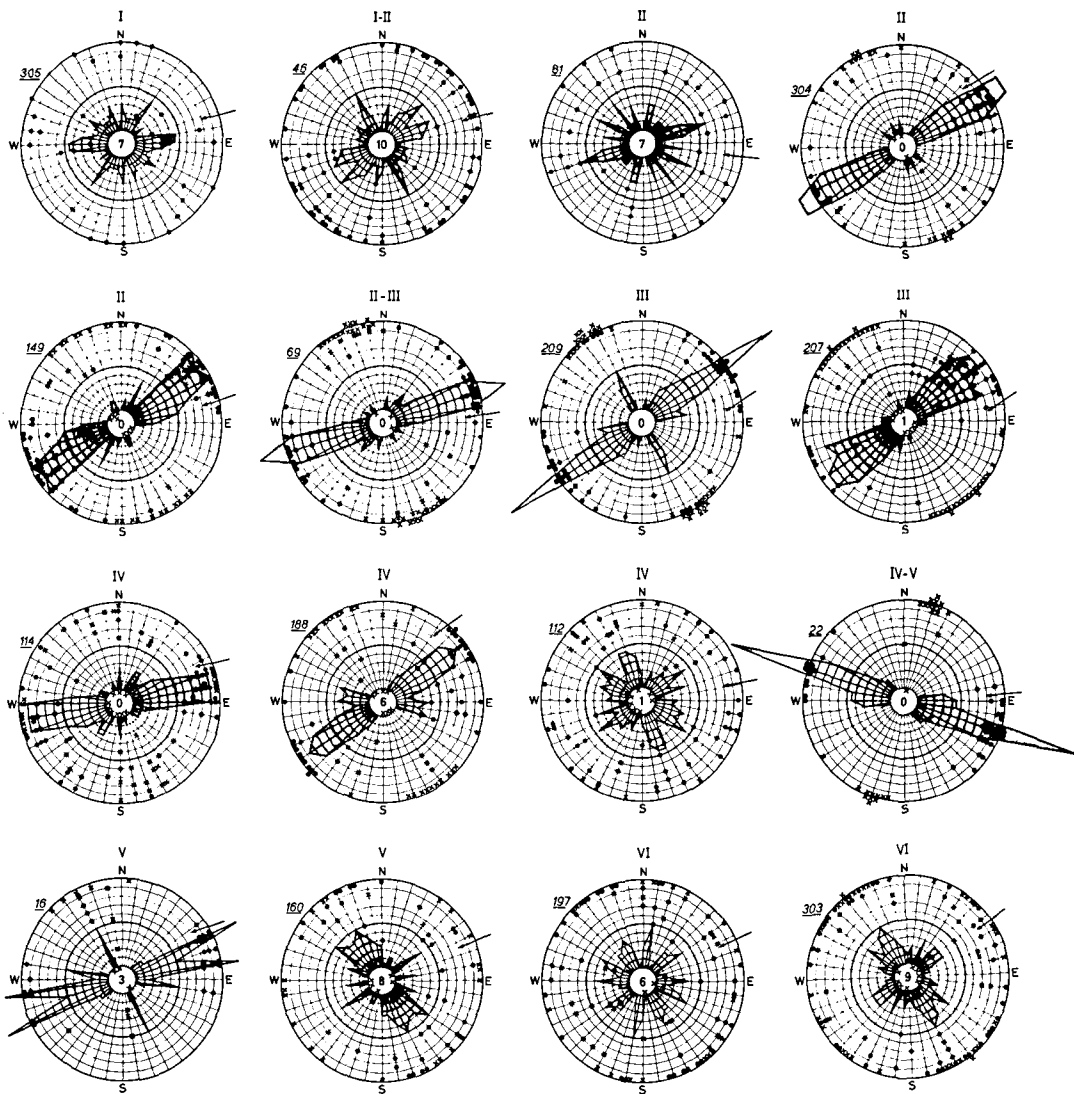


Fig. 10. Schmidt nets (lower hemisphere) and rose diagrams for some typical fabrics. See explanation in Fig. 9. Dot: Intersection by long (a) axis X: Intersection by median (b) axis of flat stones.

(V) The very gravelly subglacial till.

Most of the very gravelly subglacial till was considered to be lodgement till. However, in some cases this till could be a mixture of melt-out till, flow till and lodgement till. This is reflected in the results of the fabric analyses (Fig. 9). Only 30% of the analyzed fabrics showed a good orientation of the a-axes with a significant orientation strength. The pattern of the pebble orientation for the rest of the fabric analyses varies between weakly preferred orientation parallel with the ice-flow direction and a

preferred orientation more or less transverse to the ice-flow direction. A high number of steeply inclined a-axes and b-axes is characteristic for several of the fabrics, which resemble the fabrics of group VI. Therefore, some of the suggested gravelly subglacial tills could be supraglacial melt-out tills.

(VI) The gravelly supraglacial (ablation) till.

The fabrics of most of the analyzed gravelly supraglacial tills are characterized by (1) ran-

dom or a weakly preferred orientation, without significant orientation strength, (2) orientation transverse to the ice-flow direction is as common as orientation parallel with this direction, (3) relatively many pebbles have vertical a-axes and b-axes.

(VII) Glaciofluvial sediments.

Only one fabric analysis was carried out in the glaciofluvial sediments at Jæren, and that was in an esker near Bryne (no. 171). A cobbly gravel was analyzed, and the analysis revealed a preferred orientation of a-axis transverse to the flow direction, indicated by the cross-bedding and the orientation of the esker. The rock fragments had a very marked imbrication, as shown in Fig. 10. According to Reineck and Singh (1980, p. 126) this orientation pattern is the result of periodic water flow on a gentle slope, and this was the most likely sedimentation environment for the esker near Bryne.

Roundness analyses

Several different methods have been developed to analyse the roundness of clasts (Pettijohn 1975). Some of the methods are quick field methods. The easiest method was presented by Reichelt (1961) who used only 4 different roundness classes: well rounded, rounded, edge-rounded and angular. This method has been used by many scientists including Bergersen (1970) who found it fully adequate to characterize the roundness of the pebbles for most purposes. The method was also employed by the present writers. Altogether 350 roundness analyses were carried out in the laboratory, on collected field samples. Each sample was of 100 pebbles which were subdivided into 5 petrographic classes and 3 size classes, A (80 mm - 20 mm), B (20 mm - 4 mm) and C (4 mm - 2 mm). The detailed results of the analysis are presented in tables which are filed at N.G.U. A selected number of the analyses are presented as histograms in Plate 5.

Several different variable factors decide the roundness of the pebbles, such as (1) transport environment, (2) transport distance, (3) petrography, and (4) grain size. They will all be discussed briefly in the following:

(1) Transport environment.

The roundness of the pebbles depends to a considerable degree on the environment in which they were transported (Krumbein 1941,

Kuener 1956, Pettijohn 1975). The roundness of the pebble assemblages in the different types of till (II - VI) varies very little (Plate 5). Pebbles with rounded edges dominate (generally 50% - 90%), and there are usually less than 20% rounded and well rounded pebbles. The last mentioned pebbles were obviously stream-transported before they were incorporated in the till. This is in particular true for the gravelly tills of central Jæren where as much as 30% - 40% of the pebbles in the 80 mm - 20 mm fraction were rounded and well rounded in many samples. They must have been picked up from the glaciofluvial deposits which the glacier overrode. The percentage of angular pebbles varies in general between 5% and 40% in the tills.

Pebbles with rounded edges usually dominate in the glaciofluvial sediments too (generally 40% - 60%), which shows that they are fairly short transported. The percentage of rounded pebbles is usually higher in the glaciofluvial deposits than in the till, generally 20% - 40%, and in some cases as high as 50% - 60%, in the 20 mm - 80 mm fraction. In most cases 10% - 20% well rounded pebbles were found. They were all of hard crystalline rocks which outcrop a considerable distance to the east of Jæren. Relatively few angular pebbles, usually less than 4%, were found in the 20 mm - 60 mm fraction in the glaciofluvial sediments.

The typical roundness assemblages for tills in Jæren can most easily be distinguished from the typical roundness assemblages for glaciofluvial deposits on the basis of the difference in the number of rounded and well rounded clasts in the 20 mm - 80 mm fraction, and in differences in the number of angular clasts. In addition the number of clasts with rounded edges is usually higher in the tills. Bergersen (1970) presented results of roundness analyses carried out in central Norway, and in general they correspond well with the results from Jæren (See also the discussion in paragraph 3).

(2) Transport distance

Experiments and field studies show that the abrasion and rounding of stream transported pebbles is rapid at first but decreases quickly to very low values after a few kilometres (Pettijohn 1975, Reineck & Singh 1980). Therefore, the high number of edge-rounded pebbles in most glaciofluvial deposits at Jæren clearly indicates a very short stream transport. The

roundness of the pebbles in some glaciofluvial sediments is almost identical with the roundness of the pebbles in adjacent tills, which shows that the sediments originate from the till debris, and were transported only extremely short distances with the glacial streams.

Usually 2% to 15%, in some cases as much as 25% well rounded pebbles were found in the glaciofluvial sediments. Most of them are of anatexites which outcrop in the mountains to the east of Jæren, and they could have travelled long distances with the glacial streams.

(3) Petrography

The clasts were divided into 6 classes according to the petrography (Plate 5). Fig. 2 shows that rocks of class 1 and 2 outcrop in the mountains

to the east and southeast of Jæren and rocks of class 3 and 4 outcrop on Jæren. Classes 5 and 6 are of less interest in connection with the roundness analysis.

In general the pebbles of the hard crystalline rocks, anatexites and anorthosites, are much better rounded than the pebbles of phyllites and mica schists (mica gneisses) (Plate 5). This difference is partly the result of differences in the transport distance and partly the result of differences in rock texture and structure.

(4) The size of the clasts

Several scientists studied the relationship between abrasion-rounding and the size of the clasts, and there is general agreement that the abrasion and rounding of stream-transported

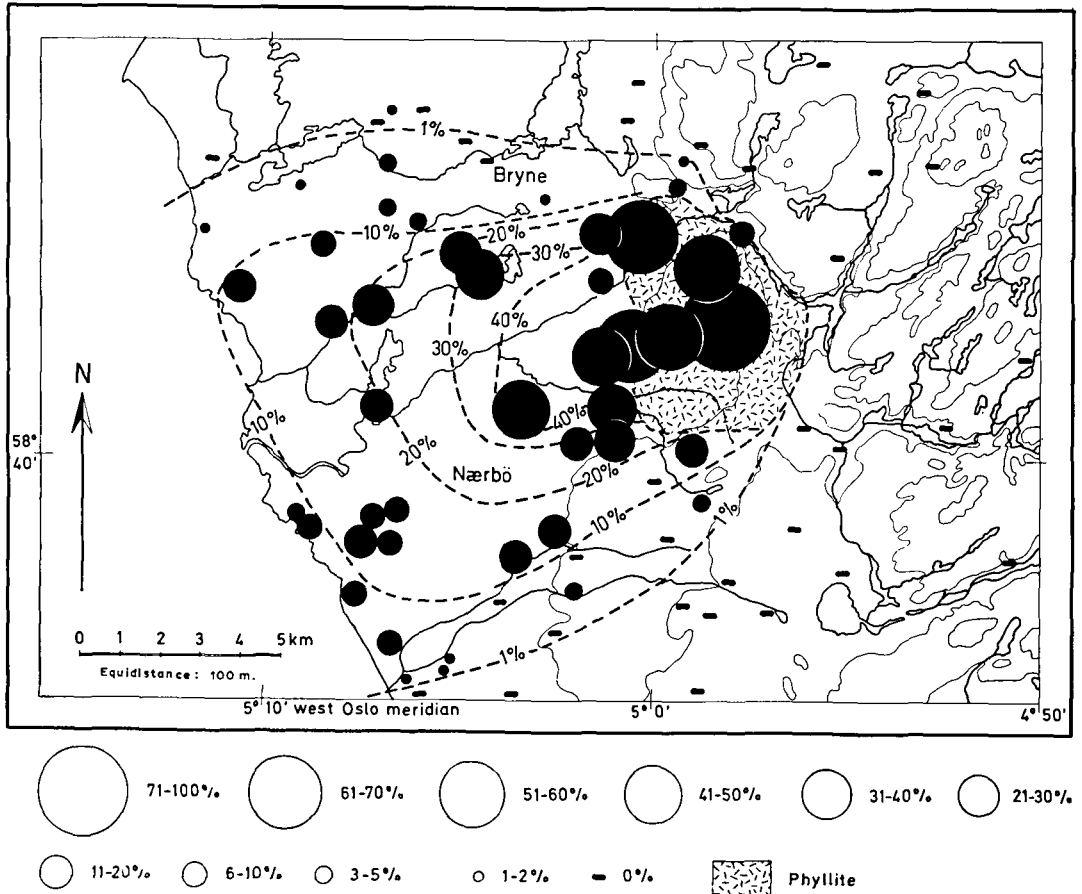


Fig. 11. 'Boulder train' to the west of the phyllite outcrop (shaded area) near Nærbø (see Fig. 2), showing the percentages of phyllite (200 mm - 20 mm) in the till, which is clayey in parts of the area.

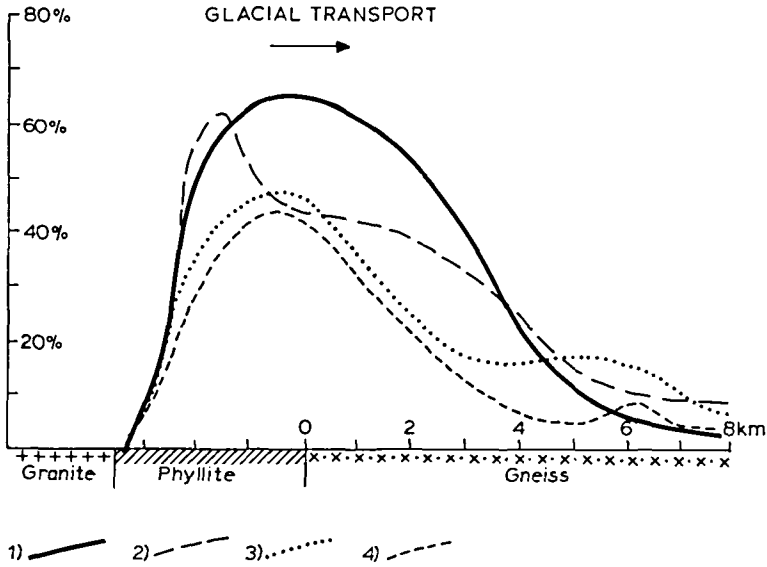


Fig. 12. Percentage of phyllite clasts in the till from an E-W section across the 'boulder train' near Nærbo. (1) in the 200 mm - 20 mm fraction, (2) in the 20 mm - 8 mm fraction, (3) in the 8 mm - 4 mm fraction, (4) in the 4 mm - 2 mm fraction.

clasts increases with the size (Pettijohn, 1975). Plate 5 records the relationship between size and roundness of the clasts at Jæren. The glaciofluvial sediments show a distinctive increase in roundness of the clasts with increasing size, and most of the tills, too, show an increase in roundness with increasing size, but it is less than the increase observed in the glaciofluvial sediments. The percentage of angular clasts in the glaciofluvial sediments decreases with increasing size, which shows that there are more crushed small fragments than large. A similar rule seems to apply for most clayey tills.

Pebble counts

As many as 350 pebble counts were carried out, using 100 pebbles for each count. All pebbles were cleaned and counted in the laboratory. The size of the pebbles was usually between 8 cm and 2 cm, and frequently three size classes were distinguished: 80 mm - 20 mm, 20 mm - 4 mm and 4 mm - 2 mm. The pebbles were divided into the following 5 petrographic classes: (1) Gneisses and granites (Anatexites), (2) Anorthosites, (3) Phyllites, (4) Mica schists and mica gneisses, (5) Rhomb-porphry and other far-travelled erratics. The detailed results of the pebble counts are presented in tables which are filed at N.G.U.

Plate 6 presents a selected number of the most typical pebble counts in the tills, and it gives a picture of the petrographical distribution of the pebbles in relation to the bedrock. Pebb-

les from the local bedrock dominate in all areas, and it is interesting to notice how quickly the petrography of the pebble assemblages changes at the borders of the bedrock outcrops. Figs. 11 and 12 show the changes along an east-west profile, at a small phyllite outcrop on southern Jæren. The percentage of phyllite clasts increases from 0% at the eastern border to 40% - 60% within 2 km from the border, and it drops to less than 10% - 20% within 5 km to the west of the western border. The changes are rapid for all size fractions, but the coarsest fraction changes most. The observations at Jæren correspond well with observations made by scientists in many other areas, i.e. pebbles from the local bedrock dominate in the till in districts which have a relatively thin cover of drift resting on bedrock (Låg 1948, Lundqvist 1949, Haldorsen 1977, 1983).

The anorthosites and phyllites occur in very limited areas (Plate 6), and pebbles from these outcrops were used as index pebbles. Two pronounced 'boulder trains' were recognized, adjacent to the phyllite and the anorthosite on southern Jæren (Plate 6 and Fig. 11). They both lie to the west of the corresponding bedrock outcrops and thus represent a westward glacial transport. All pebble counts in the very clayey tills of the 'Skagerrak moraine' show the same. Therefore the transport direction for the 'Skagerrak moraine' was not towards the north, as implied by the 'Skagerrak theory'.

Only a small percentage of far travelled erra-

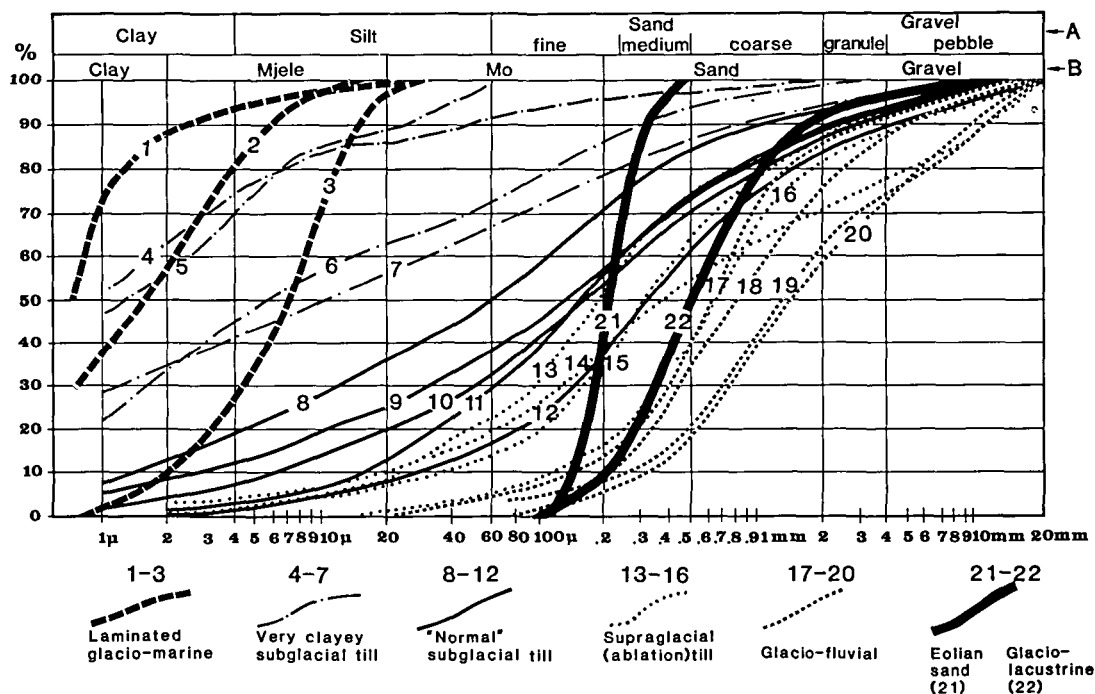


Fig. 13. Selected typical cumulative curves of grain-size distribution in various deposits. Nos. 1-3 Laminated glaciomarine silt and clay. Nos. 4-7 Tills with more than 30% clay. Nos. 8-12 Tills with less than 15% clay. Nos. 13-16 Supraglacial (ablation) tills. Nos. 17-20 Glaciofluvial deposits. No. 21 Eolian sand. No. 22 Sand in glacial lake sediment. 1 (153), 2 (153), 3 (153), 4 (124), 5 (46), 6 (50), 7 (42), 8 (113), 9 (185), 10 (137), 11 (112), 12 (34), 13 (141), 14 (117), 15 (115), 16 (104), 17 (171), 18 (111), 19 (25), 20 (75), 21 (179) and 22 (110). In the parentheses are the locality numbers for the analyzed samples shown in Pl. 4.

tics such as rhomb-porphyrries were found in the deposits on Jæren. No more than 1%, 4% and 6% were found by the writers in the gravelly till, clayey till and the beach deposits. Most of them were probably transported to this coast by ice rafting when the old glaciomarine sediments on Jæren were deposited (p. 33). The same kind of transport took place during the deglaciation period following 13 000 B.P., and ice-rafted rhomb-porphyrries etc. from that period have been found along the entire south and west coast of Norway, even at the Lofoten Islands near the 68th latitude (Holtedahl 1953). The relatively high percentage of far-travelled pebbles in some of the beach deposits at Jæren must be a result of this transport.

The pebble counts were used to characterize the gravels for more practical applications also. In general the gravels with mainly anatectite pebbles are good to excellent for most practical purposes. They are found in the mountains to the east of Jæren and in the eastern part of the Jæren lowland, near the foot of the mountains.

Gravels with mainly anorthosites are medium good to good, but gravels with many phyllite and mica schist (mica gneiss) pebbles are generally of less economical interest. Pl. 6 shows that gravels of the last-mentioned kind are found in connection with all the known outcrops of phyllite, mica schist and mica gneiss. They lie mainly in northern Jæren, to the west of Bryne in central Jæren, and near Varhaug in southern Jæren. Many pebbles of phyllite were found in a limited area at Kvål between Sandnes and Bryne also (Loc. 216, 292, Plate 4). No phyllitic bedrock has been recorded in this area, but our observations indicate that phyllite must underlie the cover of Quaternary deposits there.

Grain-size analysis

Grains smaller than 19.1 mm were analysed using sieves of the U.S. Standard Series for sizes down to 0.074 mm, and the hydrometer method for smaller sizes (Selmer-Olsen 1954). To test the hydrometer method 30 of the samples were analysed by the falling drop method (Moum

1965). For sizes smaller than 2 μm the hydrometer method gave slightly higher values than the falling drop method, but the differences are small, and the inaccuracy introduced by the hydrometer analysis is of no importance for the conclusions drawn in the following.

The size-frequency distribution of the grains was presented on cumulative curves with logarithmic scales for the grain size, and the following parameters were calculated: Median = $M_d = Q_{50}$; Sorting = $S_o = \log Q_{75}/Q_{25}$; Skewness = $S_k = \log (Q_{75} \cdot Q_{25}/M_d^2)^{1/2}$ (Selmer-Olsen 1954, Pettijohn 1975). The parameters mentioned were those most commonly used in Norway when our studies were carried out.

The results of 225 analyses were presented in tables and diagrams which are filed at N.G.U. Some of the most characteristic cumulative weight-percentage curves for various sediments are presented in Fig. 13. The curves for the very clayey tills, with more than 30% clay, show that they must be redeposited glaciomarine or marine clays in which the original grain size distribution has only been slightly altered. For instance, samples no. 4 and 5 contain more than 55% clay and no grades coarser than 0.07 mm and 1.5 mm respectively. This together with the distinctive bimodality of the two samples suggests that the till is most likely a mixture of two populations, a reworked marine clay and marine silt (sand). Most of the tills with a clay content between 15% and 30% too show a distinctive bimodal grain-size distribution, which could be the result of mixing of different original marine deposits, or mixing of gravelly subglacial till with original marine deposits, or it could reflect the original grain-size distribution in glaciomarine deposits.

The tills with less than 15% clay (classes II to V) have grain-size distributions which resemble more normal tills. The total silt and clay content is less than 30% for most of them, and this is normal for Norwegian tills with no matrix derived from marine sediments (Jørgensen 1977).

Some of the tills with less than 15% clay are weakly bimodal, which is normal for subglacial tills. Many scientists have discussed the reason for this bimodality (Lundqvist 1949, Sørensen 1969, Flint 1971, Pettijohn 1975, Dreimanis 1976, Virkkala et al. 1980). Haldorsen (1977) observed that tills which rest on fine grained sedimentary rocks in an area at Mjøsa in eastern Norway have a dominant mode in the silt fraction, and many tills which lie on Precambrian

crystalline rocks have a dominant mode in the sand fraction and a secondary one in the silt fraction. This corresponds well with observations by Jørgensen (1977) who found that Norwegian tills "derived from Cambro-Silurian sedimentary rocks have maximum concentrations in the coarse silt and fine sand fractions, while tills derived from Precambrian crystalline rocks frequently show increasing amounts in increasing grain sizes". Most tills with less than 25% clay at Jæren have their dominant mode within the sand fraction, which could indicate that the matrix was derived from the crystalline rocks. Some of the tills within the phyllite and mica schist areas have a dominant mode within the fine sand fraction and a secondary mode within the silt fraction, which could reflect a mixing of matrix from different parent rocks.

The $M_d - S_o$ diagram presented in Fig. 14 shows that the $M_d - S_o$ values for the deposits on Jæren in general correspond with the zones for genetically different sediments drawn by Selmer-Olsen (1954). Most of the tills of classes III to V (nos. 2 and 3 in fig. 14) lie within the zone for tills. However, many of the clayey tills of class II (no. 1 in Fig. 14) lie within the zone outlined for marine sediments, which again indicates that they are most likely deformation tills or tectonized marine sediments. The supraglacial (ablation) tills are clustered in a zone A between the subglacial tills and the fluvial/glaciofluvial sediments, which was expected. Therefore, zone A is characteristic for the gravelly supraglacial tills. The glaciofluvial sediments lie both within Selmer-Olsen's zone for fluvial sediments, and within the zone for glaciofluvial sediments. This again stresses the problem in distinguishing glaciofluvial deposits from fluvial deposits solely on grain-size analysis.

The median grain-size of the eolian sand lies within the fine to medium sand fraction, and the eolian sand is the best sorted sediment at Jæren, with $M_d - S_o$ values well within the zone outlined for this sediment (Figs. 13 and 14).

The median grain-size of the glacio-lacustrine bottom-set sediments generally lies within the sand fraction, and the sorting is slightly poorer than for eolian sand. Clayey and silty glacio-lacustrine sediments are rare, since most of the glacial lakes were rather small.

The quality of the sediments for economical use depends to a considerable degree on the grain size, which was one of the reasons for the numerous grain-size analyses which were carried

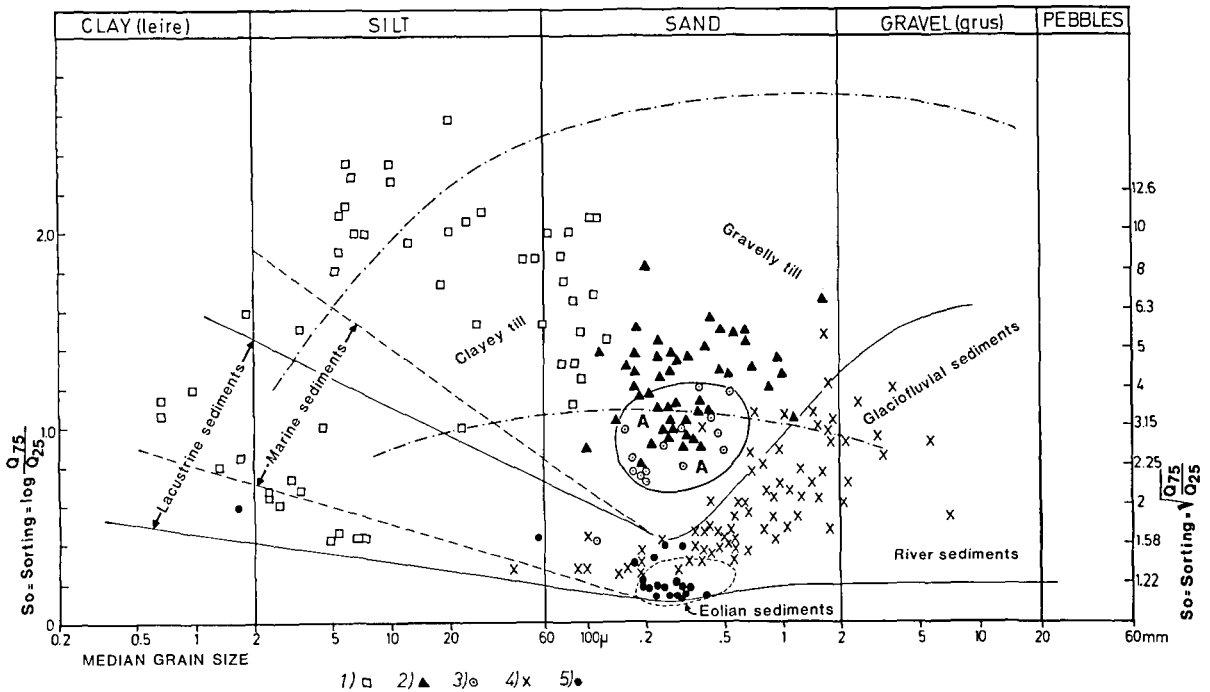


Fig. 14. Md-So-diagram for most of the analyzed samples in Jæren. The zones presented by Selmer-Olsen (1954) are outlined (dashed lines and text). 1: Subglacial till with more than 15% clay, and tectonized marine clay. 2: Subglacial till with less than 15% clay. 3: Supraglacial (ablation) till. 4: Glaciofluvial deposits. 5: Eolian and lacustrine deposits. Circle (heavy line): area for supraglacial (ablation) till.

ed out. There is in particular a considerable demand for gravel for practical purposes, and most of the gravel needed must have a low content of fines. Practically all the glaciofluvial gravel deposits on Jæren satisfy this requirement. However, some of this gravel is covered with a bouldery and slightly clayey till, which causes problems, and in some areas with mica schists and mica gneisses the gravel is not of good quality. Still, there are large quantities of good quality glaciofluvial gravel on Jæren which can be exploited relatively easily.

The marine (glaciomarine) clays on Jæren have been used for bricks etc., and there are considerable amounts of good quality clays. However, the marine (glaciomarine) clay, too, is usually covered with a bouldery till, which can make exploitation difficult.

Descriptions of deposits (distribution and origin)

The subglacial till

Both the term subglacial till and basal till have been used for tills which were deposited at the

base of glaciers. Dreimanis (1983) and Haldorson (1983) seem to favour the term subglacial till, which will be used in this paper. Dreimanis (1983) subdivided the subglacial till into lodgement till, melt-out till, flow till and deformation till. However, we found it very difficult to apply this subdivision in practical field mapping, and no attempt was made to map the different subglacial till units. What was mapped as subglacial till includes even elements of supraglacial till and tectonized marine clays. Flint (1971) indicated that a thin cover of supraglacial till was frequently deposited on top of the subglacial till, and this is true for parts of Jæren also. However, frost and cultivation activities have more or less mixed this kind of supraglacial till with the subglacial till, and it has not been possible to map the two units separately.

Origin and distribution

Most of Jæren is covered with a sheet of subglacial till of variable thickness and composition. The sheet is thinner and more patchy in the mountain districts to the east of Jæren. There bedrock is exposed over large areas, and the



Fig. 15. A typical Jæren landscape at Lake Orrevann. The main road follows the crest of a broad drumlin. The ridge in the background which dams lake Orrevann is partly the proximal remnant of the end moraine which is correlated with the Lista ice-marginal deposit. Marine beach deposits and colian deposits cover the ridge. Photo: Fjellanger-Widerøe Flyveselskap A/S.

thick sheet of subglacial till on Jæren is probably the result of both the special location of the area and of the generous supply of older Quaternary deposits at Jæren. Within the distal zone of the area covered by the Fennoscandian ice sheet, glacial deposition rather than glacial erosion took place. Therefore thick units of Quaternary sediments generally lie in this zone, and the westernmost part of Jæren belongs to the proximal part of the zone. In addition no large valleys cross Jæren, and therefore no major ice streams with much erosive power crossed Jæren.

The distribution of the tills is shown in Plate 2 where tills of class II and III and most tills of class IV are grouped together as clayey tills, while tills of class V and the most gravelly tills of class IV represent the gravelly tills.

The gravelly subglacial till
(less than 5% - 10% clay)

The Late Weichselian glaciers transported a very gravelly and bouldery sub-glacial till westwards from the mountain districts towards Jæren. This variety of subglacial till dominates in the mountain districts adjacent to Jæren, and in parts of the lowland of Jæren it is common

too, particularly in areas where the glacier moved across older glaciofluvial sediments which were incorporated into the subglacial till, such as the areas near Bryne.

In northern Jæren the old marine sediments were completely removed from large areas by Late Weichselian glacial erosion, and there too the subglacial till is generally very gravelly and bouldery, with less than 5% clay. However, there the fraction of rounded and well rounded pebbles is small, in general less than 10%. Even in southern Jæren, where large amounts of old marine (glaciomarine) clay underlie the sheet of subglacial till, a cover of gravelly lodgement or melt-out till frequently overlies a clayey till, or the gravelly and the clayey tills are strongly mixed. Where they are mixed the character of the till at the surface can change from clayey to gravelly within a few metres, which complicated the field mapping considerably. A few far-travelled erratics from Oslofjord or the Baltic regions were observed in the till. They must have been picked up by the glacier from the underlying glaciomarine deposits. In some profiles where folded stratified sediments lie within the sheet of subglacial till, the observed folds and thrust planes indicate that the force of the



Fig. 16. Stoss-side moraine at Bråsteinsnuten. The glacier moved towards the left.

overriding glacier was towards the west (Fig. 18).

Beds with gravelly tills have been found below the clayey till and even below interstadial marine sediments at several localities. They represent older glacial phases which will be discussed separately in later chapters.

The clayey subglacial till, with more than 10% clay

The sheet of clayey subglacial till at Jæren has been called the 'Skagerrak moraine' by many scientists. It is exposed in large areas on southern Jæren, and in patches on northern Jæren. The clay content is higher than 10%, and frequently exceeds 30%. In many cases the very clayey 'till' is not a true till, but a glacially tectonized marine clay. However, it is very difficult to distinguish between the true till and the tectonized marine clay, and they were both mapped as clayey tills.

The main distribution of the clayey till was shown on a map presented by Grimnes (1910). Areas with very clayey till on that map correspond well with areas of clayey till shown on Plate 2. However, the clayey till is frequently mixed with large erratics and some gravelly till, in particular at the surface, and the transition between the gravelly and the clayey subglacial tills is usually gradational and thus difficult to map.

Fragments of molluscs and foraminifera of a Boreo-arctic or Arctic fauna have been found in the very clayey tills. The fauna corresponds in general well with the fauna observed in the marine sediments which lie below the till in some areas (p. 35). The dates of shell fragments from the till correspond with dates of shells from the marine sediments below the till (p. 38).

At most localities only one bed of very clayey till was observed. The thickness of this bed varies, but is generally no more than 5 m to 10 m. Beds with clayey till or till-like deposits which lie below interstadial marine deposits have been found near Lerbrekk and Høgemork. They represent older glacial phases which will be discussed on p. .

Drumlins and stoss-side moraines

In general the sheet of subglacial till has a smooth surface without distinctive surface expression. However, in some areas there are long drumlin ridges. These are particularly well developed in the northwestern area (Plate 2, Fig. 24), but large drumlins are also found in the districts near Bryne and Egersund. Some of the drumlins are clearly associated with bedrock knobs, but for others there is no obvious connection of this kind. Garnes (1976) described drumlins near Egersund. She found that they lie on the lee sides of bedrock knobs, are caused by glacial erosion rather than deposition, and are underlain by marine sediments.

Near the eastern border of Jæren numerous stoss-side moraines lie in connection with bedrock knobs and mountains, see Figs 16 and 17. Many of the stoss-side moraines are very thick and in general consist of a gravelly till. Several of the stoss-side moraines were described by Bjørlykke (1908) and Fægri (1939).

Usually the lee-side moraines are poorly developed, but on the lee sides of some mountains there are thick sections of glaciofluvial deposits. Presumably the ice pressure was small on the lee sides during the late phases of glaciation, when the ice had become thinner. Therefore, the melt-water could more easily force its way there, and erode tunnels and chambers in

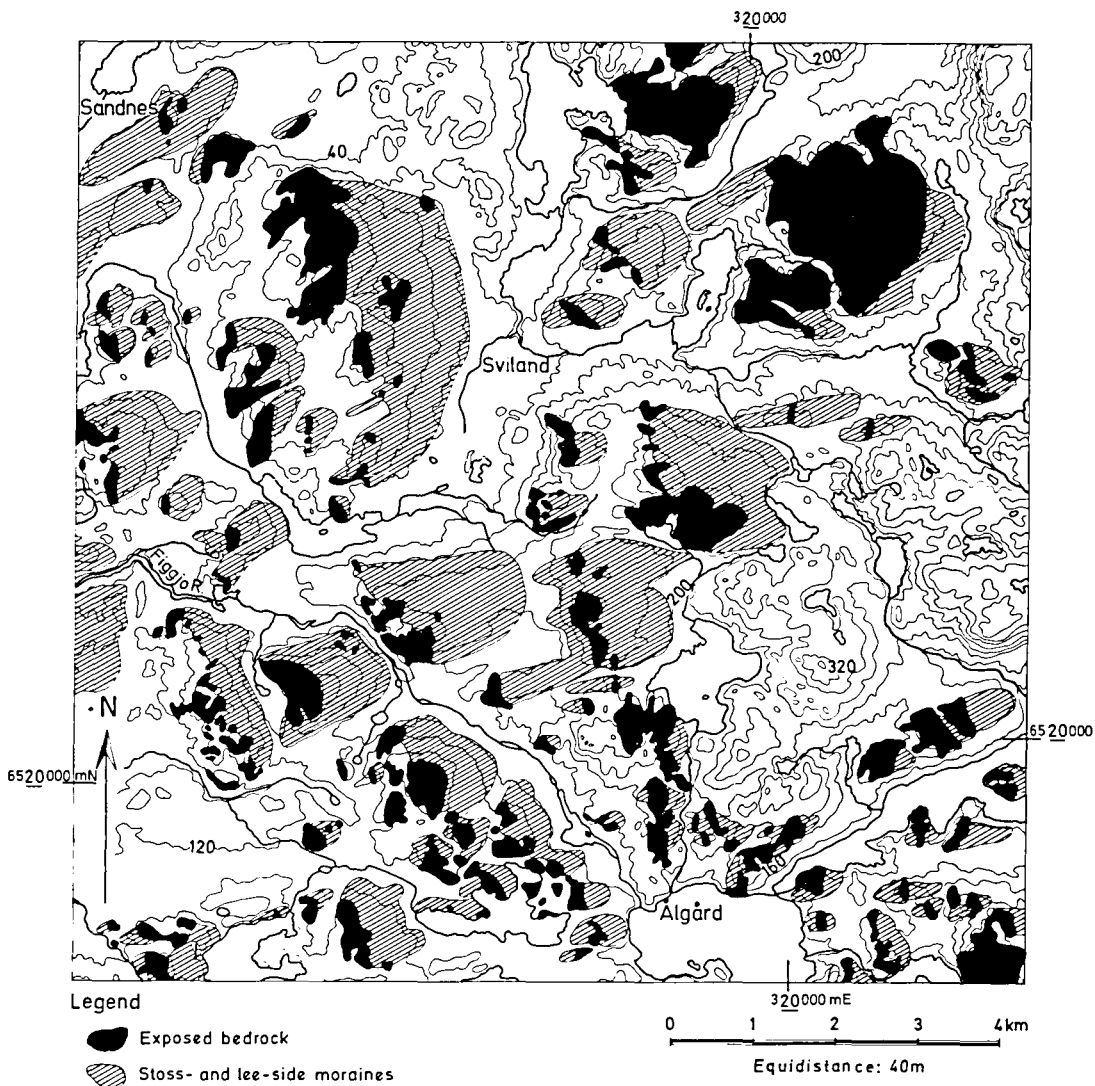


Fig. 17. Stoss- and lee-side moraines in the mountain district to the east of Jæren.

which the glaciofluvial sediments were deposited. In a publication on the origin of stoss- and lee-side moraines, Hillefors (1971) suggested a similar origin for stratified lee-side sediments observed in southwestern Sweden.

The supraglacial till (ablation till)

According to Dreimanis (1983) and Haldorsen (1983) the old term ablation till should now be replaced by the term supraglacial till, and this till is subdivided into flow till and melt-out till. In ordinary field mapping such a subdivision is very difficult to apply, and no attempts were

made to do so in Jæren. Small patches of till which could represent supraglacial till have been found at many localities. They are usually included in the gravelly subglacial till on Plate 2. Only larger areas with a typical hummocky dead-ice topography have been distinguished as areas with supraglacial till. The largest and most typical of them lie on Høg-Jæren to the east of the Mosevann moraine. Hills and ridges composed of mainly supraglacial till lie together with hills and ridges of mainly glaciofluvial sediments in this area. The last-mentioned ridges generally have a cover of supraglacial till.

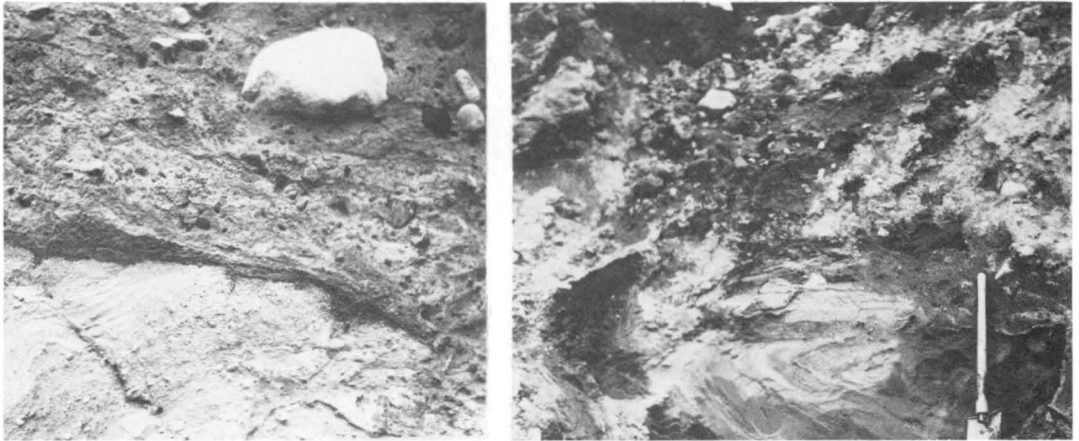


Fig. 18. Till on top of glaciofluvial beds near Bryne. The glacier flow-direction was towards the right.

The supraglacial till is very gravelly (Fig. 13) and the pebble orientation is in general poor (Fig. 9). Roundness analyses of the supraglacial till frequently show a higher proportion of rounded and well rounded pebbles than in the subglacial tills. Some of the supraglacial till even has a faint stratification. The supraglacial till on Høg-Jæren shows that a large portion of the glacier near the ice front became stagnant during the melting phase which followed the deposition of the Mosevann moraines.

The glaciofluvial sediments

A considerable amount of glaciofluvial sediments lie within the area covered by the Stavanger map-sheet. They are in general concentrated in some of the deepest valleys in the mountain districts, and in belts or zones across the Jæren lowland. The glaciofluvial sediments in the Figgjo Valley system and within a fan-shaped zone from the area near the mouth of Figgjo Valley southwestwards across the central Jæren lowland to the coast line, are particularly extensive. A pronounced esker within this system is the Time Esker which passes Bryne (Figs. 20 and 21). Other relatively large accumulations of glaciofluvial deposits lie in a valley to the east of Nærbø in southern Jæren, in the Hellvik Valley to the south of Jæren, and within the broad low-lying valley system to the east of Sandnes in northern Jæren. All of the systems mentioned comprise eskers, kames (fig. 19), and associated kettle holes, and they represent the main glaciofluvial (subglacial and subaerial) drainage systems (Plate 2).

Till-covered glaciofluvial sediments

Most of the above-mentioned glaciofluvial sediments lie beneath a generally 0.5m - 4 m thick sheet of gravelly till (Fig. 18), though some are devoid of till cover, or are only partly till-covered. Usually the surface of the till-covered deposits is subdued with broad hills and ridges, although some of the ridges can be relatively

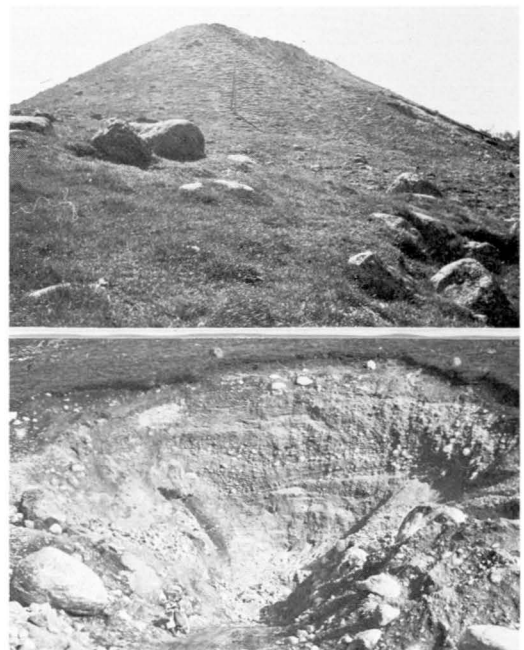


Fig. 19. The kame Smørpiggen. The pit lies on the slope on the right side of the photo above.



Fig. 20. A hummocky part of the Tim esker, to the east of Horpestadvann. Bryne lies in the background.

sharp. The glaciofluvial beds which lie in contact with the till are frequently folded and some of them are folded into the till, or lenses of till have been forced into the glaciofluvial units. Analyses of the folds and shear planes indicates that the glacier which deposited the till flowed westwards (Fig. 18). This corresponds well with the preferred pebble orientation in the till, and it shows that the till-cover in most cases was deposited by an actively flowing glacier. Therefore, the question arises of whether Jæren was more or less ice-free before the advance of the glacier, or if the glacier advance merely represents a reactivation of a fairly stagnant ice? An advance across a completely ice-free Jæren seems less likely since the many well preserved sub-till eskers and kames would then probably have been more destroyed. However, the distinctive eskers and kames could have been protected by stagnant ice which an active glacier overrode. This possibility, or the possibility

that the glaciofluvial features were formed below a stagnant, or little active ice, which was later reactivated, seems most likely.

Several well developed kames lie within the glaciofluvial drainage system in the valley near Kalberg to the east of Kvernaland. Some of the kames are more than 20 m high and they consist mainly of poorly sorted stratified gravel and sand with boulders (Fig. 19). Patches of till and many large erratics lie on the surface of the kames, in particular near the foot of the slopes. Østmo (1971) studied the kames and arrived at the conclusion that they were deposited in small but deep depressions or chambers in the ice during the final melting phase.

Glaciofluvial deposits which are not till covered

Several distinctive kames and eskers which are not covered, or only partly covered with till must have been deposited during the last Late Weichselian deglaciation phase, when the ice was thin and more or less stagnant. They were probably formed partly subaerially and partly in subglacial channels. The beds are in general not folded, or very little folded, and the patchy till cover is probably melt-out till or flow till. The best known esker of this kind is the long Time Esker, a branching esker system that can be traced from the Figgjo Valley along lake Frøylandsvann to the coast near Orre (Plate 2, Figs. 20 & 21). The pebble content of the esker corresponds roughly with the pebble content of the local till. Therefore, most of the pebbles and cobbles within the esker were transported fairly short distances by the glacial rivers. The roundness of the clasts also indicates a relatively short river transport.



Fig. 21. Cross-section of the Time esker about 2 km to the west of Bryne.

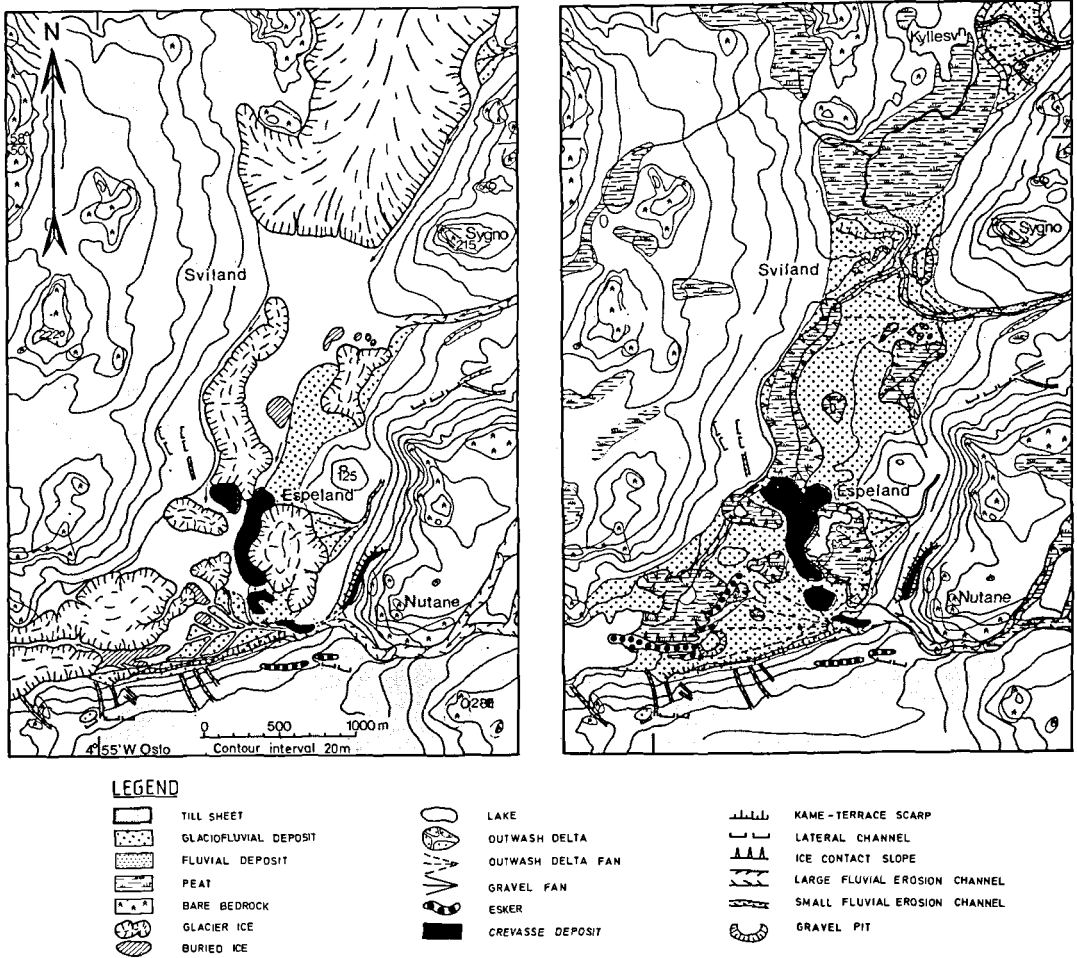


Fig. 22. The ice-dammed lake terraces at Sviland. Modified from Østmo, 1971.

Ice-dammed lake deposits

Small terraces which must have accumulated in ice-dammed lakes, mainly in small marginal ones, have been found at several localities in the mountain districts to the east of Jæren. Terraces at Hetland were described by Fægri (1939) and later both Wangen (1968) and Østmo (1971) recognized several small ice-dammed lake terraces. Their location is shown on Plate 2. A larger system of ice-dammed lake terraces was found at Sviland. The terraces were recognized by Fægri (1939), and Østmo (1971) made a more thorough study of them. They consist mainly of coarse-grained glaciofluvial type sediments, which were deposited in an irregular lake between several isolated ice bodies. The lake

was located in front of an ice lobe which occupied the northern part of the valley, see Fig. 22. Gravel pits in some of the terraces showed typical delta bedding with very coarse-grained topset beds, slightly finer grained and better sorted foreset beds, and well sorted bottomset beds of sand and silt. The highest lying conspicuous terrace level is about 65 m above sea level and the corresponding lake must have drained south-westward towards Bråstein.

Eolian sand

Eolian sand cover parts of the coast, in particular at Sola, Orre and Brusand, where belts of up to 8 m high dunes occur (Plate 2 and Fig.

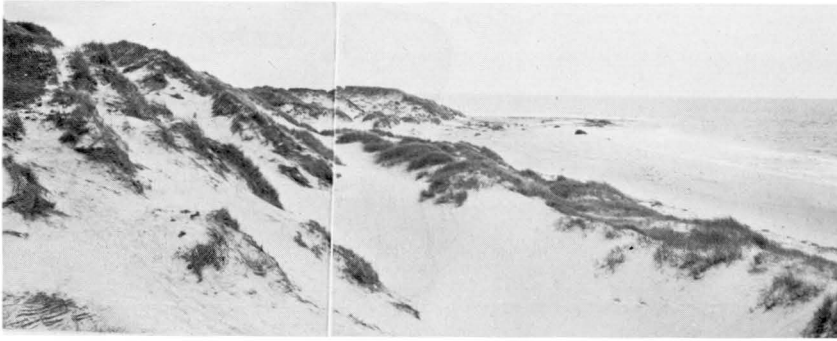


Fig. 23. Eolian sand dunes along the coast near Orre.

23). The dunes lie next to the sandy beaches, and they were probably formed in Holocene and Recent time. Today the eolian activity is restricted by vegetation. Sheets of eolian sand usually occur in areas adjacent to the dunes also. The eolian sand is very well sorted, with a median grain size in the fine- to medium sand fraction. However, the grains are generally poorly rounded, and their surfaces are generally not well polished. In addition there are many grains of dark minerals and of shell fragments (well rounded). For further information about the eolian sand and sand-dunes, see Sjulsen (1982) and Pangård (1984).

Late Weichselian and Holocene shore feature and marine deposits

Shore features

Series of distinctive beach ridges, marine abrasion terraces and cliffs lie along the coast of Jæren (Fig. 25). They were described by several scientists (Bjørlykke 1908, Fægri 1939-40) who attempted to reconstruct the former shore levels (p.). Our work with the shore features was concentrated on supplementary studies of ridges, cliffs and terraces that had not been described before, and on remeasuring some of the well known features. A hand level and a Paulin altimeter with a 1 m scale were used. Corrections were made for temperature variations and the altitudes were measured at least twice.

The Late Weichselian shore levels

Fægri (1939-40) found two Late Weichselian shore levels on northern Jæren, the Alvevann level and a slightly higher and older level. The most dominant Late Weichselian shore features correspond with the Alvevann level. Evidence of the highest level was found only at four localities, and two of these lie to the north of the

Stavanger map-area on the northeastern part of the Randaberg Peninsula. There, beach ridges at Grødheim and Randabergviken lie 25.8 m and 26.2 m above sea level, respectively. A beach ridge that Fægri correlated with the Alvevann level lies about 23 m above sea level at Grødheim. Therefore, the difference in altitude between the highest-lying level and the Alvevann level should be approximately 2.5 m - 3 m on the northeastern part of the Randaberg Peninsula. The shore levels decrease in altitude southwestward and southward along the coast of Jæren, and the difference in altitude between the two Late Weichselian shore levels must decrease in the same directions. Consequently, the two shore levels lie very close together on the southwestern and southern parts of Jæren, and usually it is impossible to distinguish between shore features formed during these two phases. In the following, the features will be described as belonging to the Late Weichselian shore complex. The two localities within the Stavanger map-area where Fægri found ridges at the highest-lying Late Weichselian shore level lie at Hogstad, south of Tananger, and at Vistehola on the Randaberg Peninsula (Fig. 24). They lie some 20 m and 25.6 m above sea level, respectively. Fægri (1939-40, p. 129) described the latter ridge as a remnant of a beach ridge that lies well sheltered just above Vistehola. Despite much searching and digging, the writers were unable to find a beach ridge at the 25.6 m level and no other shore features were seen near the Vistehola area at this level. In addition the 25.6 m level is too high to correspond with the highest-lying beach level on the northeastern Randaberg peninsula. The altitude 25.6 m is about the same as that of the Grødheim ridge, and the distance between the two ridges is 4 km, at right-angles to the isobases. The highest lying beach ridges a short distance

to the west of Vistehola are therefore more likely to correspond with the Grødheim ridge. They lie 21 m to 22 m above sea level, and according to Fægri they represent the Alvevann level. In this area, the difference in altitude between the Alvevann level and the oldest Late Weichselian shore level must be small, and the 21 m - 22 m beach ridges could represent both shore levels, i.e. they represent the Late Weichselian shore complex.

The most conspicuous Late Weichselian shore features on northern Jæren lie in a narrow belt immediately below the marine limit (ML). The features are large beach ridges, distinctive abrasion terraces and cliffs, and wave-washed zones along the most exposed west facing slopes of the coast. They form an almost continuous belt and represent the Late Weichselian shore complex. The belt can be traced into the eastern parts of the Stavanger Peninsula near Gandafjord also, but the features are less distinct in that area, generally only indistinct abrasion bluffs.

The most dominant shore features and their altitudes are plotted on the maps in Figs. 24 and 25. Beach ridges 21 m - 22 m above sea level on the western part of the Randberg Peninsula are very well developed. A 2 m to 6 m high abrasion scarp is connected with these ridges. This scarp is called Høgabråtet near Randberg. Both Bjørlykke (1908) and Fægri (1939-40) described Høgabråtet and the ridges. The abrasion scarp can be traced over long distances, as indicated on the map. In several areas where the cover of sediments was thin, the scarp grades into wave-washed zones of bare bedrock, which have a sharp upper limit. Above this limit there is generally a thin sheet of till. Below the limit, the waves have washed the sediments down into the depressions. This is particularly clear on the northwestern part of the Tananger Peninsula, where small beach ridges frequently lie at the upper limit of the wave washed zone, 20 m to 22 m above sea-level.

As already mentioned, the altitude of the Late Weichselian shore complex gradually decreases southwards. An abrasion scarp surrounding a small till covered hill at Sola Church lies 18 m to 20 m above sea-level. A beach ridge, together with an abrasion scarp, lies 15 m to 16 m above sea level near Ølbor, and the well known Alvevann ridge near the mouth of the Figgjo River was measured at 10 m to 12.5 m above sea level. The Alvevann ridge lies near

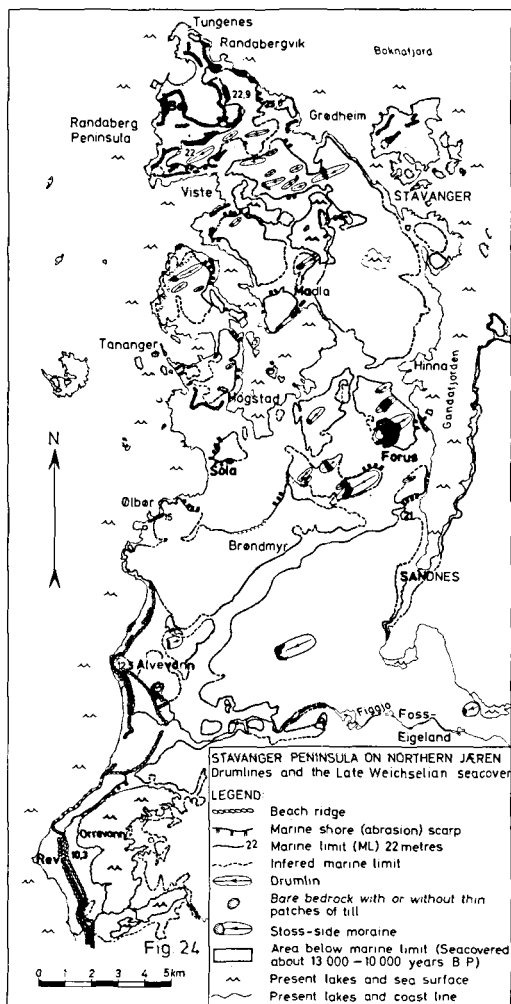


Fig. 24. The Late Weichselian paleogeography of the Stavanger Peninsula.

the foot of a till-covered slope, and therefore must represent the highest-lying shore level, the ML.

Judging by the isobases in Fig. 25, this Late Weichselian shore level and the highest-lying Holocene (Tapes) one should intersect approximately at Reve, south of Alvevann. There, series of beach ridges lie up to 10.5 m above sea level on the broad morainic ridge which dams lake Orrevann. The highest-lying ridge is large and it could have been formed both in Late Weichselian and Holocene (Tapes) time. Fægri (1939-40) also assumed that the Late Weichselian and Holocene (Tapes) shore-levels intersect

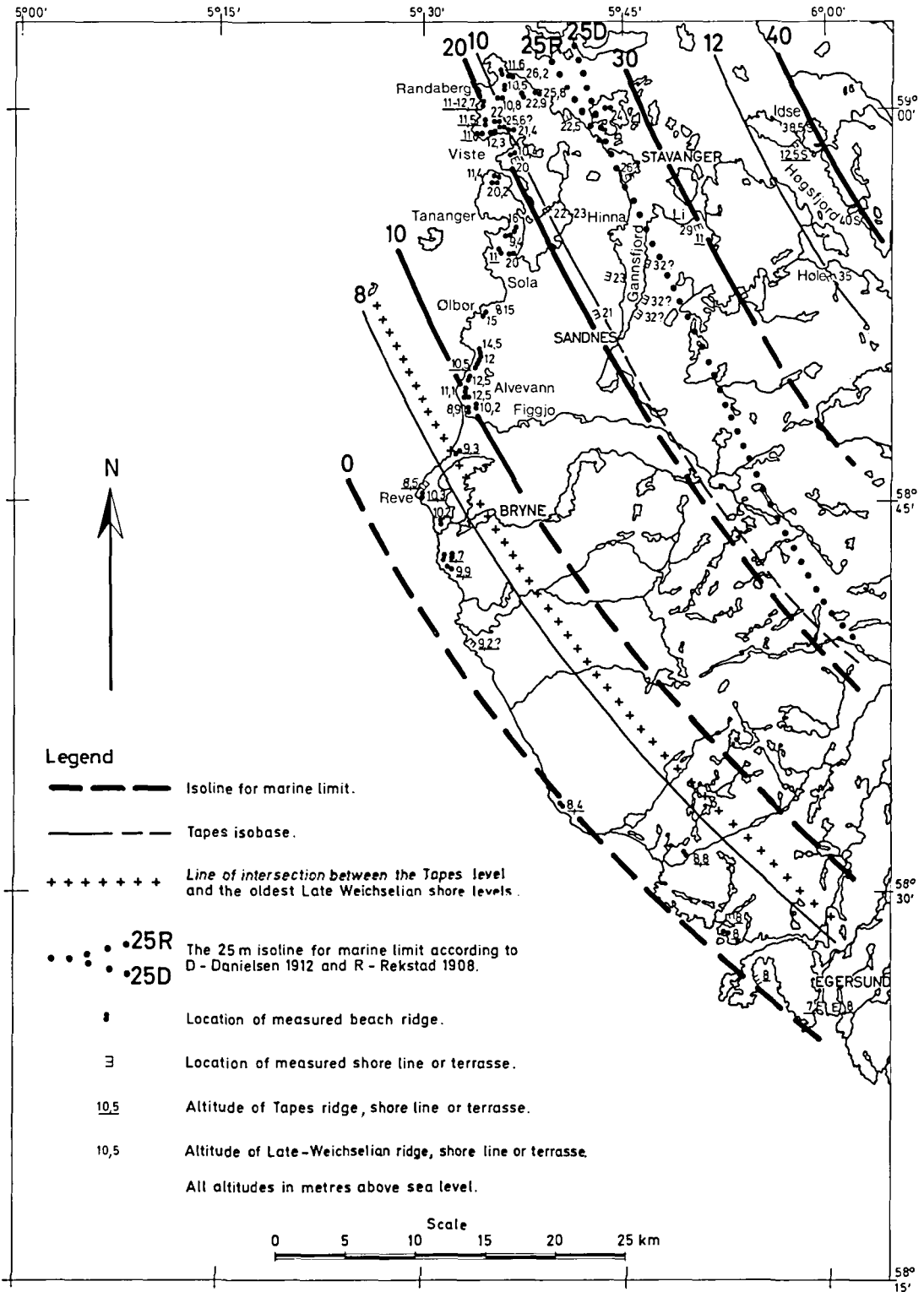


Fig. 25. Isolines for the marine limit (ML) and the Holocene 'Tapes' isobases.

near Reve. Holocene peat underlies some of the highest-lying beach ridges on the coast southeast of Reve. Therefore, the Holocene (Tapes) shore level was higher than the Late Weichselian one on that part of the coast.

The described beach ridges and abrasion scarps on the very exposed open coast at Jæren could have formed considerably above mean sea level. Fægri (1939-40) discussed this problem and found that some of the recent ridges on the most exposed parts of the coast lie 3 m to 4 m above present mean sea-level. In calculating how high above the sea level the older ridges were formed, several factors must be considered, such as the water depth offshore, the slope of the shore zone and exposure towards the open sea, (see Møller et al. 1972).

Evaluations of this kind where applied when the isobases for the Late Weichselian shore complex were constructed (Fig. 25). The supposed beach ridge at 25.6 m above sea-level at Viste was not used, and even the beach ridge 26.2 m above sea level at Randabergviken lies slightly too high for the system of isobases presented here. Otherwise, the isobases correspond well with Fægri's results.

As mentioned before, the Late Weichselian shore complex on the eastern parts of the Stavanger Peninsula is represented by indistinct abrasion scarps. They lie 22 m to 26 m above sea level between Hinna and Stavanger and 20 to 24 m above sea level between Hinna and Sandnes, both areas are relatively well protected against strong wave abrasion. Therefore the features were most likely formed close to the mean sea level.

Only a few measurements at scattered localities were made in areas to the east of the Stavanger Peninsula. Small indistinctive terraces about 32 m above sea level lie at the mouths of two small steep valleys on the east side of Gandafjord. Gravel with boulders covers the terrace surfaces, and the internal structure of the terraces is not known. They could be marine or they could be kame terraces deposited by meltwater streams against dead-ice occupying Gandafjord. If they are marine delta terraces, then this side of Gandafjord must have been uplifted, since the altitude of the terraces is 4 m - 6 m too high to correspond with the highest-lying shore features on the eastern side. In constructing the isobases shown in Fig. 25, the altitudes of these terraces were not used.

Flat raised delta plains at the mouths of two small river valleys at Li and Høle to the east

of Gandafjord lie respectively 29 m and 35 m above sea level. At both places marine abrasion features were observed up to the mentioned levels, and till-covered slopes above. At the southern part of Idsø Island Stuland (1948) observed a marine limit at 38.5 m, which agrees well with our observations. About 15 km southeast of Idsø, at the mouth of the Lysefjord, the marine limit was found to be 40 m to 42 m above sea level (Stuland, 1948 and Andersen 1954). The measured features are an outwash delta and the upper limit of a marine abrasion zone.

The isolines shown in Fig. 25 were constructed on the basis of the above-mentioned ML observations and on ML observations carried out by Rekstad (1908) on the islands in Boknafjord, immediately to the north of the Stavanger map-area. The isolines correspond well with isolines constructed by Stuland (1948) for areas near Lysefjord and with lines for southern Norway constructed by Rekstad (1922) and Danielsen (1912). The isolines could represent a complex of Late Weichselian shore levels, or they could represent a synchronous Younger Dryas (?) shore level, see the following chapter.

Fig. 26 shows a simplified equidistance shore-line diagram. All of the measured ML values lie within the upper belt, which has a gradient of about 1 m per km. In comparison, the Younger Dryas shore line in Troms has a gradient of 0.9 m to 1.0 m per km (Andersen 1968, p. 143), and the gradient of Younger Dryas shore lines in western Norway seems to vary between 1.1 m/km and 1.4 m/km (Aarseth et al. 1974).

The late Weichselian shore-level displacement
Thomsen (1981) presented a shore-level displacement graph for part of northern Jæren. Of particular interest is the transgression in late Allerød time, a transgression up to about the 21 m level, which is the Alvevann level. According to our observations this is very close to the marine limit (ML) also. Stabell (1982) recorded a similar transgression up to ML in western Norway, as did Anundsen (1977) in a district of northern Ryfylke. However, Anundsen suggested that the transgression took place in late Younger Dryas time, while Stabell considered it Allerød in age. In a recent paper Anundsen (1985) suggested that the transgressions recorded by Thomsen and Stabell correspond with the transgression in Ryfylke and that they all culminated in Younger Dryas time.

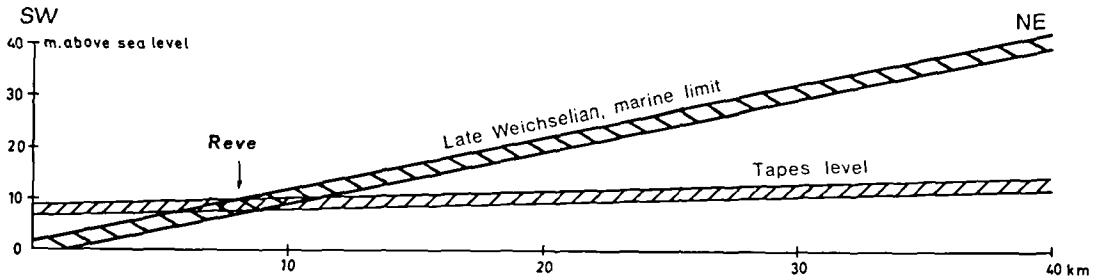


Fig. 26. Shore levels along a SW-NE profile, at right angle to the isobases, between Reve and the mouth of Lysefjord.

The Holocene shore features

Rather large Holocene beach ridges, called Tapes ridges, lie along the west coast at Jæren. They consist predominantly of well rounded cobbles and are generally 1 m to 4 m high and often several kilometres long. Between Reve and Randberg, the Tapes ridges rise from 9 m to 12 m above sea level, and between Reve and Egersund they drop from 9 m to 6 m above sea level. The Tapes ridges represent the highest-lying Holocene shore features and were deposited during the Atlantic, Tapes transgression; see Bird et al. 1986. In addition to the ridges, there are often corresponding abrasion terraces, scarps and shore lines. Beach ridges and shore lines which lie at lower altitudes are usually smaller and less distinctive. On the eastern part of the Stavanger Peninsula and within the fjord districts further to the east, the Tapes shore features are generally very indistinctive and difficult to identify. There, several small marine terraces and shorelines lie at different altitudes, and usually the most distinctive are considered to be of Tapes age. On Idsø Island, one of the best developed terraces lies 12.5 m to 13 m above sea level, and Stuland (1948) correlated this level with the Tapes level, which corresponds well with our observations. However, no fossil material that could be used to date the Tapes shore features was found.

The Tapes shore line or zone in Fig. 26 was constructed on the basis of these relatively uncertain observations. The zone has a gradient of about 0.13 m/km which is roughly the same as the gradients for the Tapes shore lines in other parts of the country (Marthinussen 1960). The Tapes isobases in Fig. 26 lie parallel with the Late Weichselian isobases and nearly parallel with the coastline to the southeast of Reve.

The marine fauna

A cold-water molluscan fauna with mainly *Mya truncata* and *Hiatella arctica* was found in Late Weichselian deposits at Forus, at Stavanger railway station and a few other localities. Warm-water molluscan faunas with a large number of species were found in connection with the Tapes ridges at Jæren. The shells usually lie slightly below the ridges. Two of the best known localities with a Tapes fauna lie at Viste-
vik about 2 m above sea level, and at Oгна 2 m to 4 m above sea level. At both places, the warm-water fauna is slightly mixed with cold-water species (see Table 2). The fauna at Viste-
vik consists of 4 Arctic, 27 Boreal and 21 Lusitanian species according to Danielsen (1912, p. 371). At Oгна there were 3 Arctic, 18 Boreal and 18 Lusitanian species (Danielsen, 1912, p. 359). The writers made no systematic collection of shells from the Tapes localities since Danielsen (1912), Øyen (1903), and Bjørlykke (1908) had already made extensive studies of the Tapes fauna.

Peat deposits and vegetation history

Peat deposits cover extensive areas of Jæren (Plate 2). The humid climate favours bog formation, and bogs of all main type exist. Peat has been cut in many bogs, and used both industrially and for local fuel supply. Today the peat cutting is limited, and many peat bogs have been drained and used as farm land. The accumulation of organic material started just after the deglaciation in some bogs, and the oldest peat date in southern Norway was obtained at Brøndmyr, see the following chapters. The writers did not carry out any special studies of the peat deposits.

The Holocene vegetation history was particularly studied by Fægri (1939-40), who described the vegetation in all major vegetation zones.

The late part of the Late Weichselian vegetation history (Fig. 27) was studied in particular at the Brøndmyra peat bog by Fægri (1939-40) and by Chanda (1965). They recognized three cold tundra phases, which were correlated with the Oldest Dryas, Older Dryas and Younger Dryas, and two warmer phases with some birch trees which were correlated with Bølling and Allerød. In a study of cores from lakes in northern Jæren, Thomsen (1981) had problems in recognizing the Older Dryas cold phase and she indicated that the suggested zone boundaries in Fægri's diagram are not synchronous with the boundaries in Chanda's diagram. Both Thomsen and Chanda presented radiocarbon dates in support of their stratigraphies.

Middle Weichselian vegetation. Pollen analysis of sediments from Høgemork and Reve suggest that tundra, with dwarf birch and possibly some birch trees, existed during the Sandnes interstadial and the Bø/Nygaard interstadial (see p. 43 and p. 49). However, much resedimented pollen was found in the sediments and the interpretation of the pollen diagrams is problematic.

Pollen in the Late Weichselian clayey till. Several test analyses were carried out of samples from the clayey tills. They all contained a substantial amount of pollen of a mixed flora including *Betula*, *Picea*, *Pinus*, *Alnus*, *Corylus*, *Quercus* etc., and *Ericales*, *Gramineae*, *Cyperaceae* etc. This indicates that the glacier which deposited the till picked up pollen from both interglacial and interstadial deposits.

The sub-till deposits

Autochthonous and allochthonous marine sediments, together with tills and glaciofluvial deposits, underlie the Late Weichselian glacial deposits in many parts of Jæren and Karmøy. The sub-till sediments are exposed in clay pits, gravel pits, etc., and some of them have been observed in cores. Several of the sections have been described before, but many are new, and some of the old sections are better exposed today than they were before. Previous attempts at working out the stratigraphy have been based

Pollen zones	Chrono zone	C-14 dates yrs B.P	Vegetation/climate
III	Younger Dryas	10,800 ± 300 T-152	Tundra with dwarf birch, cold
II	Allerød	11,300 ± 300 T-151	Warmer, with some birch trees
Ic	Older Dryas		Tundra with dwarf birch, cold
Ib	Bølling	12,650 ± 300 T-150	Slightly warmer, possibly with some birch trees
Ia	Oldest Dryas	13,000 ± 400 T-149A 13,150 ± 300 T-149B	Tundra with dwarf birch and willow, cold

Fig. 27. The Late Weichselian vegetation and climate on Jæren, on the basis of pollen analysis of samples from Brøndmyra peat bog (modified from Chanda 1965).

very much on studies of the foraminiferal and the molluscan fauna in the clays. The attempts carried out by the writers are based on studies of lithology, fossils and radiometric datings.

Some of the results and descriptions of the main stratigraphic sections were published in Andersen et al. (1981, 1983), and will be described only briefly in the following.

Methods

Lithostratigraphy

Most of the observed sub-till beds are more or less tectonized. Clearly autochthonous beds were seen only at a few localities. Our main lithostratigraphic conclusions are in general based on studies in the latter sections. Much of the sub-till sediment is glaciomarine (marine) clay, silt and sand, and it is difficult to correlate beds from one section to another. However, some beds were deposited during a low sea-level phase when sea-level was about as high as today, and other beds were deposited when the sea-level was considerably higher. At some localities the high sea-level deposits lie on top of the low sea-level deposits, which suggests that the high sea-level phase followed after the low sea-level phase. Autochthonous high sea-level marine beds have been observed up to 180-200 m above sea level. Andresen et al. (1981) suggested that the cause of this high sea level could have been isostatic depression of the area during a Middle Weichselian glacial phase. However, an isostatic depression of Jæren of the order of 200 m in Middle Weichselian time does not

Locality →	GANN, SANDNES					GRAVEREN, SANDNES					MADLA	FOSS-EIGELAND			REVE	
	zone Ia	zone Ib	zone III upper	zone III middle	zone III lower	zone I	zone I	zone II	zone III	zone III						
	1a	1b	2	3	4	5	6	7	8	9		10	11	12	13	14
Species: ↓ Column nr: →																
<i>Elphidium excavatum</i>	35	73	55	48	8	69	67	46	81	93	52	53	66	56	37	1
<i>Cassidulina reniforme</i>	13	18	34	35	5	17	21	38	3	<1	45	32	30	33	51	11
<i>Elphidium asklundi</i>	1	<1	3	<1	12	<1			5	1						
<i>Elphidium subarcticum</i>		<1			4		<1		1	1	1	<1		<1	1	<1
<i>Protelphidium orbiculare</i>	S 1	<1	<1	3	21		<1		4	1	1	<1		<1	11	50
<i>Elphidium albumbilicatum</i>	2		2			<1	1		1	<1						
<i>Elphidium bartletti</i>	S 3	1	1	2	28	2	<1		2	1			<1	<1		
<i>Elphidium incertum</i>			1		1	<1					<1			<1		<1
<i>Cryptoelphidiella itriaensis</i>	1		<1	3	1				<1							
<i>Buccella frigida</i>	3	1	<1	<1	20	1	1		<1					<1		12
<i>Cibicides lobatulus</i>	7					<1	<1					1		<1		1
<i>Silicosigmoilina groenlandica</i>	1		1	6			<1									
<i>Trifarina fluens</i>		<1				<1	1									
<i>Astrononion gallowayi</i>	b	<1				<1	1					1	<1	<1		<1
<i>Nonion labradoricum</i>	10	3				5	2					3	<1	24		
<i>Nonion barleeanum</i>	2					<1	<1						<1			
<i>Nonionella auricula</i>											<1			<1		
<i>Virgulina loeblichii</i>	1	1				<1	1	2				2	<1	15		
<i>Islandiella norcrossi</i>	12	1				4	3						1	15		
<i>Islandiella helenae</i>	b 3	<1				<1								<1		
<i>Guttulina lactea</i>	b			<1		<1			<1	<1						
<i>Hyalinea baltica</i>	b 1															
<i>Bulimina marginata</i>	2					<1										<1
<i>Uvigerina peregrina</i>						<1					<1					
<i>Pyrgo Williamsoni</i>	1	<1	1	1		<1										
Total number of specimens	153	527	295	402	109	629	302	42	308	276	1542	329	164	534	444	478
Fauna dominans	35	73	55	48	28	69	67		81	93	52	53	66	56	51	50
Fauna diversity	14	4	5	5	7	4	6		5	3	2	4	2	5	3	5
Weight of sample in grams	105	150	5	112	110	65	100	200	100	65	200	1800	200	?	300	300
Altitude above/below present sea level	+25m to +10m					+30m to +2m		+2m to +4m			+8m	+55m to +68m			+4m to +7m	

TABLE 1. The foraminifer faunas in samples from the Late Weichselian clayey till, and from marine/glaciomarine beds beneath the Late Weichselian till. Percentages of 25 selected species. b: Species occurring commonly in Boreal fauna assemblages. Most of the other species occur most commonly in Arctic assemblages. s: Typical shallow-water species.

Column nos. 1 to 9, 13, 16, 24, 26, 33 and 34 (From Feyling-Hanssen 1971, 1974), nos. 11, 12, 14, 15, 32 (From Østmo 1971), nos. 18, 22, 23 and 25 (From Wangen 1968), nos. 10, 17, 19, 20, 21 and 27 too 31 (analyzed by J. Nagy), nos. 35 to 37 (analyzed by H.P. Sejrup).

Sample no. 12 was collected immediately above the laminated unit (C, in Fig. 28) in a homogeneous clay which Østmo (1971) considered undisturbed. Sample no. 25 is from a laminated section below the till at Oppstad. Additional analyses have been carried out of samples from Reve (see Fig. 35) and from the laminated clay at Foss-Eigeland which contained very few specimens, mainly of *Elphidium excavatum* and *Cassidulina reniforme* (see Andersen et al. 1981, Fig. 9).

LERBREKK			BRUSAND	STAVHEIM		N. VARHAUG	NÆRBØ	OPPSTAD		ELGANE	HÖGEMORK					KYVERNALAND	NYGAARD, KARMØY		BØ, KARMØY		
upper till	silt	lower till		brown till	grey till						depth 8 m - 9 m	depth 15.83 m	depth 21.5 m	depth 26.5 m	depth 32.1 m				11 m a.s.l. in till	10 m a.s.l.	5 m a.s.l.
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
58	65	57	55	35	39	52	64	53	42	39	60	43	49	55	37	75	48	13	26	18	3
28	33	39	34	30	19	39	24	23	27	26	12	38	34	30	52	18	11	3	7	10	8
1										1							4	10			
		1	1		2	1		1	3	3	6	4	1	4		2	1	9	19	16	<1
4			1	2.5	1		3	2	4	2	3		8	9	2		13	23	7	6	<1
1		2						1		<1									7		
										1							10	5	5	13	<1
										1							3	2	3	4	
																		3			
					2	1		1		1			2				2	1	2	3	1
1		1	1	18	9	2		5	8	6								3	16	6	68
																			<1		
1				2.5	3.5			1		2									<1		
<1		1		1	2			1	1	2							2	3	3		<1
<1								1	3	2	6	2	1		4		1	1	2	1	<1
<1			1		1			1		<1					2				2	2	1
<1	1		1	1		1			1	2	6	9	2		4				2	2	
	1		3	3				5		4		4	5				1	1			
<1			3	1				1		2							3			6	
																		<1		3	
				1	1	2	9			<1						6			3		1
<1										<1											
223	96	180	2440	127	89	125	45	146	77	398	33	47	83	23	47	126	183	401	58	67	311
58	65	57	55	45	35	52	64	53		39						75	48	23	26	18	68
3	2	2	4	9	14	4	3	10		11						2	9	18	13	13	20
200	175	200	200	200	200	200	200	40	?	50	30	30	30	30	30	?	100	140	150	148	80
+20m to +25m			+15m	+8m		+20m	+25m	+175m		+198m	+210m to +173m					+40m	+15m	+11m to +5m			

correspond well with the observed small isostatic depression of the area during the Late Weichselian. Therefore, the possibility of tectonic uplift must be considered. A N-S oriented fault line could follow Gandafjord and the eastern border of the Jæren lowland, and all observed high-level marine deposits could possibly lie to the east of such a line. But even at localities with high-level marine deposit that lie to the east of the suggested fault line there is clear

evidence of a considerable marine transgression. Therefore, the cause of the high elevation of the marine beds could be a combination of isostatic and tectonic uplift.

Biostratigraphy

Foraminifera. About 30 samples from different clay units which lie below the upper till bed at Jæren and at Karmøy were analyzed for their

Species ↓	Sediment → Marine clay within and below the Late Weichselian till															Late Weichselian clay	Late Weichselian and Holocene deposits	Holocene deposits					
	Locality → Jæren										Karmøy							Forus	Bøvann N. Jæren	Ogna	Bø N. Jæren	Kragemyr	Viste
	Sandnes		Madla	Foss	Eigeland	Reve		Lerbrekk		Oppstad	Nygaard				Bø								
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20				
<i>Portlandia arctica</i>	●		●										●	●									
<i>Nuculana pernula</i>	●								●				●										
<i>Yoldiella lenticula</i>			●																				
<i>Hiatella (Saxicava) arctica</i>	●	●		●			●	●	●		●	●	●	●	●								
<i>Macoma calcarea</i>	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			●					
<i>Mya truncata</i>	●	●	●	●			●?	●	●	●	●	●	●	●	●	●		●	●				
<i>Astarte elliptica</i>	●						●						●?										
<i>Chlamys (Pecten) islandica</i>		●		●					●					●									
<i>Arctica (Cyprina) islandica</i>	●	●		●?			●	●	●	●		●		●				●	●				
<i>Saxicava pholadis</i>					●	●			●								●	●	●				
<i>Macoma baltica</i>	●									●							●	●	●				
<i>Pecten grönlandicus</i>			●														●	●	●				
<i>Yoldiella lucida</i>				●																			
<i>Macoma torelli</i>										●									●				
<i>Astarte crenata</i>				●												●							
<i>Thyasira sarsii</i>															●								
<i>Buccinum undatum</i>													●						●				
<i>Natica clausa</i>												●							●				
<i>Rhynchonella psittacea</i>												●	●	●					●				
<i>Echinus dröbachiensis</i>											●								●				
<i>Tectura rubella</i>											●								●				
<i>Boreochiton marmoreus</i>											●								●				
<i>Boreochiton ruber</i>											●		●						●				
<i>Nicania banksii</i>	●						●						●						●				
<i>Trophon clathratus</i>	●																		●				
<i>Balanus hameri</i>							●	●	●										●				
<i>Balanus crenatus</i>	●?						●	●											●				
<i>Panopea norvegica</i>							●	●				●	●						●				
<i>Mytilus modiolus</i>							●												●				
<i>Mytilus edulis</i>	●?				●				●								●	●	●				
<i>Cardium fasciatum</i>					●												●	●	●				
<i>Cardium edule</i>					●												●	●	●				
<i>Abra longicollis</i>					●												●	●	●				
<i>Patella vulgata</i>																	●	●	●				
<i>Littorina littorea</i>																	●	●	●				
<i>Littorina obtusata</i>																	●	●	●				
<i>Ostrea edulis</i>																	●	●	●				
<i>Pecten varius</i>																	●	●	●				
<i>Tapes aureus</i>																	●	●	●				
<i>Tapes pullastra</i>																	●	●	●				
<i>Tapes decussatus</i>																	●	●	●				
<i>Scrobicularia piperata</i>																	●	●	●				
<i>Tectura virginea</i>																	●	●	●				

TABLE 2. Shell faunas in sediments from Jæren and Karmøy. The listed faunas are from: 1) Zone I clays, possibly mixed with shells from glaciofluvial beds, bed D in Andersen et al. (1981, Fig. 1) (From Bjørlykke 1908). The writers observed all shells listed above *Arctica islandica* in the Zone I clays. 2) The glaciofluvial beds at Hove (bed D in Andersen et al. 1981, Fig. 2). 3) Clay in pit at Madla (Bjørlykke 1908). 4) Kalberg clay (Fig. 28). 5) *Cardium* clay (Bjørlykke 1908); see Fig. 34. 6) Beds below the *Cardium* clay (Bjørlykke 1908). 7) K-bed in Fig. 34 (Østmo 1971). 8) Upper Lerbrekk diamiction (Bjørlykke 1908, Danielsen 1912). Several of the species were observed by the writers; see Plate 7 III. 9) Probably from Lower Lerbrekk diamiction (Bjørlykke 1908 and the writers). 10) Kanahei clay and the Oppstad diamiction (Bjørlykke 1908 and the writers). 11-14) Nygaard gravel and Karmsund clay, see Andersen et al. 1981, Fig. 6. 15) Haugesund diamiction, a very clayey till (Øyen 1905, Ringen 1964 and the writers). 16) Blue clay below 2 m stratified sand and 1 m peat. 17) Clay (Bjørlykke 1908). 18) Tapes shell bed 2 m - 4 m above sea level (Danielsen 1912). 30 species are not listed. 19) Sand bed in a channel at lake Bøvann, 1 m to 5 m above sea level (Bjørlykke 1908). 34 species are not listed. 20) Shells collected by Øyen and Bjørlykke in a shell bed below peat near Vistevik, 2 m above sea level (Bjørlykke 1908). 16 species are not listed.

foraminiferal content. The analyses were carried out by R.W. Feyling-Hanssen, J. Nagy, M. Løfaldli, E. Bergsager, T. Fjæran, R. Føyn and H.P. Sejrup. A list of selected species is shown in Table 1. The number of specimens in many samples was so small that the results will only be mentioned in the text. Even some of the listed faunas are based on counts of less than 100 specimens. Therefore the number of counted specimens and the weight of the analyzed samples are listed too.

An important question arises in connection with the observed foraminiferal faunas at Jæren. Can they be used to distinguish between deposits from the Saalian and the Weichselian glaciations? Feyling-Hanssen (1971) found that species like *Nonion labradoricum*, *Islandiella norcrossi* and *I. (teretis) helenae* are frequently absent from the known deposits in the North Sea region that are older than the Weichselian. In addition he found that species like *Quinqueloculina stalkerii* and *Elphidium ustulatum* which occur very sparsely in the clays at Jæren, are frequent in many pre-Weichselian clays in England and Denmark. However, more recent studies indicate that it is difficult to use the foraminiferal faunas to distinguish between clays from different glaciations in the North Sea region (Knutsen 1973, 1977, Mangerud et al. 1981). Still, as Feyling-Hanssen (1971) pointed out, the different fauna assemblages observed in the clays at Jæren and Karmøy seem to be closely related to the fauna assemblages in the clays at Sandnes. This in addition to the good correspondence in lithostratigraphic position, for the clays indicate that they are very likely of about the same age. Many radiometric dates and some amino-acid dates of shells from the clays support this conclusion, and suggest that the faunas are most likely of Weichselian age, which was Feyling-Hanssen's (1971) conclusions also.

Feyling-Hanssen (1971) recognized 4 foraminiferal zones in cores from the clay near Gann clay pit at Sandnes. They have been used more or less as reference zones for the foraminiferal assemblages found in other clays at Jæren and Karmøy.

Molluscs. Table 2 shows a list of molluscs recorded in different deposits at Jæren. Most of the molluscs were observed by Bjørlykke (1908) and Øyen (1903). However, the writers noted the same species as Bjørlykke and Øyen in many deposits, as well as some new species.

The mentioned molluscs from Bø, Lerbrekk and Oppstad lie in tills or strongly tectonized marine clays. At all of the other listed localities the molluscs lie chiefly in autochthonous or para-autochthonous marine clays. All of the listed faunas from sub-till deposits except for one at Reve are Arctic to Boreo-arctic. The fauna from Reve is Boreo-arctic to Boreal. Fossils from the autochthonous interstadial and interglacial marine beds at Bø (p. 51) were presented by Andersen et al. (1981, 1983), and are not listed in Table 2.

Pollen analysis

Samples from the clayey till and from the sub-till sediments have been analyzed for their pollen content by E. Sønstegeard and K. Henningsmoen. The interpretation of the pollen diagrams is problematic, because of the large amounts of reseedimented pollen.

Dating methods

Radiocarbon dates

Altogether 19 samples of shells and 1 sample of whale bone from the marine sub-till deposits on Jæren and Karmøy have been radiocarbon-dated (Table 3). The problems involved in dating of old shells are generally related to contamination of the shells with younger carbon (see the discussion in Andersen et al. 1981).

The Thorium — Uranium dates

Altogether 11 samples of marine shells have been Th-U dated. For 9 of the samples at least two fractions were dated. Table 4 was presented by Andersen et al. (1981), together with a discussion of the dates and the dating method. They arrived at the conclusion that considerable contamination had taken place in the outer fraction of some samples. However, the dates of samples T-116, T-3631, T-140 and T-2006, and the dates of the inner fractions of samples T-3422 and T-2007, correspond relatively well with the radiocarbon dates of the same samples. This suggests that the dates could be reasonably correct.

The amino-acid dates

The amino-acid ratios in marine shells vary with time, and this has been used to date shells (Miller et al., 1980). Unfortunately other factors also influence the amino acid ratios and can create serious dating problems. This is particularly true for temperature variations.

Locality	Lab. no.	Material dated	Altitude in m.a.s.l.	Host sediment	Foram. fauna	Max. or min. shore level	* C-age years B.P.
1. Oppstad	T-3422A	Shell	170 m	Tectonized clay (till)	cold	min. 180 m	39,200 ⁺¹⁸⁰⁰ ₋₁₆₀₀
2. Oppstad	T-3422B	Shell	170 m	Tectonized clay (till)	cold	min. 180 m	38,600 ⁺¹⁶⁰⁰ ₋₁₃₀₀
3. Oppstad	T-922	Shell	170 m	Tectonized clay (till)	cold	min. 180 m	41,300 ⁺⁶²⁰⁰ ₋₃₅₀₀
4. Foss, Eigeland	T-3423A	Shell	65 m	Tectonized clay (till)	cold, >20 m depth	min. 70 m	27,900 ⁺⁸⁵⁰ ₋₇₆₀
5. Foss, Eigeland	T-3423B	Shell	65 m	Tectonized clay (till)	cold, >20 m depth	min. 70 m	31,330 ⁺⁷⁰⁰ ₋₆₄₀
6. Hove, Sandnes	Y-2377	Shell	40 m	Marine	cold, >20 m depth	min. 60 m	38,100 ⁺¹⁰⁰⁰
7. Hove, Sandnes	T-923	Shell	40 m	Gl.fluv.		?	41,400 ⁺⁴⁵⁰⁰ ₋₂₉₀₀
8. Graveren, Sandnes	T-641	whale bone	20 m	Marine clay	cold, >20 m depth	min. 40 m	>27,300(2σ)
9. Graveren, Sandnes	U-2121	whale bone	20 m	Marine clay		min. 40 m	>27,300(2σ)
10. Lura, Sandnes	T-148	Shell	?	Marine clay		?	>23,000(2σ)
11. Reve, Sandnes	T-567	Shell	8 m	Marine clay			>37,500(2σ)
12. Lerbrekk	T-116	Shell	20 m	Tectonized clay (till)			>36,000(2σ)
13. Lerbrekk	T-640	Shell	20 m	Tectonized clay (till)	cold	?	41,500 ^{±2000}
14. Lerbrekk	T-3011	Shell	20 m	Tectonized clay (till)	cold	?	43,100 ⁺²³⁰⁰ ₋₁₈₀₀
15. Lerbrekk	T-3631	Shell	20 m	Tectonized clay (till)	cold	?	46,700 ⁺³⁰⁰⁰ ₋₂₆₀₀
16. Bø, Karmøy	T-140	Shell	15 m	Tectonized clay (till)	cold	?	34,000 ^{±3000}
17. Bø, Karmøy	T-1784	Shell	15 m	Tectonized clay (till)	cold	?	35,900 ⁺¹⁹⁰⁰ ₋₁₅₀₀
18. Bø, Karmøy	T-2006	Shell	15 m	Tectonized clay (till)	cold	?	37,500 ⁺²²⁰⁰ ₋₁₇₀₀
19. Bø, Karmøy	T-2007	Shell	15 m	Tectonized clay (till)	cold	?	38,300 ⁺²⁴⁰⁰ ₋₁₇₀₀
20. Bø, Karmøy	T-2953A+B	Shell	15 m	Marine nearshore	shallow	max. 20 m	38,500 ⁺¹⁷⁰⁰ ₋₁₄₀₀
21. Bø, Karmøy	T-2953C+D	Shell	15 m	Marine nearshore	shallow	max. 20 m	42,700 ⁺²⁶⁰⁰ ₋₁₈₀₀
22. Bø, Karmøy	T-2954	Shell	15 m	Marine nearshore	shallow	max. 20 m	>46,500(2σ)
23. Nygaard, Karmøy	T-796	Shell	5 m	Marine nearshore	shallow	max. 20 m	39,200 ^{±2000}
24. Nygaard Karmøy	T-797	Shell	5 m	Marine nearshore	shallow	max. 20 m	42,000 ^{±2000}

TABLE 3. Radiocarbon dates of samples from Jæren and Karmøy. T-922 was collected by K.O. Bjørlykke and submitted by the writers. T-148 was collected and submitted by R. Selmer-Olsen. T-140 was collected and submitted by H. Holtedahl (in Ringen 1964). T-796 and T-797 were collected by P.A. Øyen and submitted by the writers. All other samples were collected and submitted by the writers. T-3422A, T-3423A and T-2953A + B are dates of outer fractions. T-3422B, T-3423B and T-2953C + D are dates of inner fractions. From Andersen et al. (1981).

The dating method was discussed, and the results of dates shells and foraminifera from western Norway were presented by Miller et al. (1983), and Andersen et al. (1983).

Description of the profiles

Sandnes. An outline of the result of our studies at Sandnes was presented by Andersen et al.

(1981), and the following is a short summary, see Pl. 9. The lithostratigraphy was studied in two open pits at Graveren and Austråt. At Graveren a unit of marine clay, about 30 m thick (Gann clay), was observed below a 3 m - 6 m thick unit of mainly sand (Austråt sand) and a thin sheet of till (Stavanger diamicton). The lowermost 10 m of the Gann clay was observed only in core samples collected by the

Locality	Lab.no.	Material dated	Fraction g	²²⁶ Ra c/min. 10 g	²³⁴ U c/min. 10 g	Ra/U	Th/U-age years B.P.	¹⁴ C-age years B.P.
1. Oppstad	T-3422A	<i>Mya truncata</i>	7.15	18.3	25.6	0.61	109,000	39,200 ± 1800
Oppstad	T-3422B	<i>Mya truncata</i>	7.40	19.9	50.0	0.35	48,800	38,600 ± 1600 1300
2. Foss-Eigeland	T-3423A	<i>Mya truncata</i>	3.75	11.3	12.8	0.75	166,000	27,900 ± 850 760
Foss-Eigeland	T-3423B	<i>Mya truncata</i>	7.59	4.9	9.0	0.47	74,000	31,330 ± 700 640
3. Lerbrekk	T-116	<i>Arctica islandica</i>	24.36	1.9	5.1	0.33	46,000	> 36,000
4. Lerbrekk	T-116B	<i>Arctica islandica</i>	8.34	2.8	6.2	0.39	57,000	Not ¹⁴ C-dated
Lerbrekk	T-116C	<i>Arctica islandica</i>	4.59	2.0	1.3?	1.34	Lost	
5. Lerbrekk	T-230B	<i>Arctica islandica</i>	12.64	4.4	7.6	0.50	80,600	Not ¹⁴ C-dated
Lerbrekk	T-230C	<i>Arctica islandica</i>	9.19	2.8	5.6	0.44	65,700	
6. Lerbrekk	T-3631A	<i>Arctica islandica</i>	7.50	2.9	8.7	0.29	39,400	46,700 ± 3000
Lerbrekk	T-3631B	<i>Arctica islandica</i>	7.78	1.8	3.7	0.42	58,000	± 2600
7. Bø, Karmøy	T-140	<i>Mya truncata</i>	28.66	4.5	13.4	0.30	40,400	34,000 ± 3000
8. Bø, Karmøy	T-2006A	<i>Arctica islandica</i>	2.94	8.3	20.1	0.36	50,800	
Bø, Karmøy	T-2006B	<i>Arctica islandica</i>	12.07	4.0	16.8	0.21	27,000	37,500 ± 2200
Bø, Karmøy	T-2006C	<i>Arctica islandica</i>	12.14	3.8	12.8	0.27	36,200	± 1700
9. Bø, Karmøy	T-2007A	<i>Mya truncata</i>	1.90	9.4	13.1	0.63	113,000	
Bø, Karmøy	T-2007B	<i>Mya truncata</i>	8.16	3.7	11.3	0.29	38,900	38,300 ± 2400
Bø, Karmøy	T-2007C	<i>Mya truncata</i>	8.21	3.8	11.5	0.29	38,900	± 1700
10. Bø, Karmøy	T-2953A	<i>Mya truncata</i>	12.11	7.1	41.6	0.15	18,600	38,500 ± 2300 1800
Bø, Karmøy	T-2953B	<i>Mya truncata</i>	15.61	4.6	21.9	0.18	23,100	39,200 ± 2600 2000
Bø, Karmøy	T-2953C	<i>Mya truncata</i>	11.65	4.5	11.8	0.24	46,100	42,200 ± 3600 2500
Bø, Karmøy	T-2953D	<i>Mya truncata</i>	12.42	3.1	6.1	0.45	63,600	43,000 ± 3700 3500
11. Bø, Karmøy	T-2954A	<i>Chlamys islandica</i>	7.53	4.9	5.2	0.82	197,000	> 46,500 2σ
Bø, Karmøy	T-2954B	<i>Chlamys islandica</i>	14.20	1.2	2.6	0.54	88,000	

TABLE 4. Thorium/Uranium dates versus radiocarbon dates for 11 shell samples from Jæren—Karmøy. All samples were collected and submitted by the writers. A: Outer fraction. B: Inner fraction. From Andersen et al. (1981).

writers. The foraminifer fauna in the Gann clay was observed in core samples from Lura and Graveren and in samples from the pit walls at Graveren and Austråt. Most of the analyses were carried out by Feyling-Hanssen (1971) who recognized 4 foraminiferal zones: *Zone IV* lies at the base and is almost barren of fossils. *Zone III* clays contain a cold-water fauna. The fauna in this zone is a typical shallow-water fauna (Table 1). Located 10 m to 15 m below present sea level the clay in this zone must have been deposited when the sea level was no higher than today. *Zone II* clays contain stones in the upper part and are almost barren of fossils. In the *Zone I* clays there are alternating Arctic and Boreo-arctic to high Boreal foraminiferal faunas which must have lived in waters at least 10 m - 20 m deep. Since in situ *Zone I* clays lie up to at least 20 m above sea level a transgression

of minimum 50 m must have taken place in the period between the deposition of *Zone III* and *Zone I* clays (Andersen et al. 1981). Feyling-Hanssen suggested that the *Zone I* fauna represents a relatively warm Sandnes interstadial of Middle Weichselian age. Several dates presented by Andersen et al. (1981) supports the suggested age, but the presence of *Portlandia arctica* and many dropstones in parts of the clay, together with its great thickness, indicate that much of the clay was deposited near an ice front.

Feyling-Hanssen correlated *Zone II* and *III* with a Foss-Eigeland stadial of supposedly Early Weichselian age, but Andersen et al. (1981) suggested a correlation of the *Zone III* fauna with an early Middle Weichselian Bø/Nygaard interstadial fauna at Karmøy, since the two faunas are very similar (Table 1), and they both lived during a low sea-level phase. *Zone II* could

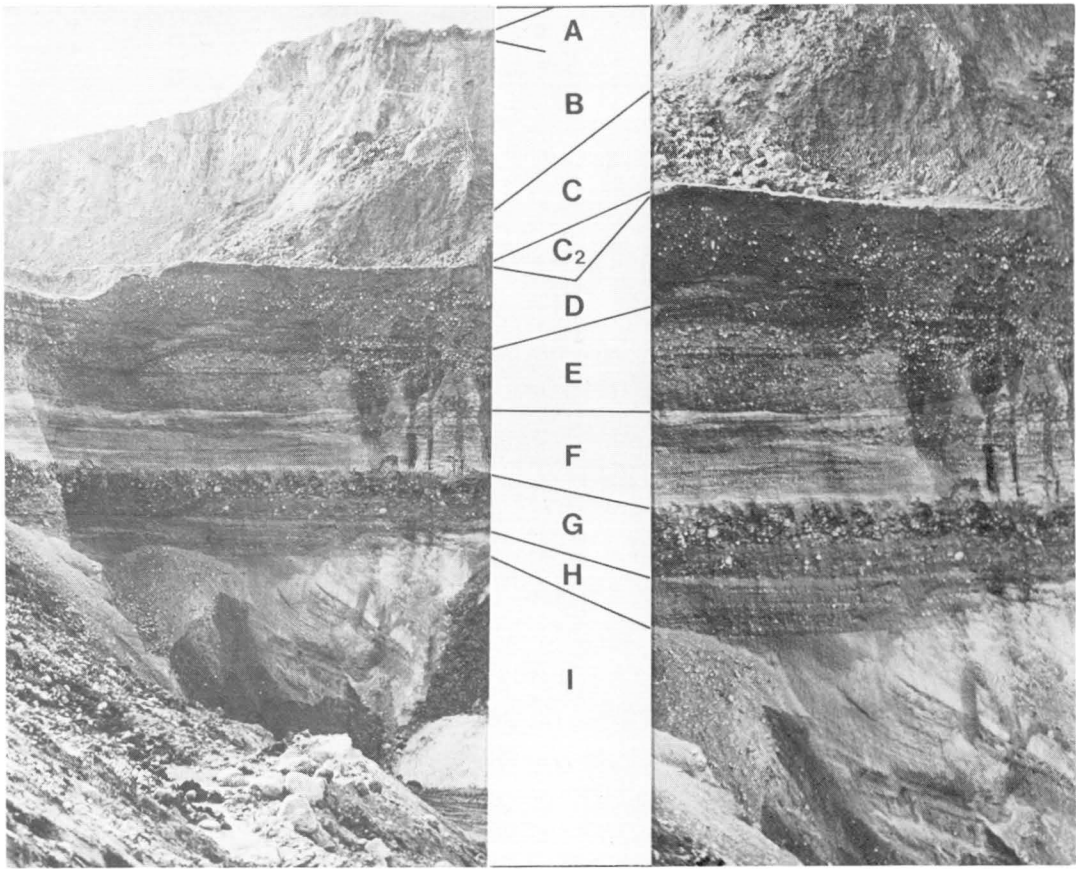


Fig. 28. The Foss-Eigeland profile. A: Kverneland diamiction, B: Kalberg clay unstratified unit, C: Kalberg clay stratified unit C₂: Vagle boulder bed, D: Foss-Eigeland diamiction, E-H: Figgjo gravel topset beds, I: Figgjo gravel foreset beds. The profile is about 30 m high.

represent a Middle Weichselian Jæren (Foss-Eigeland) glacial phase according to Andersen et al. (1981).

Foss-Eigeland

The Foss-Eigeland section too was described and discussed by Andersen et al. (1981), and was previously discussed by Østmo (1971), Bergersen et al. (1971) and Feyling-Hanssen (1974). The stratigraphy and interpretations presented by Andersen et al. is shown in Fig. 28 and Plate 9. An ice-contact outwash delta (Figgjo gravel) is overlain by a Foss-Eigeland diamiction (a till?) and Vagle boulder bed (C₂), succeeded by the 10 m thick unit of Kalberg clay of which the lower 2 m is laminated silt and clay, with a Kverneland diamiction on top (figs. 29 and 30).

The gravel in several beds in the Figgjo gravel delta is very poorly sorted (till-like), and the sorting becomes poorer and the boulder size larger in the upstream (ice-contact) direction. This is therefore a typical ice-marginal delta.

The interpretation of the Foss-Eigeland diamiction is more problematic. All of the mentioned scientists, except Østmo (1971), suggested that it is a true till. A small clay content (about 5%) in the matrix of the diamiction favours this interpretation. However, Østmo observed that the bed lies conformably on top of the topset beds, and that the roundness of the cobbles and boulders is about the same as in the beds below. He therefore suggested that it is the upper bed of the delta topset unit.

Between the Foss-Eigeland diamiction and the Kalberg clay there is a cobble and boulder

layer (C₂ in Fig. 28) which Østmo (1971) described, and he suggested that the lag was formed during a transgression of the sea across the delta.

The foraminiferal fauna observed in the Kalberg clay (Table 1) is of the Arctic Sandnes Zone I type (Feyling-Hanssen 1966, Østmo 1971), and it most likely lived at depths greater than 20 m (Andersen et al. 1981). Thus a considerable transgression must have taken place between the deposition of the Figgjo delta and the Kalnes clay. Radiocarbon dates of molluscs of an Arctic fauna from this clay suggest an age somewhat higher than 31.000 yrs. B.P. (Andersen et al. 1981). The dates are probably a minimum.

Høg - Jæren

Profiles from the *Oppstad* clay pit (175 m above sea level) and *Elgane* (198 m) were presented and discussed by Andersen et al. (1981), and both profiles show a clayey *Oppstad* diamicton (till) of Late Weichselian age, which overlies marine clays. The clays contain a Boreo-arctic foraminifer fauna which was correlated with the Sandnes Zone I fauna. A molluscan fauna in the diamicton at *Oppstad* too is of a Boreo-arctic type, and radiocarbon dates of two shell samples suggest an age of about 40.000 yrs. B.P. (see Table 3).

A simplified profile from *Høgemork*, 210 m above sea level, was presented by Andersen et al. (1981). A more detailed profile is shown in Fig. 31. The profile was constructed on the basis of cores collected by the Norwegian Geological Survey and studied by the writers. About 5.5 m of clayey *Oppstad* diamicton (till) overlies a 27 m thick unit of *Høg-Jæren* clay and 4 m of *Høgemork* gravel. The *Oppstad* diamicton can be traced laterally across a wide area and represents the Late Weichselian Stavanger stadial. The *Høg-Jæren* clay unit is stratified and contains sand, silt and clay beds, in part laminated (Fig. 33). Several clay beds are pebbly and cobbly, and were interpreted as glaciomarine beds or flow tills. Some of them could even be true subglacial tills. A foraminiferal fauna of the Arctic Sandnes Zone I type was observed in the analyzed samples (Table 1). Pollen analysis was carried out on samples from 4 levels (Figs. 31 and 32). A mixed flora was observed, but it was assumed that the pollen of all thermophilous species were re-sedimented, and the pollen of the Boreal species like *Pinus* was either rese-

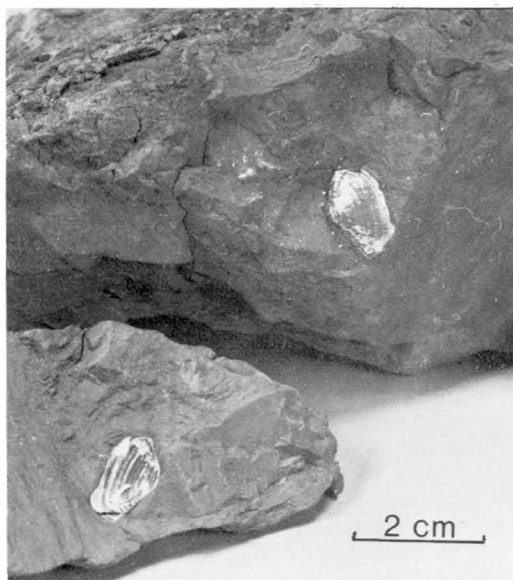


Fig. 29. *Yoldiella lucida* in the autochthonous part of the Kalberg clay near Foss-Eigeland.



Fig. 30. Laminated Kalberg clay and silt in the pit on the south side of the Figgjo River, near Foss-Eigeland.

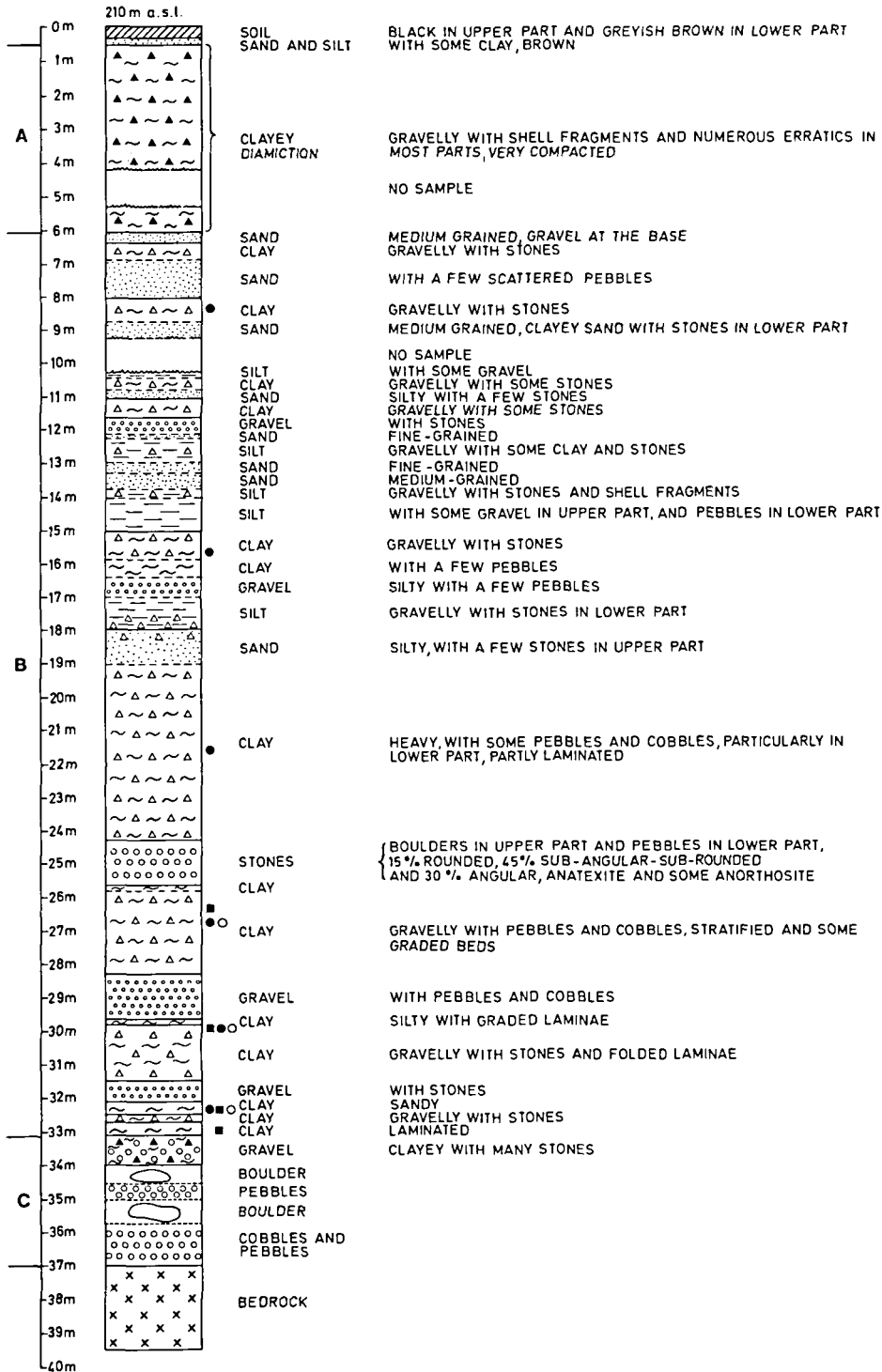


Fig. 31. The core profile from Høgemork, 170 m - 210 m above sea level. A: Oppstad diamiction. B: Høg-Jæren clay. C: Høgemork gravel. Black circle: foraminifer analysis. Black square: pollen analysis. Open circle: picture shown in Fig. 33.

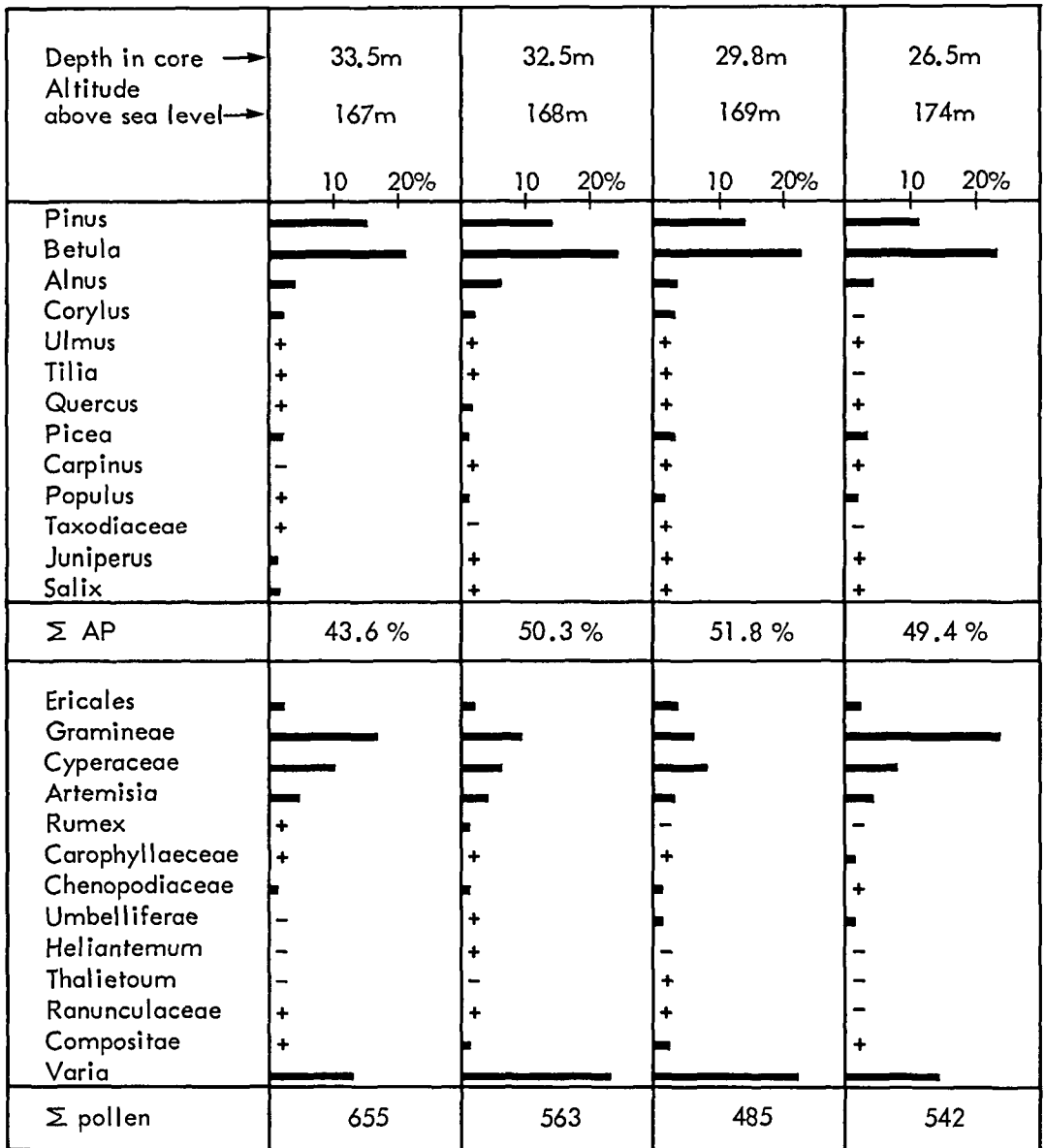


Fig. 32. Pollen in four core samples from Høgemork. A preliminary study carried out by I.L. Kristiansen.

dimented or far travelled by air. The non-arboreal pollen (50%) and *Betula* pollen (20%), too, may all be secondary pollen. However, the dominance of this type of pollen suggests that much of it could represent the vegetation at the time of deposition. Since many *Betula* pollen are of the small *nana* type, this vegetation was most likely of an open Arctic or sub-Arctic type with a strong element of *Artemisia*.

The Høgemork gravel consists of a 3 m thick gravel and boulder member, which is overlain by a clayey and bouldery gravel member. Edge-rounded stones dominate in both members, which were interpreted respectively as glaciofluvial deposits and till. The upper part of the boulder-gravel member, including the large boulders, could be a gravelly till also.

The Høgemork gravel unit was tentatively

correlated with the Jæren stadial and the Høg-Jæren clay unit was correlated with the Sandnes interstadial.

Grødeland

A core profile, about 100 m deep, from the present shore zone at Grødeland showed 3 m clayey till on top of 44 m gravel and sand, in turn underlain by 32 m sand and 13 m clay with cobbles, which rests on bedrock (Plate 7). Bjørlykke (1908) suggested that the upper clayey till and the lowermost cobbly clay could represent two glaciations older than the last, and he indicated that the sand-gravel unit could represent an interglacial. Isachsen (1942) considered all of the beds in the Grødeland profile to be of Saalian age. Feyling-Hanssen (1971, p. 116) analyzed a small sample (11.9 gram) from the lowest-lying clay, and found the following foraminifera: *Elphidium excavatum* (9 specimens), *Cibicides refulgens* (5), *Cassidulina crassa* (4), *Cibicides lobatulus* (3), *Textularia* (1), *Dorothia* (1), *Trifarina angulosa* (1), *Pseudonodosaria* (1), *Islandiella norcrossi* (1), *Islandiella teretis* (1). Feyling-Hanssen considered that this fauna was very different from the fauna in the Sandnes clays, and suggested that it is older.

In the autumn of 1970 a 12 m-deep well was dug for a destruction plant at Grødeland. On the basis of observations from this well and on information from a well-driller, a revised Grødeland profile can now be presented. The following main units were distinguished (Plate 7, IV): A: Reime diamicton, B: Grødeland diamicton, C: Sunde gravel, D: Stemma sand and E: Hobberstad clay, which rests on bedrock.

Units A and B, the Reime and Grødeland diamictons, were exposed in the walls of the well. There, about 5.5 m of very clayey Reime diamicton overlies 5 m of a very gravelly Grødeland diamicton with numerous large erratics. The gravelly diamicton rests on stratified sand of which about 2 m was exposed approximately at sea level. Both diamictons are tills. The clayey Reime diamicton was subdivided into a light brown upper member about 2 m thick, and a bluish-grey lower member about 3.5 m thick. The colours of the two beds most likely reflect the colours of different marine sediments from which much of the matrix was derived. Therefore different red-ox conditions in the original marine environment could be the cause for the colours. Both the brown and the grey till units

contained some gravel and erratics, including some large erratics. Small fragments of shells lay in the grey till. Rounded and edge-rounded stones dominate, and fabric analysis in both till types showed a preferred orientation of the a-axis in a west-southwest direction (Plate 3). Pebble counts showed about 1% rhomb-porphyr, 12% - 14% anorthosite and about 85% anaxite in both members of the Reime diamicton. This diamicton must therefore have been deposited by a glacier which flowed in a westerly direction. The brown clayey member is definitely of Late Weichselian age, and the grey member could be of the same age or older.

The very gravelly Grødeland diamicton contains almost no clay. Unfortunately the pit walls were too steep for a detailed analysis of the Grødeland diamicton, but all observed large boulders were of Precambrian rocks which outcrop in the mountains to the east of Jæren. Therefore the transport of this till too must have been towards the west. The small amount of clay in the till suggests that it could be older than the presumed Middle Weichselian marine clays on Jæren, and it was tentatively correlated with the Karmøy stadial of Early Weichselian age (p. 51).

The Sunde gravel unit consists of about 44 m of gravel and sand beds, according to the old core record. However, information about the Sunde gravel unit is very sparse. Isachsen (1942, p. 44) quoted from Dahl's reports to a newspaper in Stavanger, stating that a shell-sand was observed about 38 m below sea level. Recent information from a well-driller suggests that there are beds of silt and clay within the upper 30 m of the Sunde gravel unit, and shell fragments were pumped up from several horizons not far from Grødeland. Therefore, the Sunde gravel unit contains sand, silt and clay beds, and beds with shells. This indicates that the section is of marine or glaciomarine origin.

The Stemma sand unit consists of 33 m of sand beds, according to the old core record, and no additional information has been obtained. Located 40 m to 70 m below present sea level this unit too is most likely marine or glaciomarine.

The Hobberstad clay is a 13 m-thick unit of cobbly clay with a cold-water foraminiferal

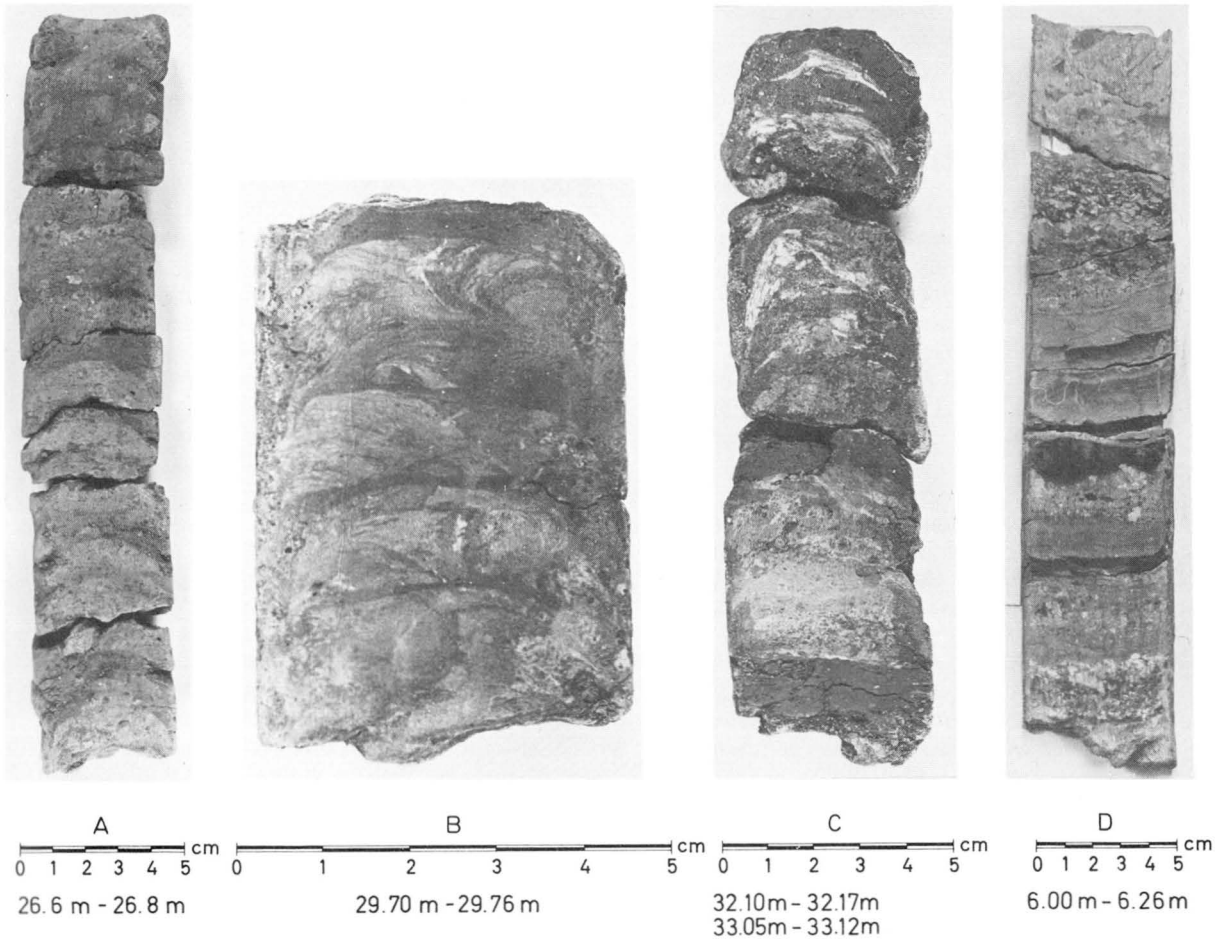


Fig. 33. Sections of cores from Høgemork (A, B, C) and Oppstad (D). The depths below the surface are indicated, in metres.

fauna, and it is most likely glaciomarine or a deformation till. As indicated by Feyling-Hanssen (1971) the foraminiferal fauna in the clay is probably older than the Sandnes clay. Therefore an older Weichselian age, or a Saalian age, is tentatively suggested.

Lerbrekk

Three lithological main units were observed at Lerbrekk, 15 m to 30 m above sea level: The Upper Lerbrekk diamiction, the Tvihaugbekken sand and the Lower Lerbrekk diamiction. The 3 units were observed by Dahl, who was in charge of the drilling in the area (Plate 7, II), and by Bjørlykke (1908) who found 3 m to 3.5 m of clayey diamiction with shell fragments above 2

m of medium sand which grades downward into fine sand. This sand rests on another clayey diamiction with shell fragments. Bjørlykke observed the described profile in a bluff at the brook Tvihaugbekken. This bluff is now covered with slump and vegetation, but the writers observed the three main units by excavating several small parts of the 10 m-high bluff at Lerbrekk, about 100 m from Bjørlykke's profile. At this locality a bed of clayey Upper Lerbrekk diamiction, about 5 m thick overlies 0.5 m of stratified silt and fine sand which in turn rests on a bed of Lower Lerbrekk diamiction, at least 3 m thick. The silt bed must correspond with the lower part of the Tvihaugbekken sand unit, and the two diamictions are most likely sub-glacial deformation tills.

The Upper Lerbrekk diamicton contains 34% clay and some shell fragments. *Mya truncata* and *Hiatella arctica* were identified, and an Arctic foraminiferal fauna of Sandnes Zone I type (Table 1). Feyling-Hanssen (1971) who analyzed the clay sample correlated the fauna with the Sandnes interstadial fauna. However, there is a possibility that the fauna is a mixed population. A fabric analysis 0.5 m - 1 m above the base of the diamicton bed showed an east-west orientation of the pebbles (Fig. 9) and this, together with the result of the pebble count, shows that the diamicton was deposited by a glacier which flowed westwards. The contact with the underlying silt is irregular and lumps of silt lie folded into the lower 0.2 m of the diamicton.

The Tvihaugbekken sand unit has a silt member at its base. The foraminiferal fauna in this silt is Arctic of Sandnes Zone I b type (Table 1). No molluscs were found in the silt.

The Lower Lerbrekk diamicton is a very clayey till with shell fragments. Fragments of *Mya truncata*, *Arctica islandica*, *Chlamys islandica* and *Hiatella arctica* were found. The foraminiferal fauna resembles the one in the Upper Lerbrekk diamicton (Table 1). A "micro" fabric analysis carried out on the largest grains in an oriented sample showed that the till was deposited by a glacier which flowed towards the west.

The radio-carbon and U-Th dates (Tables 3 and 4) Three shell samples were radiocarbon and Th-U dated. The radiocarbon dates range between 39.000 yrs B.P. and 47.000 yrs B.P., and the Th-U dates range between 39.000 yrs B.P. and 80.000 yrs B.P. One of the samples was of a thick single piece of *Arctica islandica*. On the basis of the discussion presented by Andersen et al. (1981) an age somewhere between 45,000 and 70,000 B.P. seems most likely for the shell samples and the *Arctica islandica* fauna, and a correlation with the Bø/Nygaard interstadial was suggested.

Since no *Arctica islandica* was observed by the writers in the Upper Lerbrekk diamicton, the dated shells were most likely derived mainly from the Lower Lerbrekk diamicton, which must be younger than the shells. Therefore, the Lower Lerbrekk diamicton was tentatively correlated with the Middle Weichselian Jæren stadial. The Tvihaugbekken sand unit was correlated with the Sandnes interstadial and the Upper

Lerbrekk diamicton with the Late Weichselian Stavanger stadial.

Varhaug

T. Dahl drilled at several localities on Jæren. Beside the one at Grødeland the core from the shore zone at Varhaug (Plate 7) is of particular interest (Bjørlykke 1908, p. 20, and Reusch 1890, p. 30). There the following profile was observed: 3 m clay with boulders, 44 m gravel and 31 m sand which rests on a bouldery clay. The drilling was stopped in the bouldery clay. This is about the same stratigraphy as at Grødeland and it shows that the observed beds are of considerable lateral extent. The 44 m gravel unit very likely includes the gravelly Grødeland diamicton in its upper part.

Brusand

In an excavated pit for a new barn at the farm Sandvik near Brusand, about 15 m above sea level, the following profile was observed: 0.5 m to 1 m of till above 3 m stratified greyish-blue marine silt and clay. The till is clayey with some gravel, and the marine section consists of laminated silt and clay in the upper part, and thicker beds of clay in the lower part. All the marine beds contained well sorted sediments with no large clasts. The beds were not tectonized, except for a thin zone near the contact with the till. A sample from 1 m below the till contact contained a few foraminifera, mainly *Elphidium excavatum* and *Cassidulina crassa*. The fauna in a clay bed about 3 m below the till is shown in Plate 1 and is of Sandnes Zone I type. The corresponding sea-level must have been at least 25 - 30 m higher than today; the post glacial marine limit in this area is about 8 m above the present sea-level.

East-West cross-section from Høg-Jæren to the coast

On the basis of the above-mentioned core profiles, T. Dahl (in Bjørlykke 1908) constructed an east-west cross-profile of the Quaternary deposits on southern Jæren (Plate 7). This profile corresponds in general well with the writers' observations and with a seismic profile which was shot and interpreted by a team from the Norwegian Geological Survey (Plate 8). A sheet of Quaternary sediments about 50 m to 100 m thick, covers the bedrock. The sheet can be

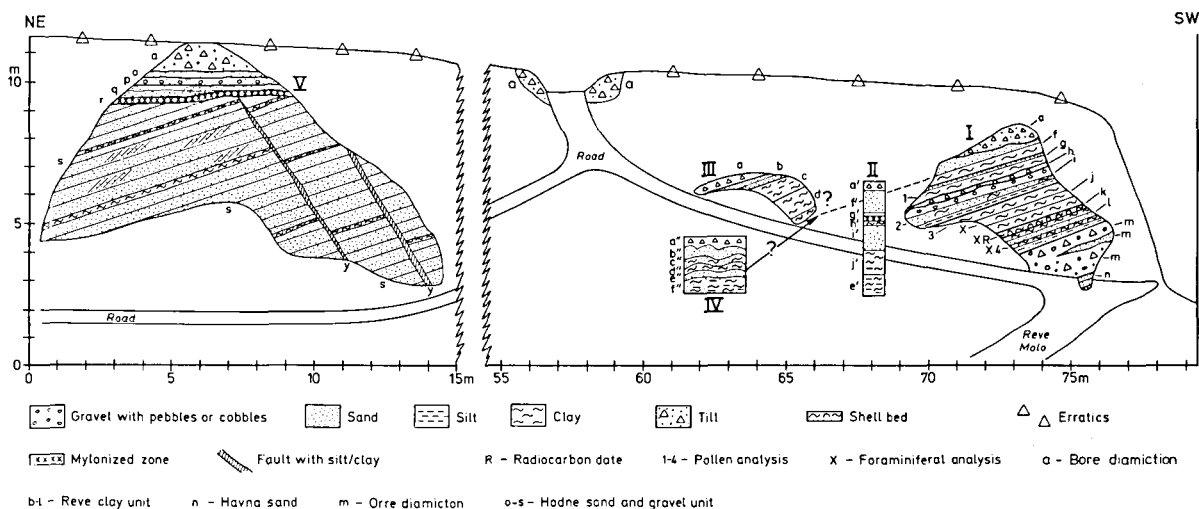


Fig. 34. Reve Harbour.

Profile I and III: (a) Bore diamiction, a sandy till, 1m-2m was exposed. (b - 1): *Reve clay unit*, (b) 1.0 m sand and silt, stratified and brown coloured in upper part. (c) 1.0 m clay, with silt and sand beds, well sorted, grey. (d) 1.0 m clay and silt, weakly bedded, bluish-grey. (e) 0.2 m silt and clay, partly laminated, bluish-grey. (f) 0.7 m - 0.3 m sand, stratified. (g) 1.0 m clay with lenses and beds of silt and sand. (h) 0.5 - 0.1 m gravel with some silt, clay and erratics, till-like. (i) 0.5 m gravel above 0.5 m sand and silt with lenses of clay. (j) 0.25 m clay, weakly bedded, greyish-blue in lower part and brown in upper part, with scattered shell fragments and pebbles. (k) 0.2 m clay, strongly brown coloured with numerous shells of *Hiatella arctica* and a few *Mya truncata*. (l) 0.6 - 0.8 m laminated clay and silt with a few sand beds, scattered pebbles and shell fragments. (m) *Orre diamiction* 2.5 m - 3 m till, sandy and gravelly with many erratics, and a sand lens. (n) *Havna sand*, 1.0 m sand and silt beds, somewhat tectonized.

Profile II. A core profile. The beds correspond well with beds marked with the same letters in profile I.

Profile IV was described by Bjørlykke (1908). a": till, gravelly with boulders, b": sand, c": clay, sandy with a *Cardium* fauna, d": clay, e": sand, f": clay with sand and *Saxicava pholadis* and *Macoma calcarea*.

Profile V: a: 1 m till, gravelly with many well rounded cobbles.

Hodne sand and gravel unit:

o: 0.3 - 0.5 m sand

p: 0.3 - 0.5 m gravel with many rounded and well rounded cobbles and pebbles. Beach gravel?

q: 0.3 - 0.7 m sand

r: 0.2 m mylonitized zone

s: 6 m medium sand, stratified with a few thin beds of clayey silt. The beds dip about 15° in northeasterly direction. The sand is yellowish - brown in upper 3 m - 4 m and yellowish in lower 2 m - 3 m.

y: fault.

divided into 4 main units on the basis of seismic velocity. A thin unit near the top and a thin lower unit with relatively high velocities (29000 m/sec.) were interpreted as clayey till beds. A thick middle unit with much lower velocities (1000 m/sec.) most likely represents the described glaciomarine and marine beds. In addition a thin discontinuous unit with velocities between 550 m/sec and 1500 m/sec overlies the upper clayey till. The interpretation of this unit is more problematic, but in some areas it must likely represent glaciofluvial deposits and gravelly tills.

Reve

Bjørlykke (1908) observed strongly folded marine beds with shells below a gravelly till on the

sea bluff at Reve, about 6 m above sea level. A *Cardium* fauna (Table 2) found in one of the beds was correlated with the fauna that lives today at Lofoten in northern Norway, and an Eemian age was suggested. The stratigraphy indicated by Bjørlykke is shown in Fig. 34. The writers observed a series of beds exposed on the same sea bluff. However, no bed with *Cardium* shells was seen, and the exact stratigraphical position of Bjørlykke's *Cardium* bed cannot be determined.

The beds observed by the writers lie between 2 m and 10 m above sea-level in four profiles at Reve Harbour (Fig. 34). One profile is a core profile. Beds dipping about 10° to 15° towards northeast were seen in all of the open profiles. This dip in addition to the orientation of step-

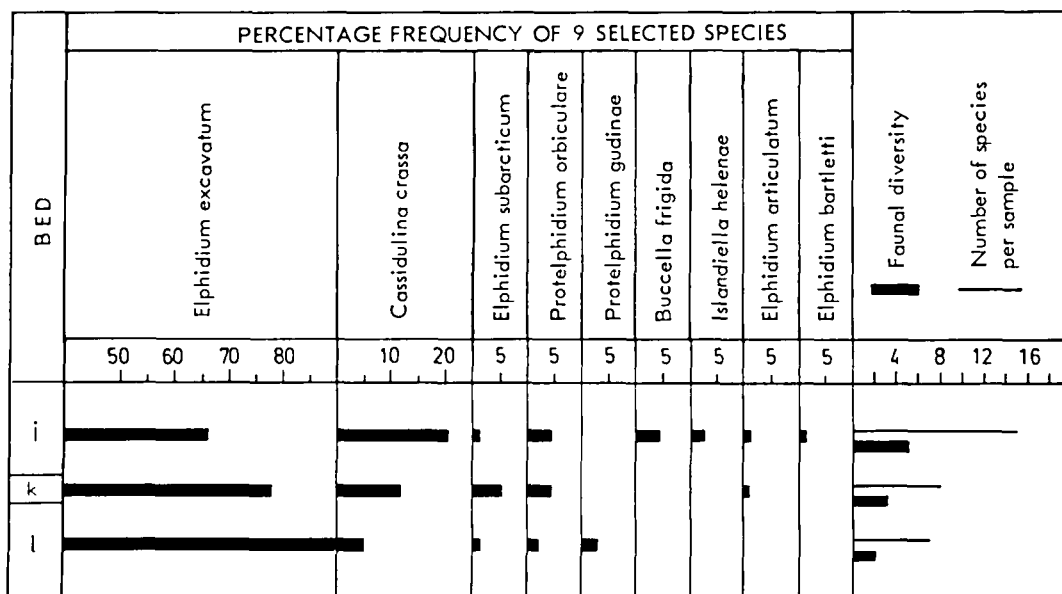


Fig. 35. Foraminiferal analysis from Reve Harbour. The samples are from beds i, k and l in section I, (see Fig. 34). Analyzed by J. Nagy.

faults in the northeastern profile (V) shows that the beds were tilted by an overriding glacier which pushed them in a southwesterly direction, the direction of the glacial striations and the drumlins in this part of Jæren. Some of the beds within the profiles are brecciated and mylonitized.

A very sandy and gravelly Bore diamicton, a Late Weichselian till (a) was exposed at the top of all the profiles. It contained numerous rounded and well rounded cobbles and pebbles (40%) in addition to several large erratics.

Profiles I and III

Below the Late Weichselian till lie the Reve clay unit, the Orre diamicton and, at the base, the Havna sand unit.

The Reve clay unit (b to l in Fig. 34) is about 10 m thick and consists mainly of clay beds and some sand and silt beds. A thin bed with clayey and bouldery gravel (h) lies in the middle of the unit and could be a till (flow till?) or a glaciomarine deposit. Scattered pebbles and cobbles were found in the lowest-lying beds (j to l). Bed l is about 1 m thick and consists of laminated clay and silt with some sand beds. The lithology suggests that the Reve clay unit is glaciomarine,

and this corresponds with the environment suggested by the observed fossils.

Scattered fragments of unidentified shells were seen in bed j and in the upper part of bed l. Bed k is an about 10 cm thick clay unit with abundant shells. *Hiatella arctica* dominates and a few small *Mya truncata* were also seen. Most of the shells were soft and disintegrated in water. The small remnants of a large sample were radiocarbon dated to a minimum of 37,500 years B.P. (T-567). Østmo (1971) described an Arctic shallow-water foraminiferal fauna in clays from l and k (Table 1). Samples from the basal 10 cm of bed l, from bed k and the upper part of bed j were analyzed by J. Nagy, and they contain a foraminifer fauna very similar to the one described by Østmo, see Fig. 35. An upwards increase in diversity (from 2 to 6) and an increase in shallow water species like *Protelphidium orbiculare*, *Buccella frigida*, *Elphidium articulatum* and *Elphidium bartletti* suggests that the water became slightly warmer and shallower during deposition of the lower part of the unit. This corresponds well with the stratigraphical position of the beds, on top of the Orre till, and with the pollen flora. A decrease in water depth could be the result of an isostatic uplift of the land. No fossils were found in the

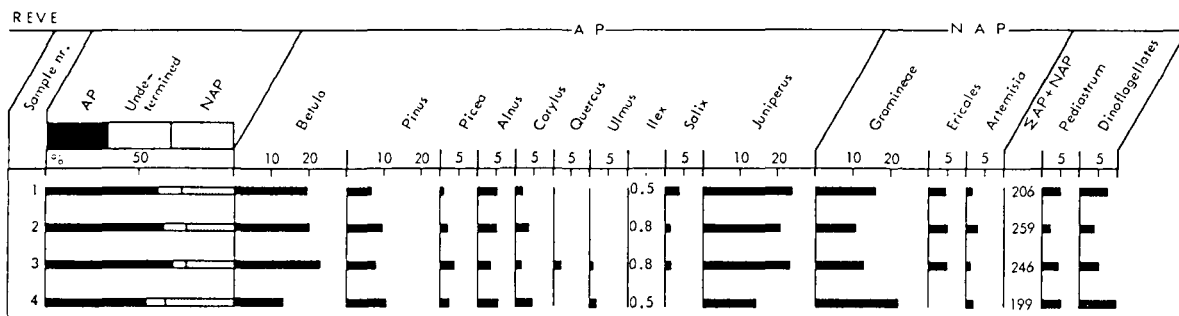


Fig. 36. Pollen analysis from Reve Harbour. The samples are from beds g (1), i (2), j (3) and l (4), (see Fig. 34). Analyzed by E. Sønstegeard.

higher-lying part of the Reve clay unit. However, the sand beds are more dominant in this part, which could reflect a shallower environment. The tectonization increases upwards in the Reve clay unit and the highest-lying beds are not necessarily in their correct stratigraphical position.

Pollen analyses from 4 horizons (Fig. 36) showed a mixed flora in all of them. Species like *Ilex*, *Ulnus*, *Corylus*, *Alnus*, *Pinus*, and *Picea* do not correspond with the lithology of the sediments, which suggest a glaciomarine environment. Therefore the pollen of these species must be redeposited or far-transported. The pollen of the other species could represent a vegetation which correspond in age with the host sediment, but they may be resedimented also. The upwards increase of *Juniperus* and *Betula* (which could in part be *Betula nana*), and the decrease of *Gramineae* suggest a change from open tundra to a tundra with scattered trees. This was indicated by E. Sønstegeard who did the pollen analysis. Test analyses, where less than 50 grains were counted, of samples from beds k and g correspond well with the analysis shown in Fig. 36.

The Orre diamicton is an about 3 m thick bed of sandy and gravelly till with many boulders. Some of the boulders are striated. The fabric analysis showed no well-defined pebble orientation. A dominance of anatexite and mica gneiss pebbles was recorded, and no far-travelled erratics were seen (Fig. 37). Edge-rounded stones dominate (78%, Fig. 38A). A maximum 0.5 m thick sand lens lies in the upper part of the bed, and together with much of the sand in the till was most likely derived from the Havna

sand at the base of the profile. The poor pebble orientation could indicate that the Orre diamicton is a supraglacial (ablation) till.

The Havna sand unit

About 1.5 m of yellowish stratified sand was exposed in a test pit below the Orre diamicton. The upper part of the sand was strongly tectonized. No fossils were found in the sand, which could be of marine or fluvial origin.

An approximately 8 m-thick sand-gravel section, the Hodne sand and gravel, was exposed below the Late Weichselian Bore diamicton in profile V. The Hodne sand and gravel consists of an upper, 1 m-thick unit of sand and gravel beds which rests on an about 7 m-thick unit of mainly medium sand with a few thin silt and clay beds. A 10 cm-thick brecciated and mylonitized zone separates the two units. The upper 4 m to 5 m of the sand-gravel section is oxidized and iron stained yellow and brown. The staining is strongest along all faults. A weak current bedding with beds dipping in a northeasterly direction was observed in some of the sand beds. The main beds in the sand unit dip 10° – 20° to the northeast and several step faults are oriented transversely to this direction. The tilting of the beds and the faulting must have been caused by the overriding Late Weichselian glacier.

No fossils were found in the Hodne sand and gravel beds, which are most likely of shallow-water marine, or possibly fluvial, origin. Their position in the bluff suggested that they lie stratigraphically on the top of the beds in profile III. However, the area between the two profiles is covered with slumped material which could

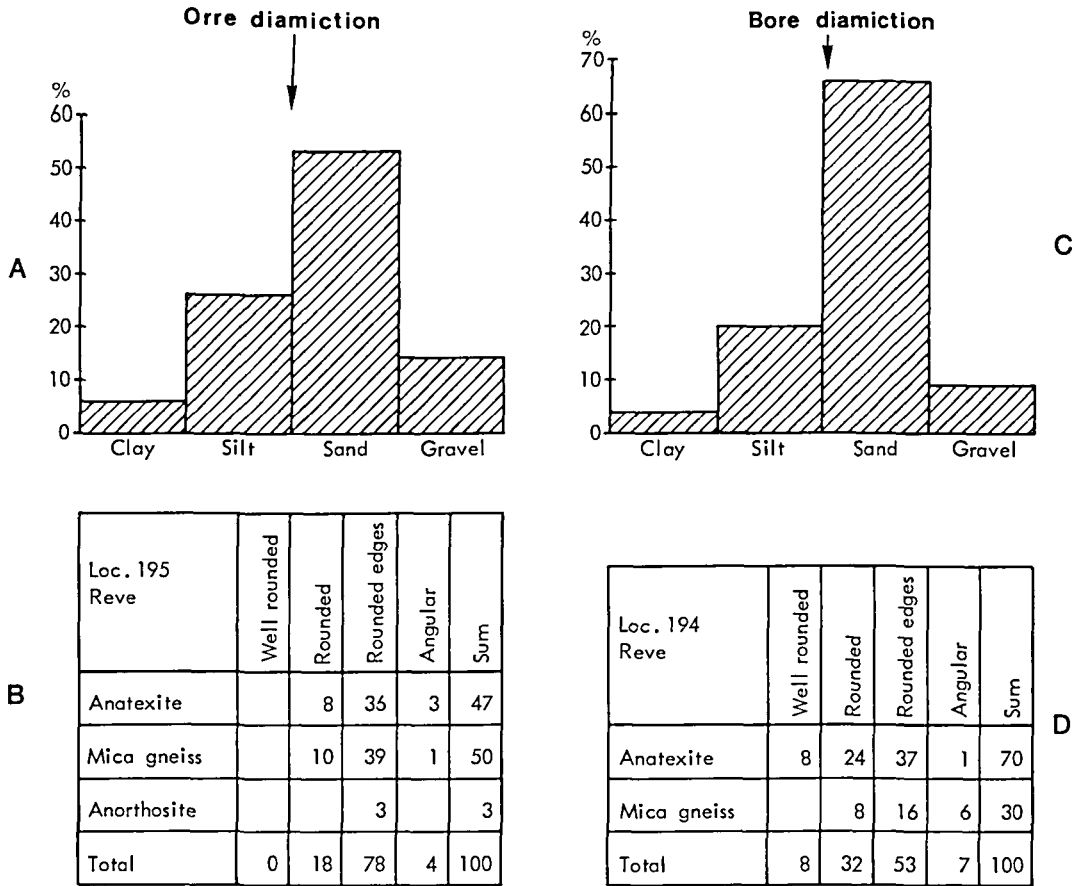


Fig. 37. Reve: Grain-size distribution, pebble counts and roundness analysis (20 mm - 60 mm fraction) in Orre diamicton (till) A and B, and in the Bore diamicton C and D. Anatexite: mainly gneisses and granites.

hide larger faults. Therefore the Hodne sand and gravel beds could be older than the Reve clay unit, and the oxidation and very strong iron staining of the beds could represent an interglacial (Eemian?) oxidation.

Bjørlykke's profile (IV)

The profile which was described by Bjørlykke (1908) is shown in Fig. 34. Strongly folded clay beds with a relatively warm-water *Cardium* fauna (Table 2) lie on top of beds with a colder-water *Macoma* and *Hiathella* (*Saxicava*) fauna. The last mentioned fauna corresponds well with the fauna in profiles I and II. However, no evidence of a *Cardium* fauna was found by the writers despite much drilling and digging on the slope. Therefore the folded clay beds with the *Cardium* fauna very likely represented a limited

lens. Since *Cardium edule* has been found in interglacial deposits of supposedly Eemian age both at Bø on Karmøy and at Fjøsanger in Bergen (H.P. Sejrup, pers.comm.), and no *Cardium* has ever been observed in the interstadial deposits on Jæren and Karmøy, a correlation of the *Cardium* fauna at Reve with a cool phase of the Eemian seems likely.

However, the stratigraphical interpretation of the Reve profiles is problematic because of the textonization of the beds. A tentative correlation is shown in Plate 9.

Districts to the east of Jæren Egrebakken

A small clay pit, 144 m above sea level, was in operation about 50 years ago at Egrebakken in

Gjesdal, 12 km to the east of Jæren (Plate 4, nr. 261). Isachsen (1942) proposed that the clay was deposited in an ice-dammed lake. However, Østmo (1971) drilled 5 m deep into the clay and found 1 m of gravelly clay with many boulders on top of 4 m clay with no stones. Sections of the clay were silty and laminated and samples collected at four levels in the clay contained altogether 8 specimens of *Elphidium excavatum*, 4 *Cassidulina crassa*, 1 *Protelphidium orbiculare* and 1 *Islandiella* sp.. This is a cold-water marine fauna which shows that the clay was deposited under Arctic conditions in the sea, and the sea level was at least 145 m higher than today in this area. A series of narrow fjords and sounds must have occupied the valley systems to the east of Jæren when the clays at Egrebakken were deposited, which was most likely during the Sandnes interstadial.

Karmøy

Three good stratigraphical profiles have been recorded on Karmøy (Fig. 1), one at Nygaard and two at Bø (I and II), all in clay pits. The Nygaard profile was described by Øyen (1905) and samples from his collection at the Paleontological Museum, Tøyen, were studied by the writers and by Feyling-Hanssen (1971), who did foraminiferal analyses of two samples (Table 1).

Andersen et al. (1981) published the Bø I profile, a revised version of the Nygaard profile and a preliminary profile of the Bø II section. Later, Andersen et al. (1983) presented the preliminary results of the more detailed stratigraphical studies in the Bø II section, and Sejrup (1986) presented the final results of his studies of the marine fauna.

The Nygaard profile consists, in stratigraphic order, of (1) a very bouldery and gravelly Karmøy diamicton (till) which rests on bedrock, overlain by (2) the Nygaard gravel unit with a *Mya truncata* fauna, (3) tectonized Karmsund clay with *Portlandia arctica* (the *Portlandia arctica*-*Hiatella arctica* Zone), (4) Haugesund diamicton (till) and (5) Dalen sand on top.

The combined Bø I—Bø II profiles (Plate 9) consist in stratigraphic order of the following units and zones: (1) Avaldsnes sand (*Ostrea edulis* Zone) with a pollen flora and marine fauna supposed to be Eemian, (2) Torvastad sand (*Mytilus edulis* — *Mya truncata* Zone) with an interstadial fauna and flora, (3) Karmøy diamic-

ton (Mixed fauna Zone) which is a very gravelly and bouldery till with some shell fragments, (4) Bø sand (Zones: Barren, *Hiatella arctica*, *Mya truncata*, *Portlandia arctica*) with an interstadial fauna and flora, (5) Haugesund diamicton. The fauna and flora together with radiocarbon dates, Th-U dates and amino-acid dates suggest the correlation indicated in Plate 9.

Conclusions

On the basis of the observations presented, the correlation shown in Plate 9 is suggested. The correlation of the different units between several profiles is problematic and must be considered tentative. The suggested ages of the stadials and interstadials, too, are tentative since they are based on amino-acid dates and radiometric dates of uncertain reliability.

However, the general trend of the dates together with the observed biostratigraphy and lithostratigraphy suggest that the following main conclusions should be relatively correct.

The Hobberstad clay at the base of the Grødeland profile probably represents a pre-Eemian (Saalian?) glaciation.

The Avaldsnes sand at Bø and the *Cardium edulis* zone at Reve are most likely of Eemian age.

Most of the sub-till beds on Jæren and Karmøy are of Middle Weichselian and Early Weichselian age, and there is evidence of three interstadials (Torvastad, Bø/Nygaard and Sandnes).

The gravelly Karmøy diamicton at Bø represents an Early Weichselian stadial, and gravelly tills in Jæren could be of the same age.

The Foss-Eigeland diamicton and the Figgjo gravel represent phases of a Jæren stadial which in part could overlap with the Sandnes interstadial.

The Late Weichselian till-sheet which covers most of Jæren and Karmøy is older than about 12.500 years B.P.

In situ sub-till marine deposits about 200 m above sea-level at Høg-Jæren most likely represent the Sandnes interstadial. The high elevation of the deposits is probably the results of combined isostatic and tectonic uplift.

A considerable marine transgression which took place immediately before the Sandnes interstadial was most likely caused by the load of the Jæren stadial glacier.

Andersen et al. (1981) attempted a correlation of the stadials and interstadials in Jæren and

Karmøy with stadials and interstadials recorded in other parts of the world, and they arrived at the following conclusion:

"The late Early Weichselian cold phases and glacier advances recorded in many areas correspond well with a late Early Weichselian Karmøy stadial. However, in most areas the dominant Middle Weichselian cold phases and glacier advances seem to be younger than $40,000 \pm 1,000$ years B.P., which is the suggested approximate age of the Jæren stadial". The age of between 41,000 and 50,000 (?) years B.P. for the Bø/Nygaard interstadial corresponds relatively well with the age of "warm" interstadials recorded in several areas. The indicated age for the cool to cold Sandnes interstadial, somewhere between 30,000 and 39,000 years B.P., corresponds with the age of cool interstadials in some areas, and cold stadial in other areas.

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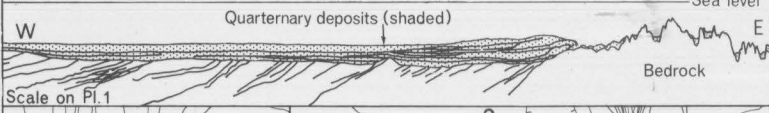
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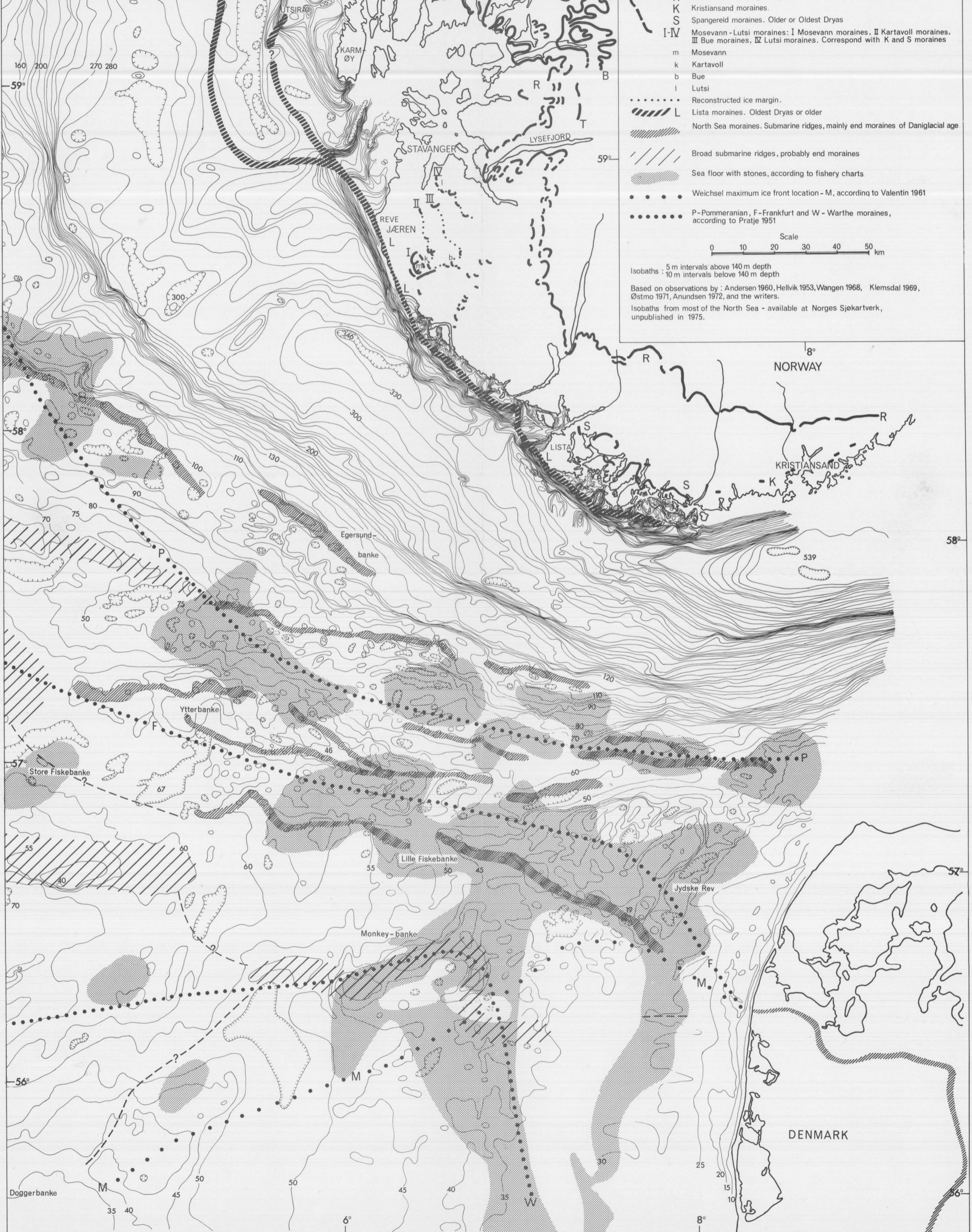
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Pl. 1 A Simplified seismic section across the Norwegian Channel, from Flodén and Sellevoll 1972. Location of the profile is west of Bømlo, see Pl. 2.

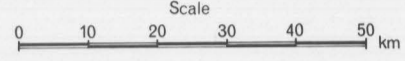


Scale on Pl. 1



Pl. 1
End moraines in southwestern Norway and adjacent part of the North Sea.

- Legend
- B Blåfjell moraines. Preboreal?
 - T Trollgaren moraines. Preboreal?
 - R Ra moraines. Younger Dryas
 - K Kristiansand moraines.
 - S Spangereid moraines. Older or Oldest Dryas
 - I-IV Mosevann - Lutsi moraines: I Mosevann moraines, II Kartavoll moraines, III Bue moraines, IV Lutsi moraines. Correspond with K and S moraines
 - m Mosevann
 - k Kartavoll
 - b Bue
 - l Lutsi
 - Reconstructed ice margin.
 - L Lista moraines. Oldest Dryas or older
 - North Sea moraines. Submarine ridges, mainly end moraines of Daniglacial age
 - Broad submarine ridges, probably end moraines
 - Sea floor with stones, according to fishery charts
 - Weichsel maximum ice front location - M, according to Valentin 1961
 - P-Pommeranian, F-Frankfurt and W - Warthe moraines, according to Pratje 1951



Isobaths : 5 m intervals above 140 m depth
 10 m intervals below 140 m depth

Based on observations by : Andersen 1960, Hellvik 1953, Wangen 1968, Klemsdal 1969, Østmo 1971, Anundsen 1972, and the writers.

Isobaths from most of the North Sea - available at Norges Sjøkartverk, unpublished in 1975.

THE JÆREN MAP AREA



Quaternary deposits

Legend












Superficial deposits

-  Till, continuous cover, locally of great thickness
-  Till, discontinuous or thin cover
-  Till, with high content of clay
-  Marginal moraine/Marginal zone
-  Till, Marginal moraine overlying glaciofluvial deposits
-  Glaciofluvial deposits
-  Esker/kame
-  Lacustrine deposits
-  Fluvial deposits
-  Marine deposits, continuous cover, usually of great thickness (shore deposits not included)
-  Marine shore deposits, continuous cover
-  Eolian deposits
-  Sand dune
-  Talus
-  Organic material
-  Anthropogenic material







Exposed bedrock

-  Exposed bedrock
-  Small exposure of bedrock





Sporadic deposits in areas dominated by other superficial deposits/exposed bedrock

-  Till
-  Till with high content of clay
-  Glaciofluvial deposits
-  Fluvial deposits
-  Marine deposits
-  Shore deposits
-  Weathering material
-  Small talus
-  Eolian deposits
-  Organic material
-  Anthropogenic material
















Grain size

-  Block (B) >256 mm
-  Stone (St) 256 mm - 2 mm
-  Gravel (G) 64 mm - 2 mm
-  Sand (S) 2 mm - 0.063 mm
-  Silt (Si) 0.063 mm - 0.002 mm
-  Clay (C) <0.002 mm

Direction of ice movement

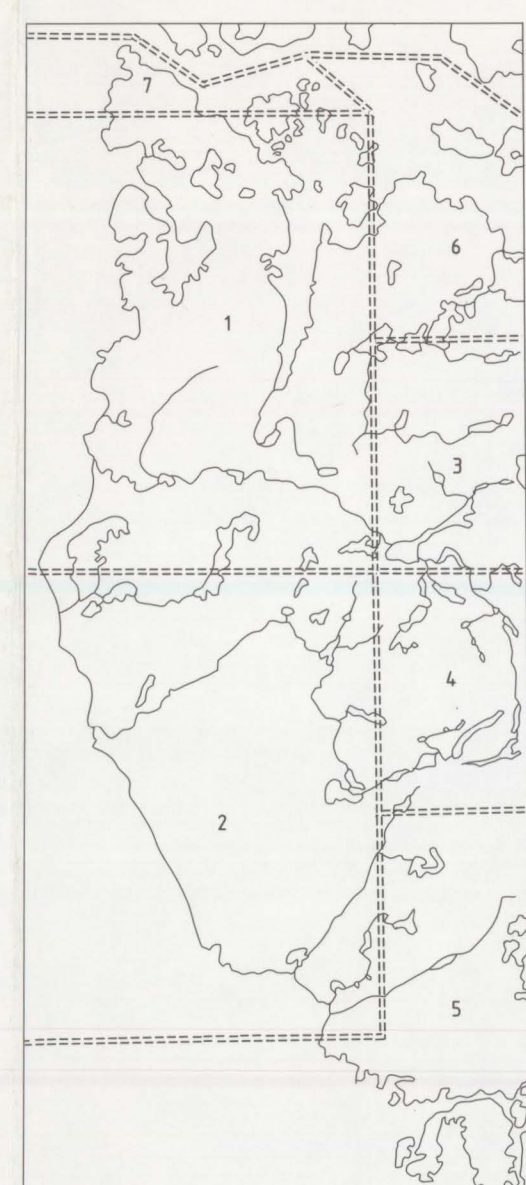
-  Glacial striae
-  Crossing glacial striae, increasing number of ticks with increasing relative age
-  Drumlin
-  Till fabric

Other symbols

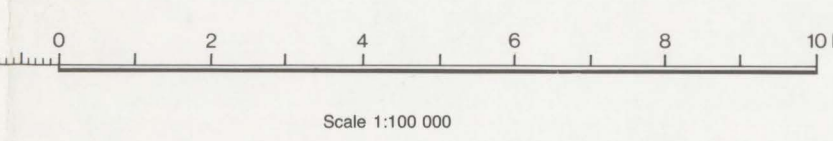
-  Shoreline from glacial ice-dammed lake
-  Glaciofluvial erosion brink
-  Meltwater channel in superficial deposits
-  Canyon
-  Kettle-hole
-  Ice-contact slope
-  Terrace-brink
-  Fluvial drainage channel
-  Fan
-  Beach ridge
-  Erosion brink
-  Hummocks and ridges
-  High frequency of boulders on the surface
-  Gravel pit
-  Seismic refraction profile with reference

The mapping of the quaternary sediments has been carried out by O. P. Wangen, S. R. Østmo, K. S. Olsen, B. G. Andersen and Th. Hellvik.

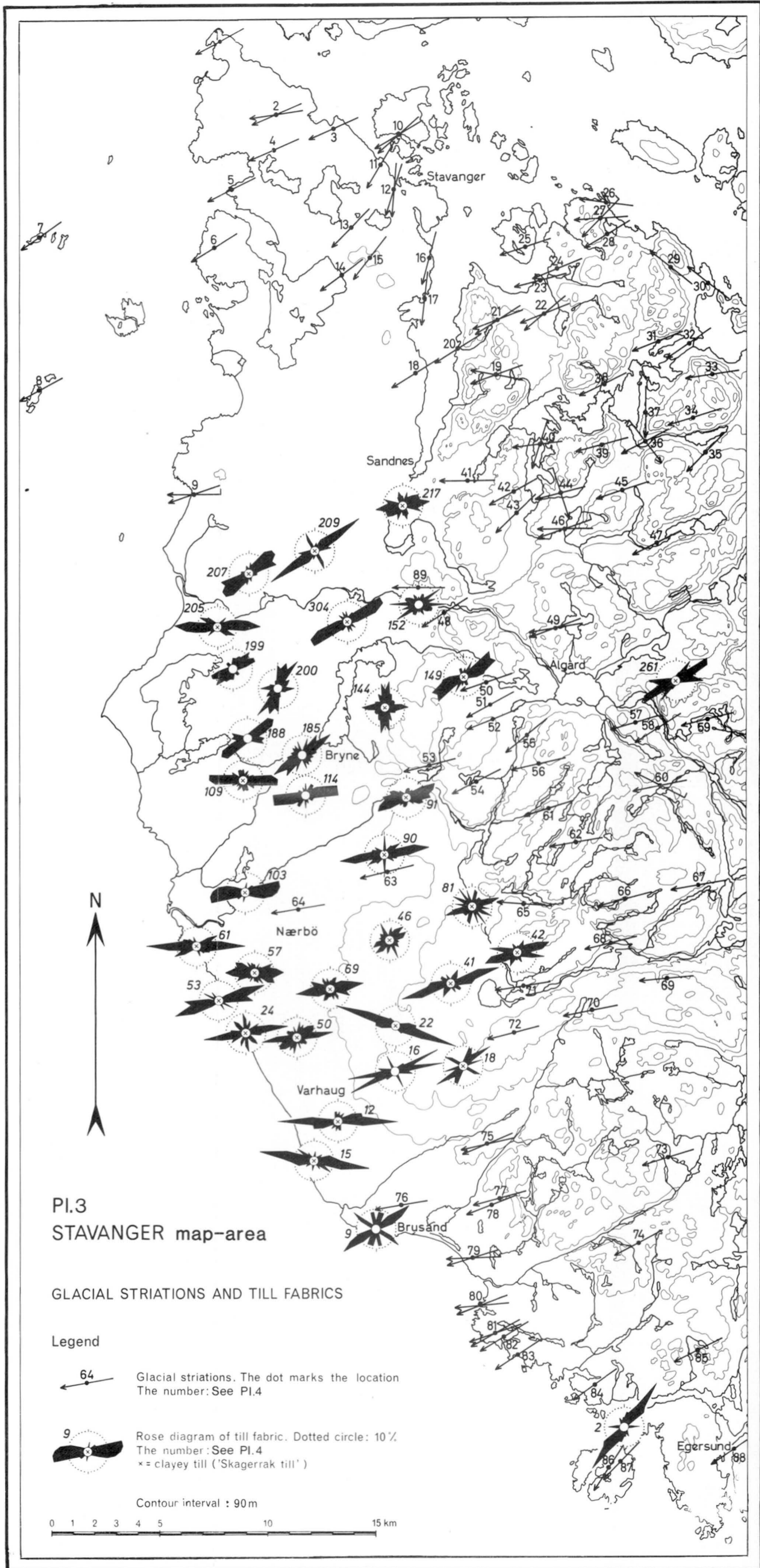
Reference to this map: Wangen, O. P., Østmo, S. R. and Andersen, B. G. - 1987. THE JÆREN MAP AREA, Quaternary deposits - Scale 1:100 000

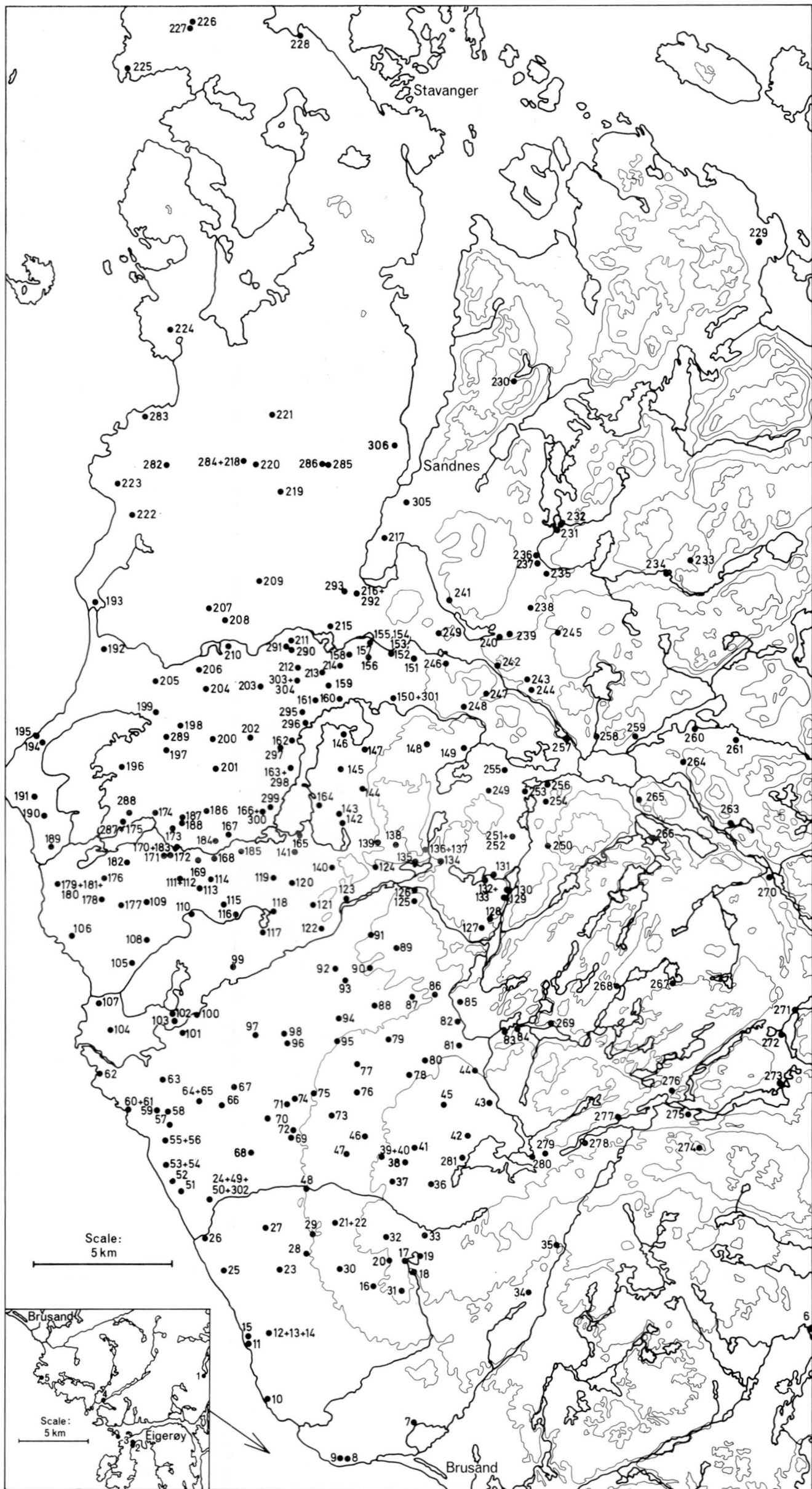


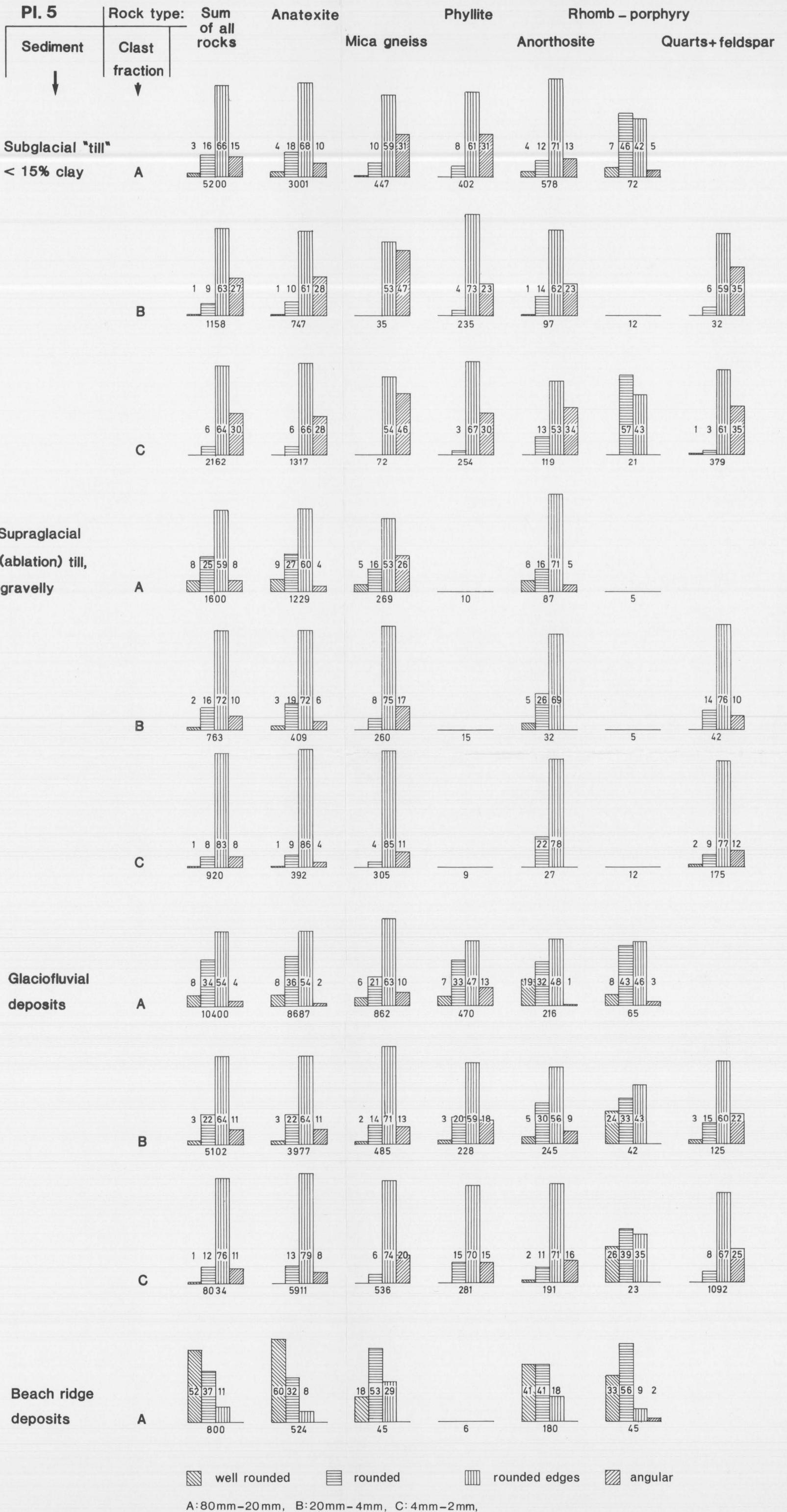
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2. Wangen, O. P.: Quaternary map, Nærba, Scale 1:50 000.
3. Østmo, S. R.: Cand. real. thesis at Dep. of Geol., Univ. of Oslo, Scale 1:50 000.
4. Wangen, O. P.: Can. real. thesis at Dep. of Geol., Univ. of Oslo, Scale 1:50 000.
5. Wangen, O. P., Andersen, B. G., Hellvik, Th. and Garmes, K.: Field work and aerial photo interpretation.
6. Østmo, S. R.: Aerial photo interpretation.
7. Østmo, S. R.: Field work and aerial photo interpretation.

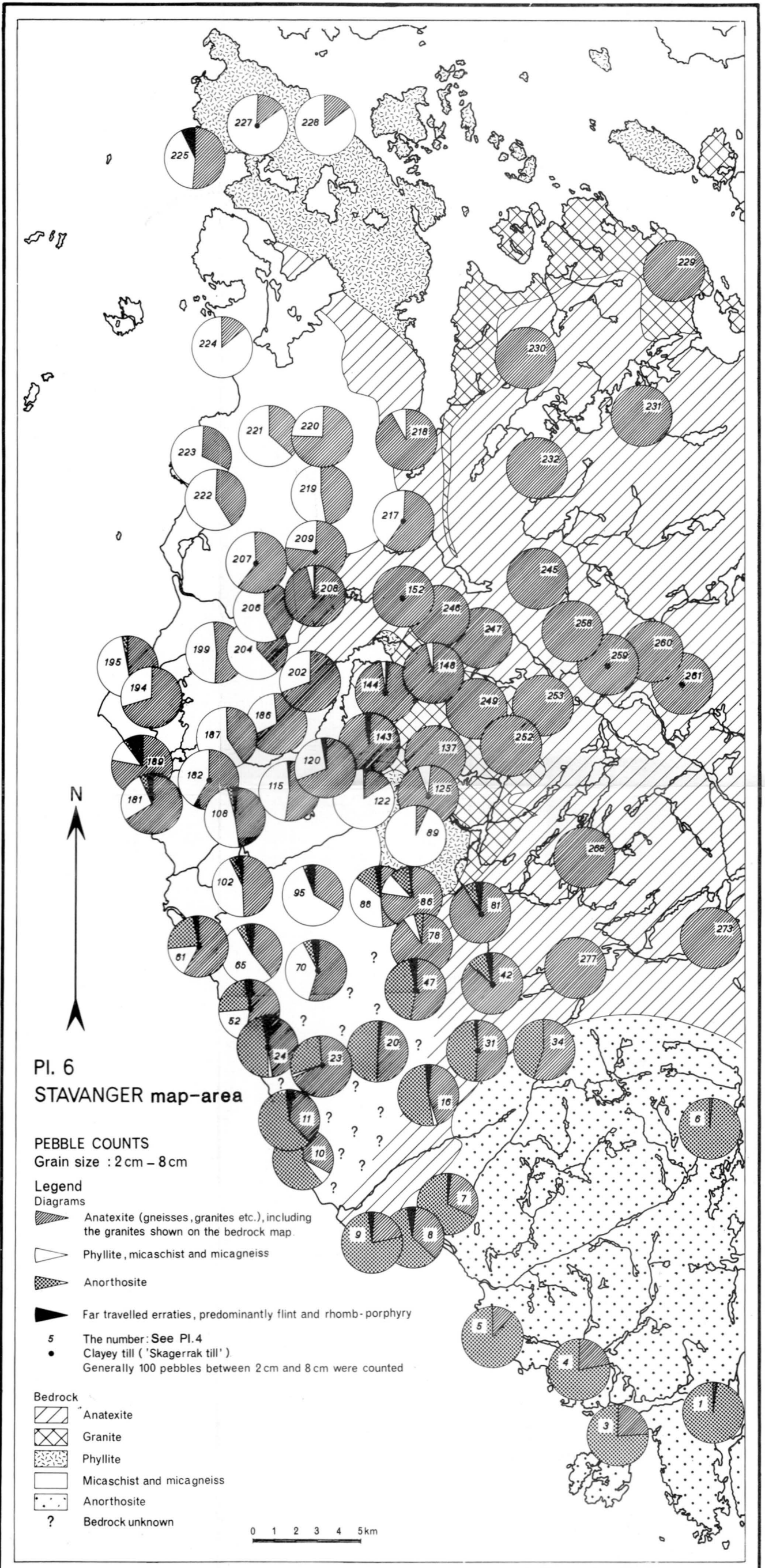


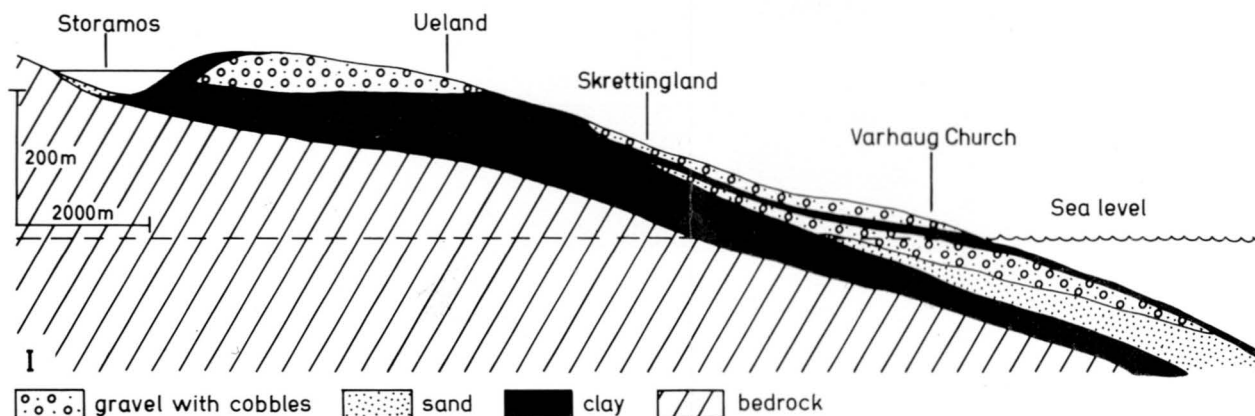
Kartgrunnlag : Norges geografiske oppmålings kart etter tillatelse
 Reprografi : Norges geologiske undersøkelse
 Trykk : A/S Adresseavisen, Trondheim 1987



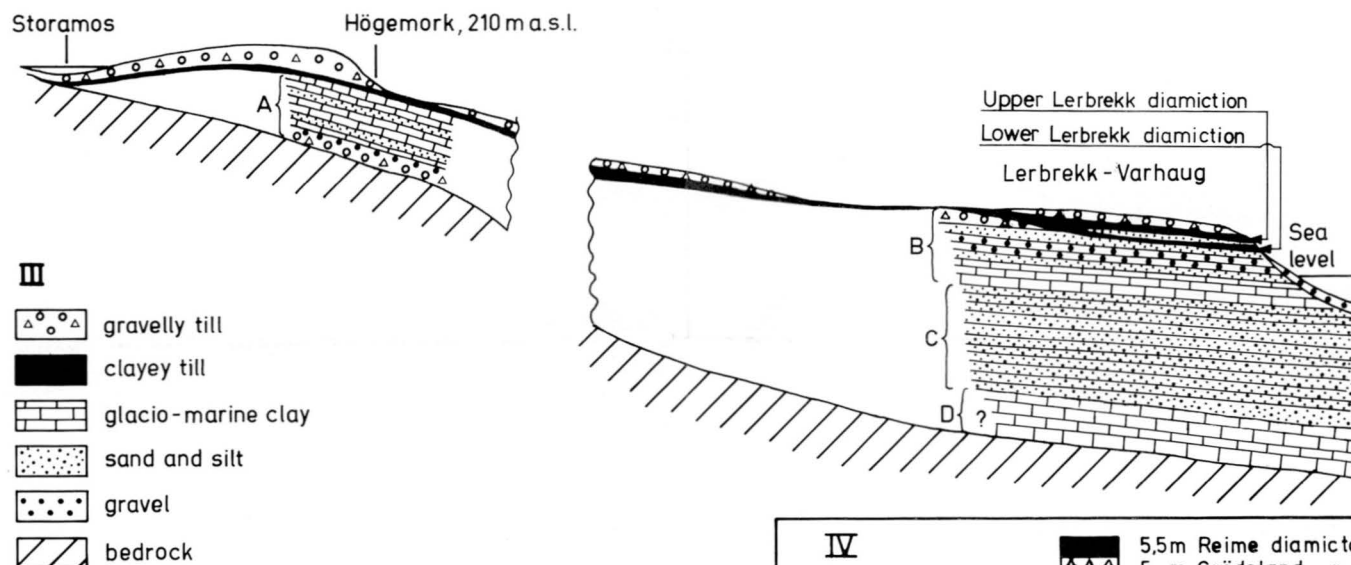
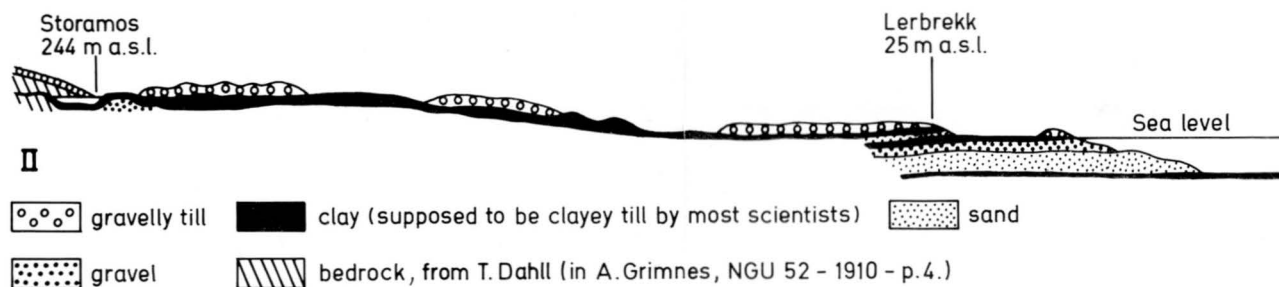




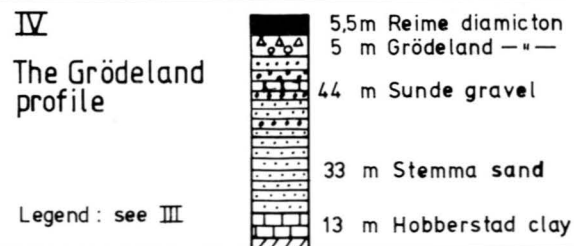


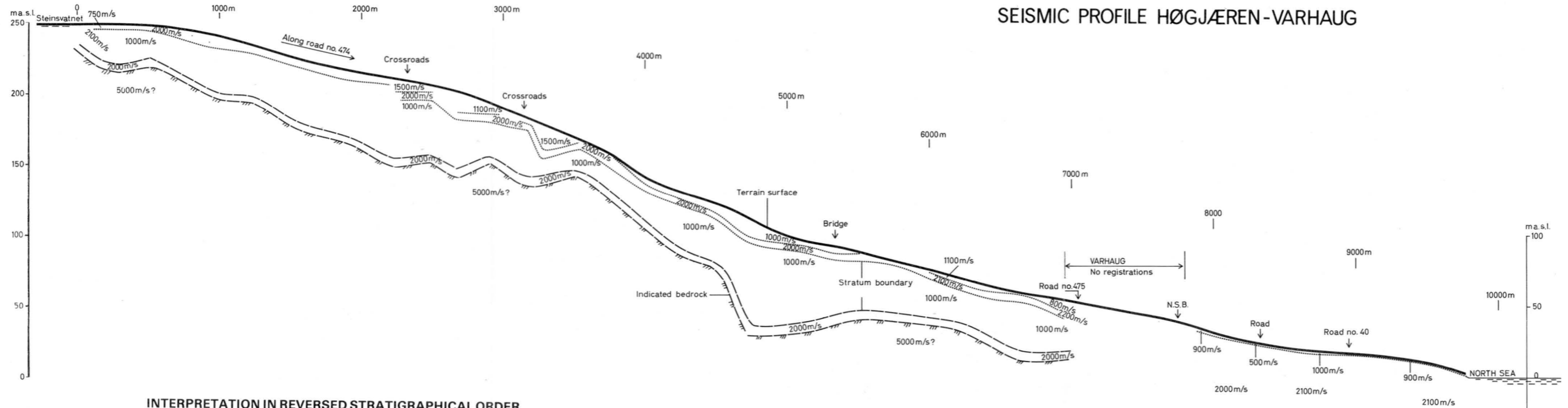


Profile Storamos - Varhaug Church. From A.Grimnes, NGU 52 (1910) p.13.



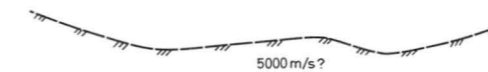
A: Observations from core
 B: Observations by Dahll (in Reush 1890) and the writers
 C: _____ " _____
 D: Marine clay or till





INTERPRETATION IN REVERSED STRATIGRAPHICAL ORDER

- 700 - 1500 m/s Probably glaciofluvial deposits, ablation till or redeposited marine deposits
- 2000 m/s Probably till
- 1000 m/s Probably stratified marine deposits
- 2000 m/s Probably till
- 5000 m/s Bedrock



Pl.9 Preliminary correlation

SANDNES		FOSS-EIGELAND	HØG-JÆREN	LERBREKK GRØDELAND	REVE		KARMØY		Climate events	Geochronology	
Bio zones	Lithology	Lithology	Lithology	Lithology	Bio zones	Lithology	Bio zones	Lithology		Zones	Years B.P.
?	Stavanger diamiction	Kverneland diamiction	Oppstad diamiction	Upper Lerbrekk Upper Reime diamictions	?	Bore diamiction	?	Haugesund diamiction	Stavanger stadial	Late Weichselian	~ 25.000
?	Austråt sand	Kalberg clay	Høg-Jæren clay	Tvihaug bekken sand	Macoma c.	Reve clay	Portlandia a. and Hiatella a.	Karmsund clay	Sandnes interstadial	Middle Weichselian	
Zone I	Gann clay										
Zone II		Foss-Eigeland diamiction	Høgemork gravel	Lower Lerbrekk Lower Reime diamictions	?	Orre diamiction	Portlandia a. Mya tr. Hiatella a. Barren	Bø sand Nygaard gravel	Jæren stadial		
Zone III	clay	Figgjo gravel		Grødeland diamiction					?	Havna sand	Mixed fauna
		Sunde gravel	?	Hodne sand	Karmøy stadial	Early Weichselian					
Zone IV				Stemma sand	?	Hodne sand	Torvastad sand	Torvastad interstadial			
				Hobberstad clay				Cardium e.	Ostrea e.	Avaldsnes sand	Avaldsnes interglacial
										Saalian	~140.000