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The most recent maps available from NGU are listed inside the back cover.

MANUSCRIPTS

Instructions to contributors to the NGU Series can be found in NGU Nr. 273, p. 1–5.

Publication No. 29 in the NTNF's Continental Shelf Project

Two Sediment Cores from the Norwegian Continental Shelf between Haltenbanken and Frøyabanken (64°06'N, 7°39'E)

HANS HOLTEDAHL, SYLVI HALDORSEN & JORUNN OS VIGRAN

Holtedahl, H., Haldorsen, S. & Vigran, J.O. 1974: Two sediment cores from the Norwegian continental shelf between Haltenbanken and Frøyabanken (64°06'N, 7°39'E). *Norges Geol. Unders. 304*, 1–20.

Two sediment cores, 1.5 and 4.5 m long, were obtained on the continental shelf west of the coast of Trøndelag, W. Norway, from a depression 320 m deep, and in an area with a very thin cover of Quaternary deposits. The upper part of the cores consists of stratified silt and clay with a mainly Postglacial fossil assemblage, a grading with increased clay content downwards, and a clay mineral content of 10–20% kaolin, 50% illite, 0–10% chlorite and 10–20% mixed layer minerals of different kind. The lower part of the cores is different from the upper part in its more uniform grain size distribution, its content of poorly consolidated sedimentary rock-fragments in a finer matrix, and in a higher content of organic matter. The fossil assemblage of the rock-fragments, as well as of the matrix, indicates material of Jurassic, Cretaceous and Lower Tertiary age. Furthermore the clay mineral composition is different, with approximately 30–40% kaolin, 1–20% illite, 0–5% chlorite and 30–40% montmorillonite.

The lower part of the cores is believed to represent till, consisting mainly of short-transported rock debris from the underlying bedrocks.

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Introduction

Holtedahl (1955) concluded that glacial sediments covered the entire continental shelf and upper continental slope in an area west of Møre in western Norway. He also demonstrated that the glacial material had mainly two sources and two means of transport: 1) from the adjacent land brought out by glaciers, and 2) from the Oslo–Skagerrak area transported by floating icebergs.

Since 1968 sediment investigations have been carried out, mainly on the Møre–Trøndelag shelf between 62°N and 65°N. Seismic work has also been carried out in the same area, refraction work as well as seismic profiling. (Sellevoll et al. 1967, Eldholm, 1970, Nysæther 1970, Holtedahl & Sellevoll 1971). One of the results of the seismic investigations was the demonstration of the great variation in thickness of the Quaternary desposits, from almost nothing to more than 400 m (Eldholm & Nysæther, 1969, Holtedahl &

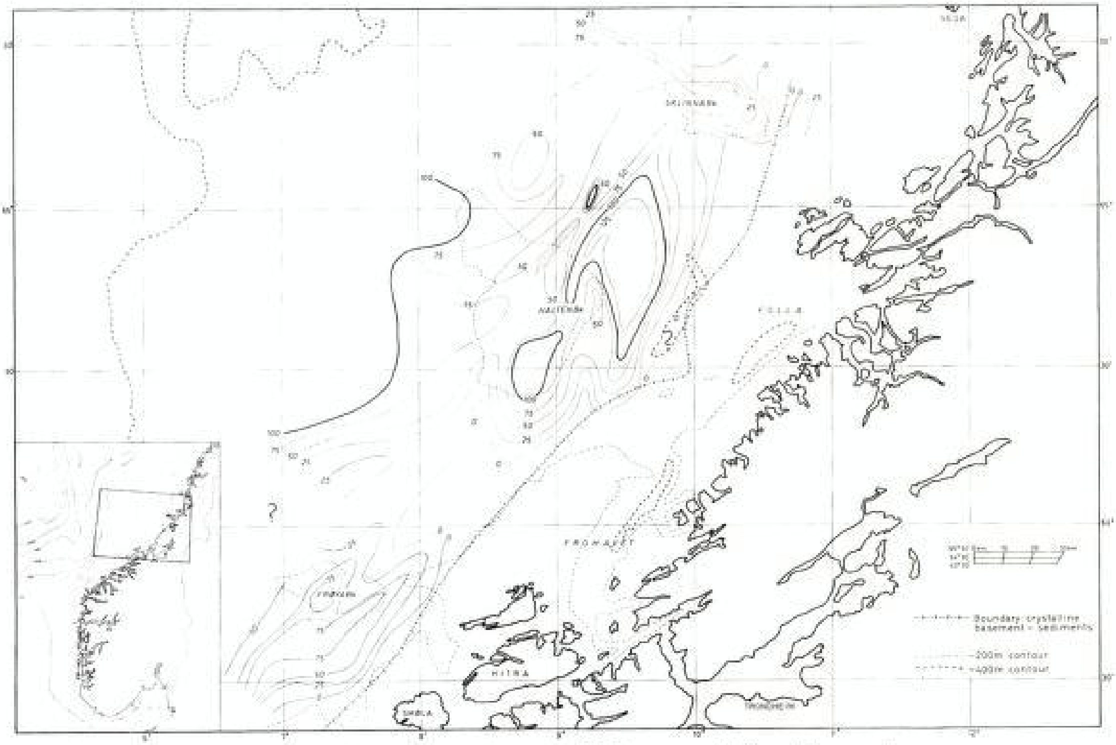


Fig. 1. Variation in thickness of Quaternary sediments off the coast of Trøndelag and Nordland. Contours in milliseconds. (Eldholm & Nysæther, 1969.)

Sellevoll 1972), as well as the rather irregular and uneven sub-Quaternary surface, supposed to have been formed to a great extent by selective glacial erosion. In Fig. 1 is shown the variation in thickness of Quaternary sediments on the continental shelf off the coast of Trøndelag and Nordland. As will be seen the greatest accummulations are found on the eastern flank of Haltenbanken, to a great extent filling in the submarine depression in that area. Further south another thick accumulation of Quaternary sediments is present in the Frøyabanken area, here with its maximum conciding more with the shallowest part of the bank.

The Quaternary deposits appear to be practically absent or very thin, in a zone which more or less coincides with the longitudinal channel between the banks and the 'skjærgårdsregion', and also in the wide and low depression which exists betwen the two bank areas.

Sediment samples, previously taken from shelf areas with thick Quaternary deposits, showed almost exclusively rock material from the adjacent mainland, with the exception of long-transported iceberg-drifted material. Rocks from the younger sedimentary formations on the shelf were not recovered. It was therefore of considerable interest to collect sediment samples in areas where the Quaternary cover, according to the seismic recordings, was thin and possibly absent. A remarkably high content of unmetamorphosed sedi-

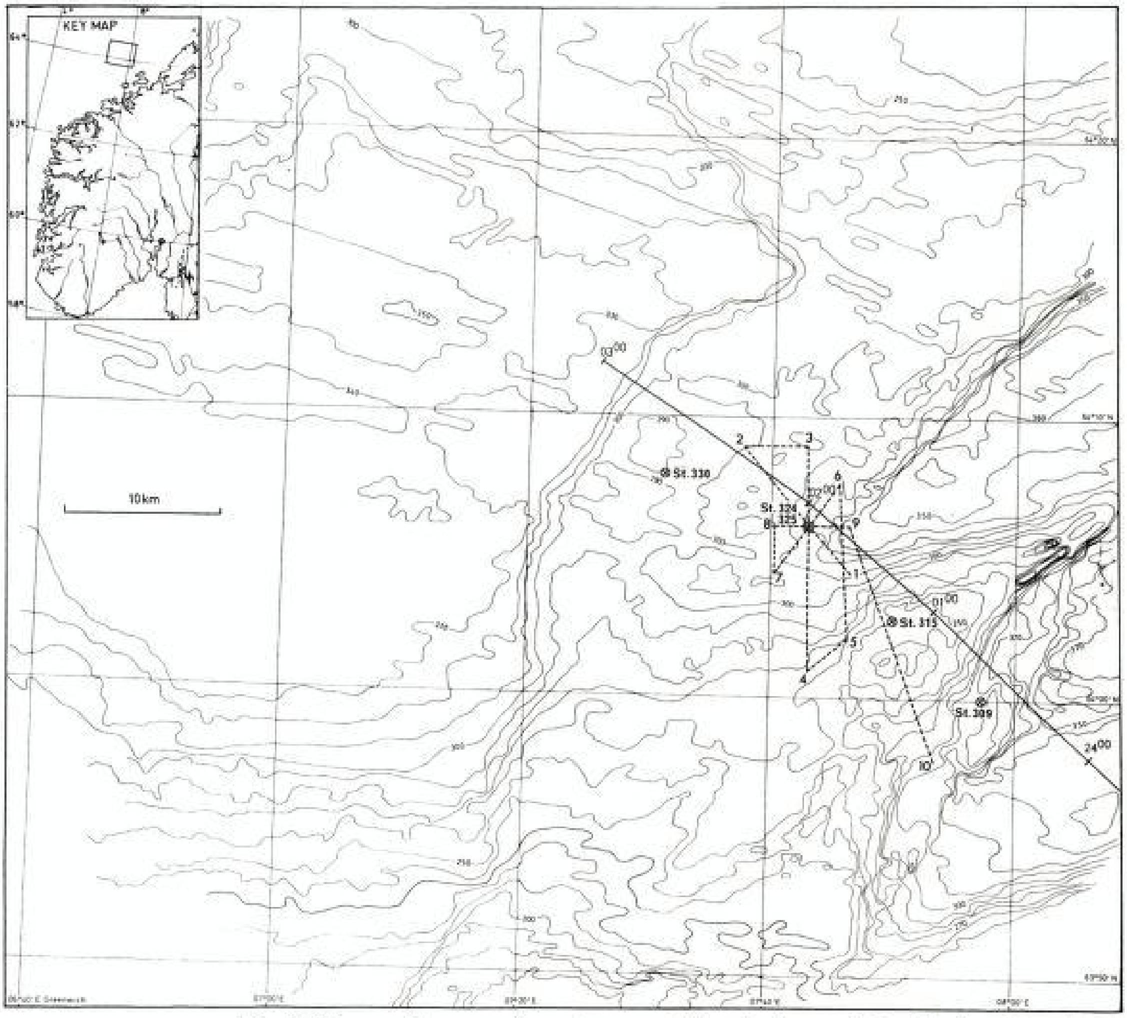


Fig. 2. Topographic map of area between Haltenbanken and Frøyabanken. Location of core samples 324 and 325 are shown, as well as neighbouring sample-stations. Tracks of continuous seismic profiling are shown by stippled and solid lines. (Map is drawn from soundings carried out by The Norwegian Hydrographic Office, and published with their permission.)

mentary rocks (sandstones, claystones, limestones) have been shown typical for the surface sediments in these areas. Macro- and microfossils from these rocks indicate an age corresponding to Upper Jurassic to Cretaceous (Holtedahl 1970).

During a cruise in 1969 on the research-vessel *Johan Hjort,* belonging to the Institute of Ocean Research, Directory of Fisheries, Bergen, a number of sediment samples: dredge- grab- and core-samples, were collected in the area between Frøyabanken and Haltenbanken. A number of the core-samples have been described by Haldorsen (1974). Core No. 324, collected in the depression at 64°06′N, 7°39′E, at a depth of 320 m, proved to be especially

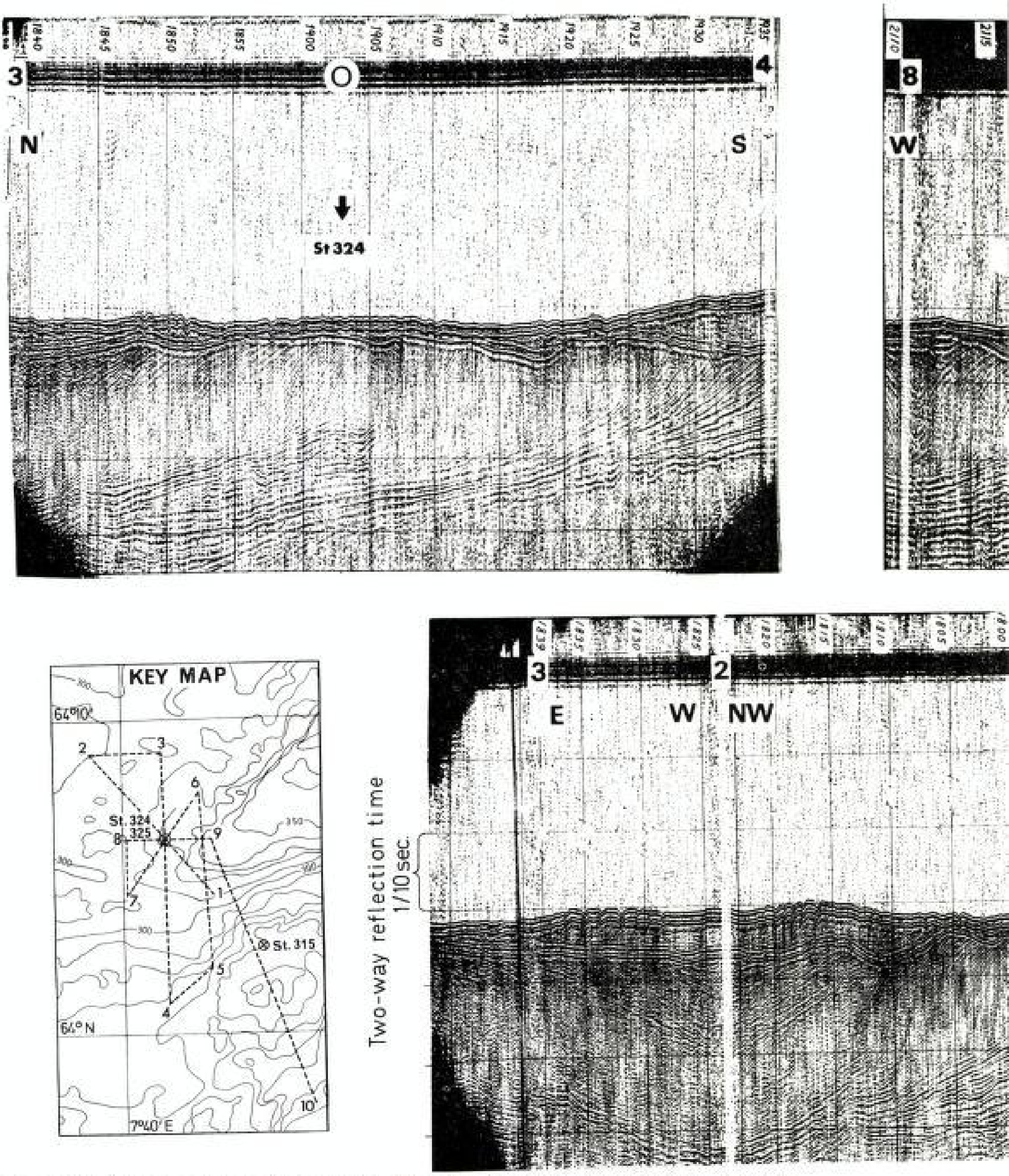
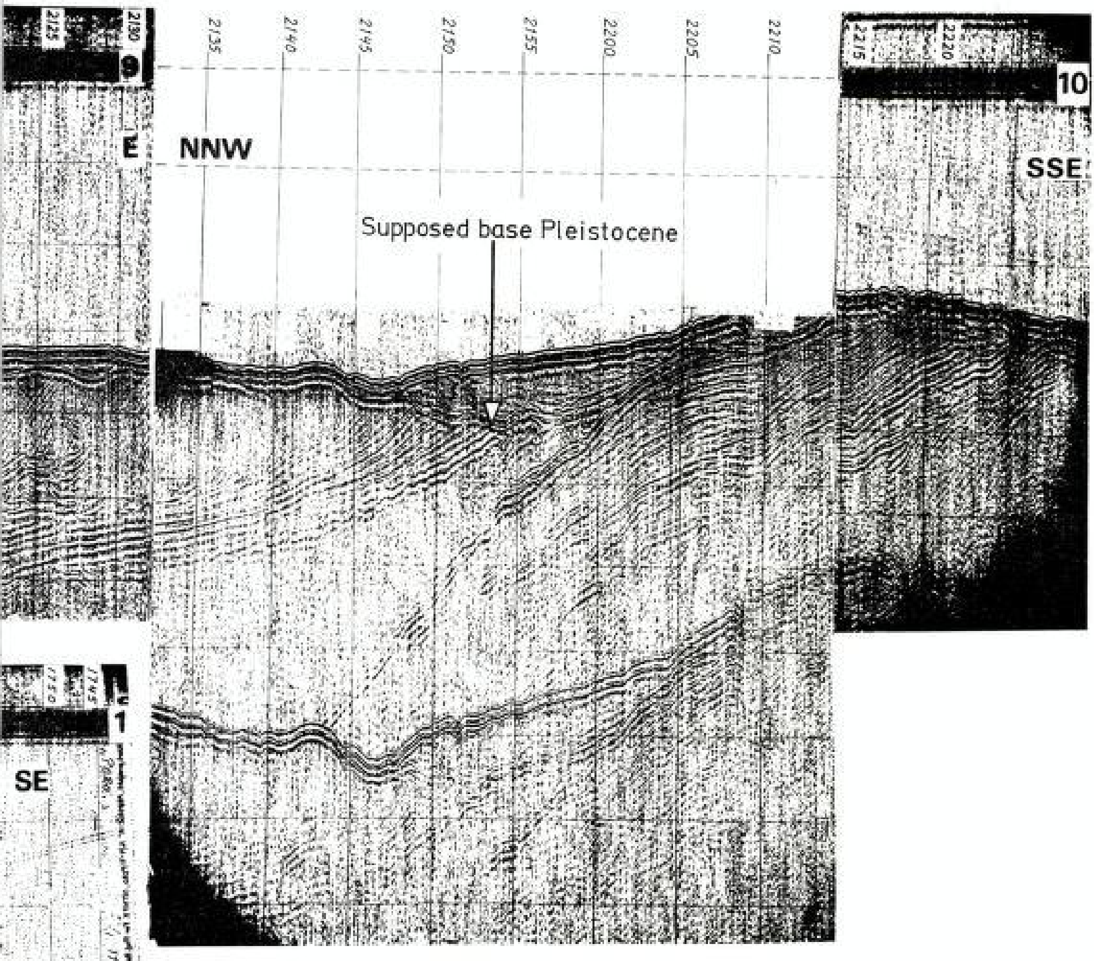


Fig. 3. Continuous seismic profiler records from area of samples 324 and 325. Distance between horizontal lines 1 millisecond. (NTNFK registration.)

interesting, both lithostratigraphically and biostratigraphically; another and longer core, No. 325, was obtained from about the same location in 1970, also from the vessel *Johan Hjort*. These two sediment cores will be described in the present paper.



Submarine topography

The area under consideration has recently been surveyed by the Norwegian Hydrographic Office, and data from these soundings have kindly been placed at the disposal of the authors.

The map, Fig. 2, has been drawn from the sounding data with a contour interval of ten metres, and the location of the core samples 324 and 325 and some neighbouring samples stations are shown.

The localities of the described core samples are in the northwestern part of a large depression with a roughly north-easterly direction. This depression, which increases in depth northeastwards to about 500 m, is bounded by the Haltenbanken bank-area in the north, and the Frøyabanken bank-area in the south. A smooth ridge of about 280–290 m separates the depression from another depression further west, which leads out to the edge of the shelf.

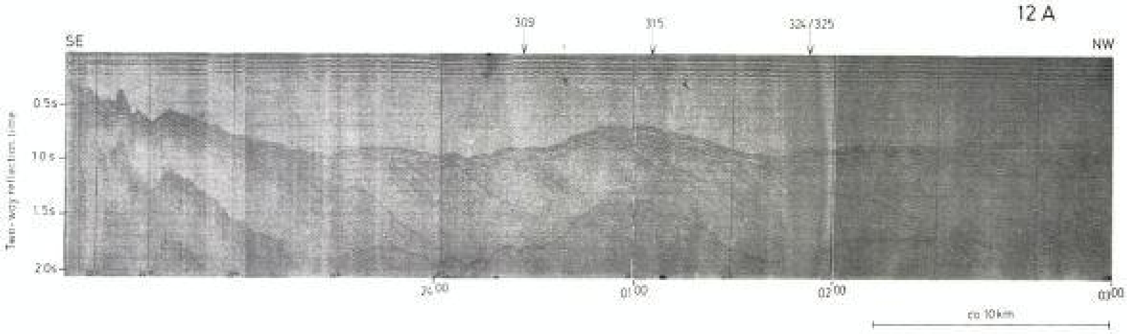


Fig. 4. Continuous seismic profiler record across the inner part of the continental shelf between Haltenbanken and Frøyabanken. Distance between horizontal lines 1 millisecond. Location of samples 324 and 325 shown. (Seismological Observatory, Univ. Bergen registration.)

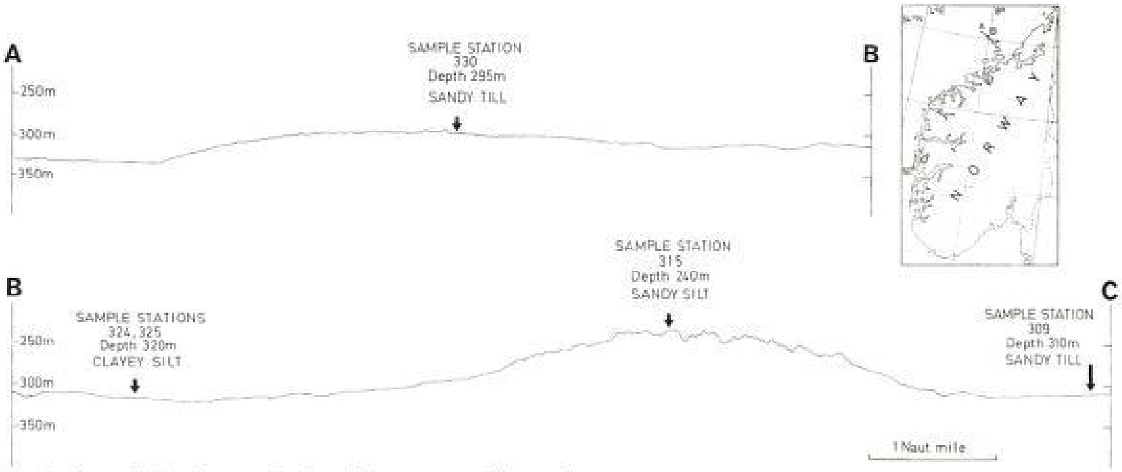


Fig. 5. Record of echogram obtained between sampling-stations.

The most conspicuous feature topographically is the ridge dividing the western part of the eastern depression in two. This ridge, which is especially noticeable NE of St. 315, is asymmetrical with a fairly steep southeast slope and a gentle slope to the northwest. The fairly steep southeast slope of the northern part of the depression, NE of St. 324 and 325, and the parallelism in direction between these steep slopes are also conspicuous. From a purely geomorphological point of view one would interpret this landscape as one which was to a large extent determined by bedrock with strata dipping slightly to the northwest and striking northeast. As will be seen from the seismic profiles taken in the area, Fig. 3 and Fig. 4, the landscape is determined by the pre-glacial sedimentary rock surface, as well as glacial and postglacial deposits. In Fig. 5 is shown a record of echograms taken between sample-stations.

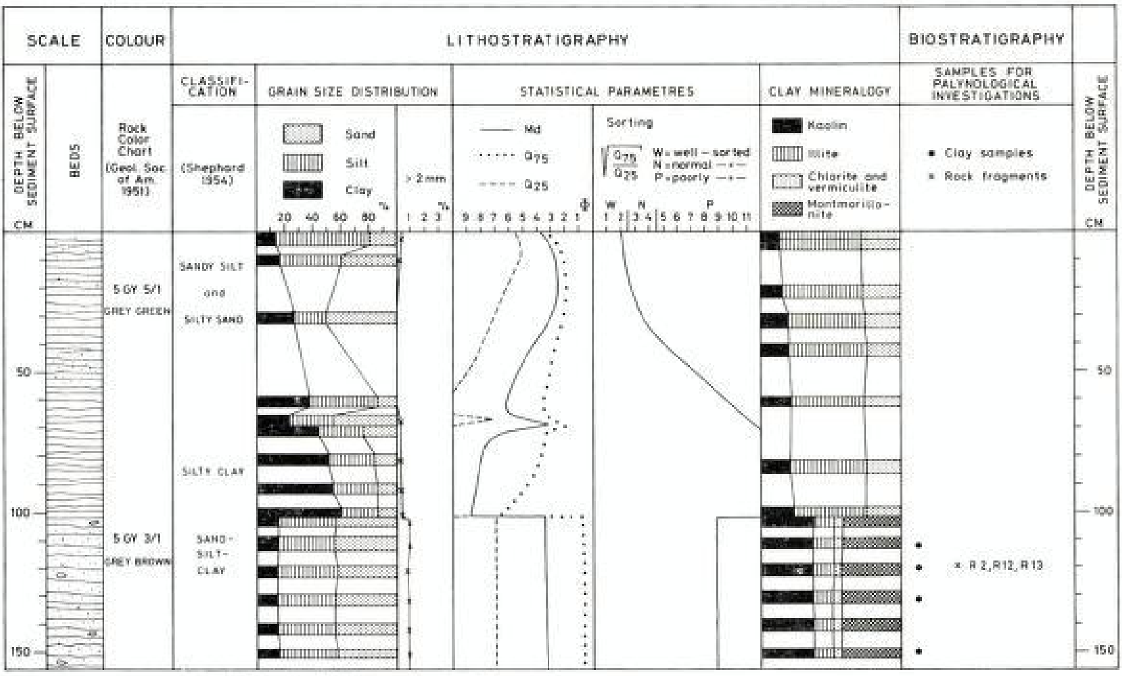


Fig. 6. Sedimentological data of core 324.

Description of the Cores

The two cores examined were collected in 1969 and 1970 with a gravity corer and piston corer respectively. The two cores, Nos. 324 and 325, were taken in approximately the same locality. The material was kept in airtight plastic tubes until the laboratory investigations were carried out.

The total length of core 324 is 1.5 m (Fig. 6). The upper 1.0 m consists of a stratified grey green clayey and sandy silt and silty clay. There is a distinct increase in the percentage of clay towards the bottom of this section. This part of the core contains marine fossils of Quaternary age. No systematic investigation was carried out on the Foraminifera in this core, but there was shown to be a definite change in the benthonic fauna from the top towards the bottom of the section. *Uvigerina peregrina* is the predominant species in the upper 60 cm of the core, with *Höglundina elegans, Hyalinea baltica, Nonion barleeanum, Cassidulina laevigata* and others as less commonly occurring forms. From 60 to 100 cm *Nonion labradoricum* and *Virgulina loeblichi* occur and increase in number, while *Uvigerina peregrina* disappears. *Elphidium incertum clavatum* is present in the lowest 10 cm of this section.

From these sedimentological and micropaleontological data, it seems reasonable that the deposition of the upper 100 cm of core No. 324 has taken place during the Holocene and possibly into the late parts of the Weichselian. This sediment type is described by Haldorsen (1974) and these investiga-

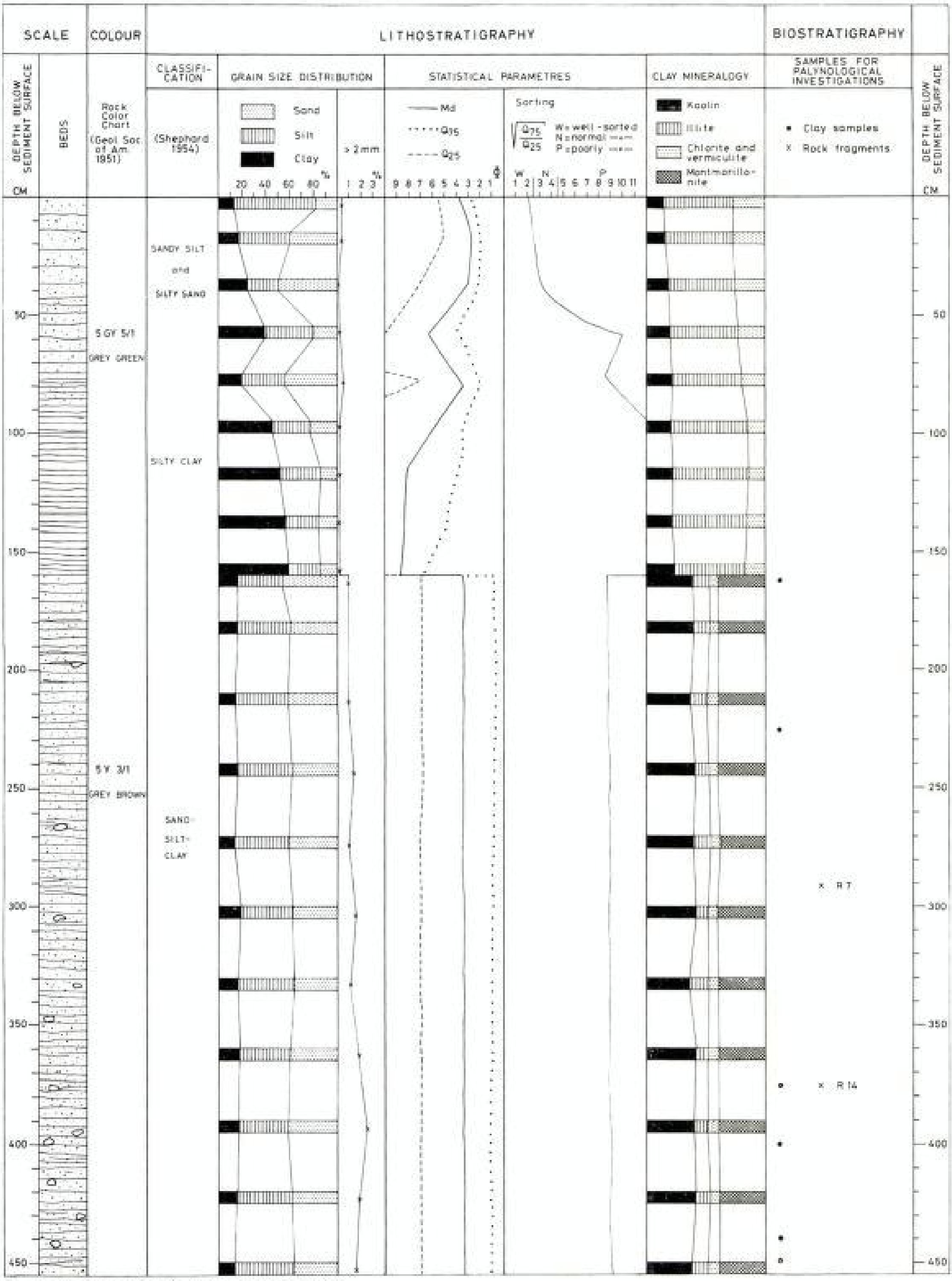


Fig. 7. Sedimentological data of core 325.

tions will not be further discussed in this paper. At 1.0 m below the sediment surface there is a very distinct boundary between the upper grey green material and a brownish sediment. This lower part of the core consists of material which is coarser and somewhat more homogeneous than the upper 100 cm. No fossils of Quaternary age have been found, though the sand fraction has been thoroughly examined and palynological investigations have been carried out.

The length of the other core, No. 325, is 4.5 m (Fig. 7). The upper 1.6 m of this core consists of the same type of material as the upper part of core 324. The lower part of core 325 below the level of 1.6 m contains a brownish sediment similar to the lower part of core 324. There is some material of gravel- and stone-size in the lower parts of the cores. By inspection this coarse material is shown to consist of more or less fragile rock fragments, with claystones and siltstones as common components.

The loss of ignition of the lower part was measured in relation to the dry weight of the samples and the content of organic matter was calculated to be about 3%.

The shear strength varied between 1.1 and 1.5 t per m^2 and the sensibility was about 1.0.

GRAIN SIZE DISTRIBUTION

Organic matter and salt pore-water were removed from the samples, and grain size analysis was carried out by the sieving and pipette methods. Samples were taken from each tenth to twentieth centimetre through the cores, and about 10 g material was used for the pipette analysis.

The grain size distribution for the two cores is shown in Fig. 6 and Fig. 7. While the upper parts of the cores show varying grain size distribution, with a distinct increase in clay content downwards, the material below the boundary has a more even distribution consisting of about 40% sand, 40 % silt and 20% clay. (The limits between the different size classes are shown on Fig. 6 and Fig. 7.) The median value of this lower part is 36 μ and the sediment is poorly sorted, according to Trask (1932). The content of material $>$ 2 mm varies between 1 and 3%, the greatest values found in the lowest part of core 325. The material $>$ 2 mm mainly consists of claystones, which are easily decomposed into clay. Though sieving was carefully carried out, decomposition of claystones undoubtedly has altered the grain size composition of the samples during the laboratory work, giving too high a clay content.

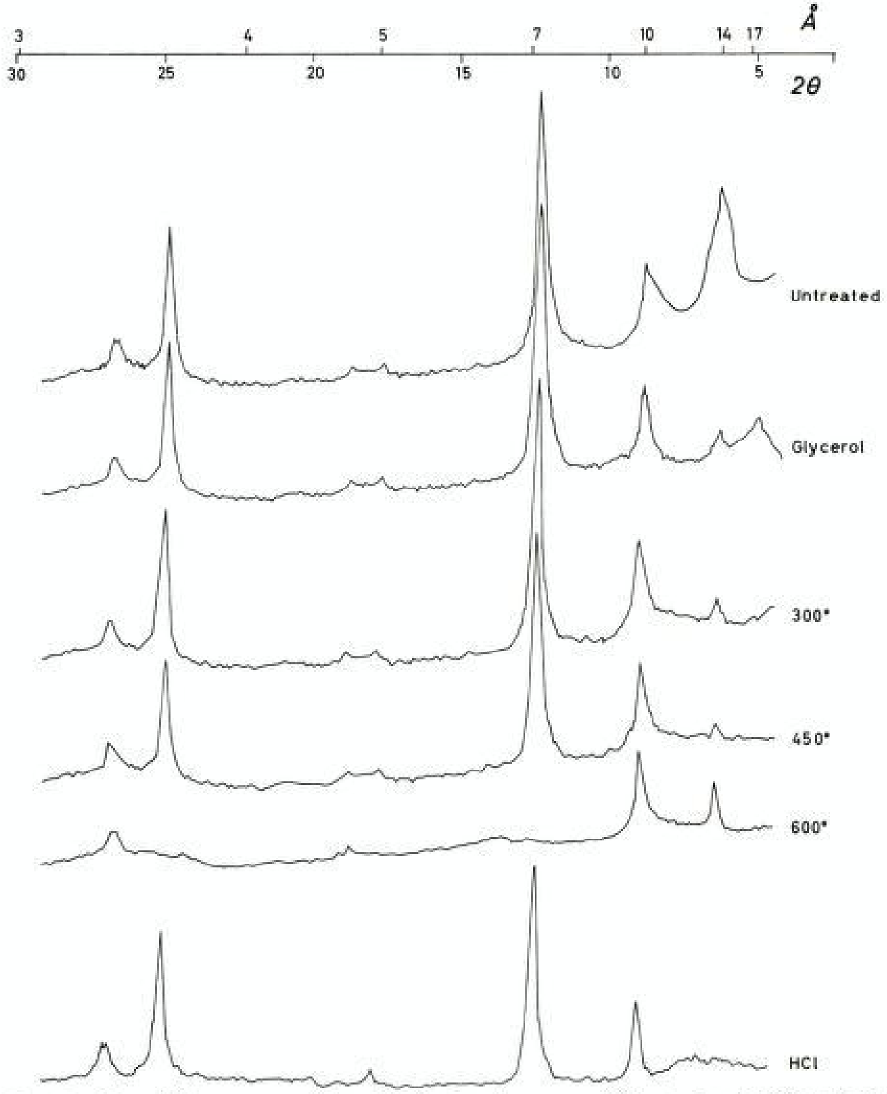


Fig. 8a. X-ray diffractogram of the clay fraction from core 324, at a level 130 cm below the surface. Oriented sample.

CLAY MINERALOGY

The clay fraction of several samples from the two cores has been subjected to X-ray diffraction analysis. A Philips diffractometer with a Ni-filtered CuKα radiation was used. The goniometer speed was ½°2Θ per minute.

Iron oxide was removed from the samples by using a buffered dithionite-citrate solution (Mehra & Jackson 1960).

The oriented samples were made by sedimenting an aqueous suspension of clay particles on a glass slide and drying in air at room temperature. In addition, one unoriented sample was made by using the technique of By-

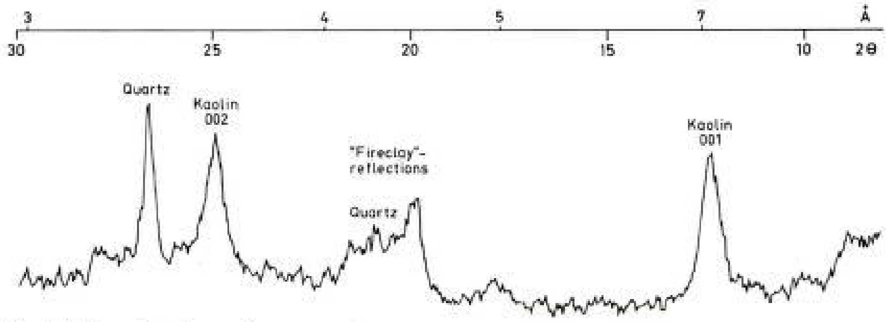


Fig. 8b. Unoriented sample.

ström–Asklund (1966). The mineral constituents were identified according to the criteria used by Brown (1961). DTA has been carried out on the clay fraction.

Fig. 8a shows the diffraction patterns for a sample from the lower part of core 324. The principal mineral constituents are kaolin, montmorillonite and illite, with smaller amounts of chlorite and quartz. Montmorillonite minerals are identified by the expansion of the 14 Å peak to 17–18 Å by a glycerol-treatment. The 10 Å mineral is mainly a dioctahedral illite. The 7 Å reflection is a combination of the (001) reflection of kaolin and the (002) reflection of chlorite. The presence of both these minerals is seen from the pattern of the 600°C heated specimen and the pattern of the specimen treated with 6 N HCl.

Fig 8b shows the diffraction pattern of an unoriented clay sample from the lower part of core 324. The reflection band at 20°2Θ is typical for a kaolin of the 'fireclay' type. (Graff-Petersen 1960, p. 26). A DTA-curve for the same size fraction showed that this mineral has no exothermal reaction at 900°C. According to Brindley et al. (1963) it is evident that b-axis disordered kaolinite ('fireclay' minerals) is the main kaolin mineral in this sediment.

The semiquantitative evaluations of the mineralogical composition have been done by using the methods of Gjems (1965) and Biscaye (1964). The estimations give the weighed intensity ratios of the different minerals. Fig. 6 and Fig. 7 show the composition of the bulk clay fraction given in the form of bars. The quantity of quartz in the samples has not been estimated.

The vertical variation in the clay mineral composition of the lower parts of cores 324 and 325 is small. The clay fraction consists of approximately 30–40% kaolin, 10–20% illite, 0–5% chlorite and 30–40% montmorillonite. In comparison the part above the boundary has a composition of 10–20% kaolin, 50% illite, 0–10% chlorite and 10–20% mixed layer minerals of different kinds.

An oriented sample was made from the colloid fraction by using a supercentrifuge and making a clay film on a glass slide from the material still in suspension. The X-ray diffraction pattern for untreated and glycerol-treated

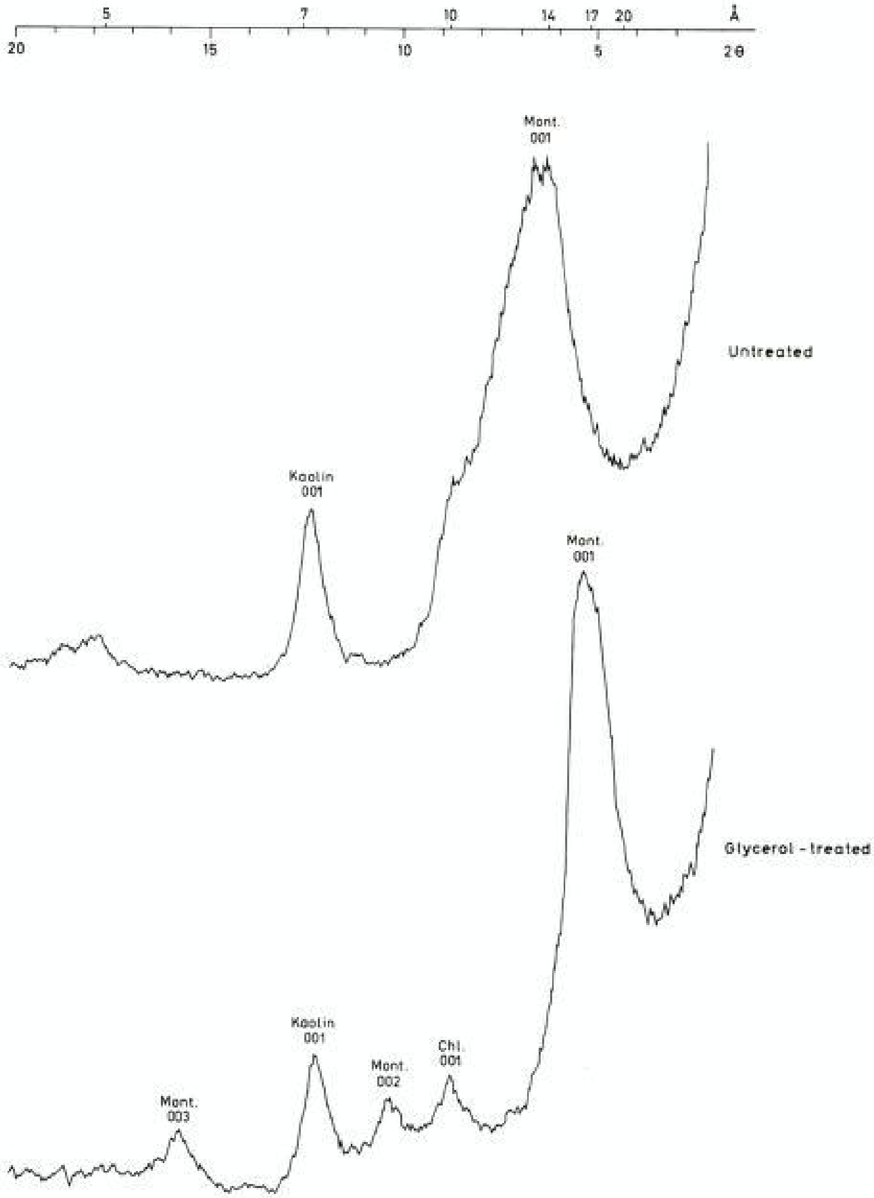


Fig. 8c. Oriented sample, colloid fraction.
Mont. = Montmorillonite, Chl. = chlorite.

specimens is shown in Fig. 8c. The sample consists of about 80% montmorillonite, and 20% kaolin with a small proportion of chlorite.

The claystone fragments in the sediment have not been systematically examined with respect to the clay mineralogy. For the fraction > 2 cm, however, some investigations have been carried out. First, the fragments were classified, and the following two main types were recognized: 1. A black, extremely fine-grained claystone, and 2. a grey, silty claystone. Of the bulk stone fraction 30% consists of type 1 and 60% of type 2. The black claystone has a clay mineral composition which is nearly identical to the colloid fraction of the sediment (Fig. 8c), while the grey claystone contains about 60% kaolin, 20% illite and smaller amounts of chlorite and quartz.

PALYNOLOGICAL INVESTIGATIONS

Samples of clay were taken first from core 324, later also from the longer core 325. The stratigraphic positions of the samples are shown in Fig. 6 and Fig. 7. Each sample, about 2 cm^3 of the deposit, was given a standard treatment, a maceration by chemicals, using hydrochloric acid, hydrofluoric acid, nitric acid, and ammonia. Judged from the gas evaporating when hydrochloric acid was added to the samples, carbonaceous material was present only in parts of the core. The time required for a sufficient oxidizing (by nitric acid) varied much, and it was supposed that the organic content was variably coalified. Further, remaining after the chemical treatment, were variable amounts of organic residues. These features are all in contrast to what would be expected from an evenly coloured deposit with no clear signs of a stratification.

The palynological assemblages extracted were rather variable, and it was suspected, at least in parts of the cores, that one was dealing with mixed assemblages of more than one geological age. However, no rebedded fossils could be traced from their state of preservation.

A repeated inspection of the still moist core material revealed small rock fragments of poorly consolidated claystones and sandstones. The rock fragments, being almost as soft as the embedding clay, had to be separated by hand, and their outermost layers were removed to prevent contamination from the adhering clay.

Such fragments could not be recovered when samples of the deposit were given a standard treatment. The claystones then got more or less crushed against the cloth used for separating larger rock fragments from the clay, and the sandstones, cemented by carbonates, were already disintegrated during the treatment by hydrochloric acid. Fossils from rocks of both lithologies therefore appeared in the mixed assemblage of the embedding deposit.

The palynological investigation had to be concentrated upon the assemblages of fossils enclosed in the various rock fragments. A group of 4 claystones and 2 sandstones were treated with the same chemicals as mentioned above. The stratigraphic positions of the analysed samples are shown in Fig. 6 and Fig. 7.

The claystones are the most frequent ones. Most of them are poor in carbonates, they are all of dark colour, and they are rich in organic residues. The organic residues are usually dominated either by finely disintegrated amorphous debris or by wood remains, or also by both. In addition are found pollen, spores, and supposed marine cysts. From the cyst assemblage it was concluded that the claystones were marine deposits formed during Middle and Upper Jurassic and Lower Cretaceous time. The oxidation of the material was needed more to remove unwanted organic debris sticking to the fossils, than to make the grains of lighter colour. Prolonged maceration tended to reduce the number of taxa present in the assemblages.

The sandstones, only two fragments, contained fossil assemblages of clearly different ages, and neither of them was dominated by disintegrated organic debris nor by wood remains. The older rock, a coarse sandstone with large grains of quartz, judged by the content of a few colporate grains (angiospermous affinity) was formed during the mid-Cretaceous or early Upper Cretaceous time. Such an age may also be supported by the cyst assemblage which indicates deposition in marine surroundings.

The younger of the sandstones, R 7, also represents the youngest of the rebedded rocks from the core material.

R 7 was a fragment the size of a small bean, embedded at about 120 cm below the upper Late- and Postglacial clay in core 325. It represents an extremely light-coloured deposit, an almost white sandstone, with only a few darker grains discernible. Half of this fragment was used for maceration. The rock disintegrated in hydrochloric acid within a very short time. Most of the minerals remaining, well-rounded grains of quartz and of variable sizes, were removed by passing the residue through a cloth with 200 μ meshes.

A sparse assemblage of fossils, only a couple of hundred grains, were left after the maceration, and the material was stained in order to detect, if possible, redeposited grains.

Explanation of Plate 1, Figures 1–16.

Photomicrographs were made using a Leitz Orthomat 698672 belonging to the Department of Botany, University of Trondheim.

Magnification: Figs. 1, 2, approximately × 700. Figs. 3–16, approximately × 1200.

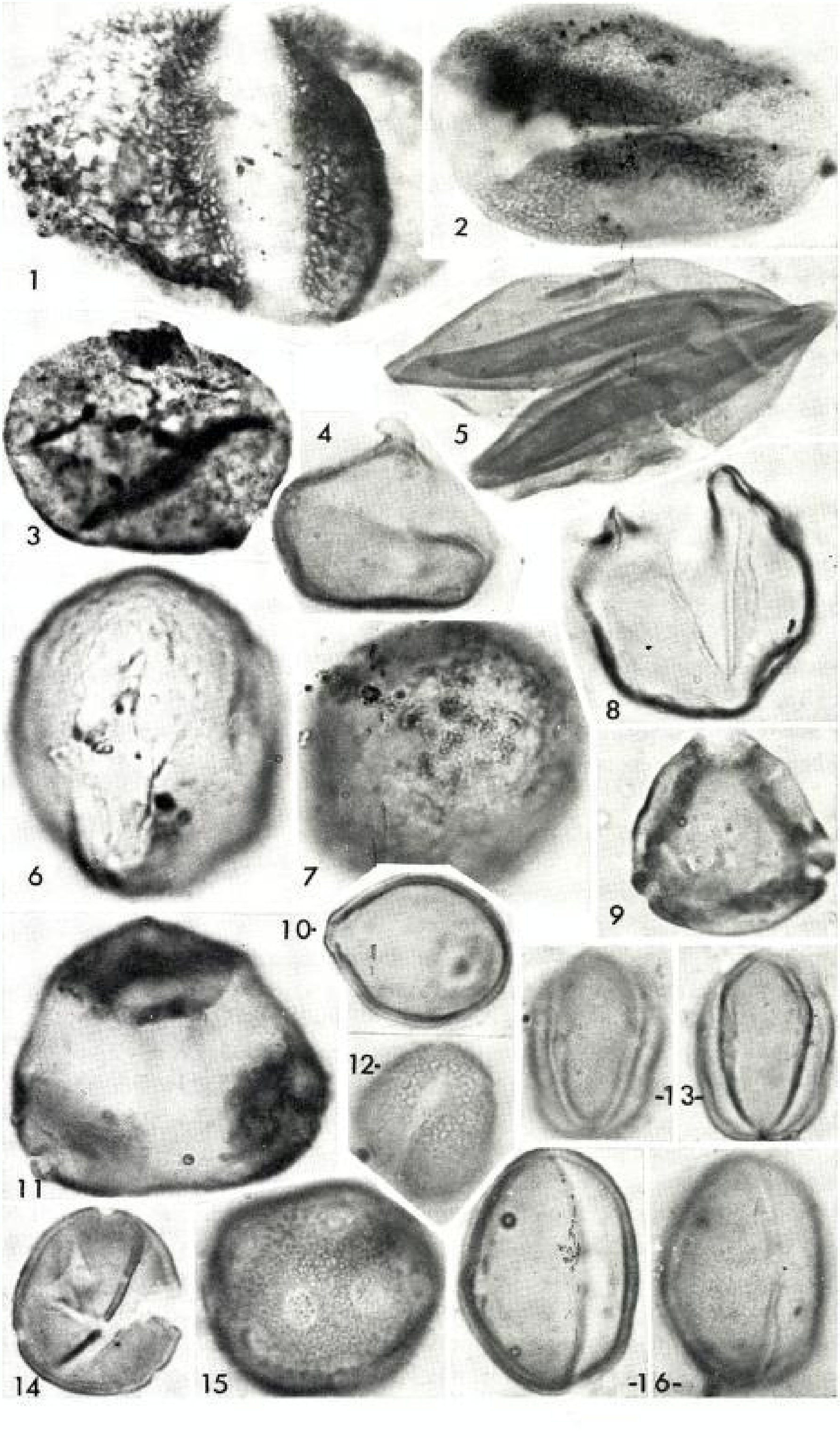
Coniferae (Figs. 1–8)

Pinaceae: Fig. 1, *Pinaceae* sp. A, Width of grain 95 μ. – Fig. 2, *Pinaceae* sp. B, height of corpus 80 μ.

Taxodiaceae: Fig. 3, *Metasequoia* (Fig. 35, Martin & Rouse, 1966) 34 μ – Fig. 4, *Sequoia* cf. *S. lapillipites* (Figs. 37, 38, Martin & Rouse 1966) 27 μ – Figs 5,? *Glyptostrobus* (Figs. 63, 64, Piel 1971) 53 μ – Fig. 6, *Sciadopitys* sp. 40 μ – Fig. 7, *Sciadopitys* cf. *S. serratus* (Pl. 11, Figs. 1–9, Manum, 1962, *Sciadopityspollenites serratus* and Fig. 33, Martin & Rouse, 1966) 35 μ – Fig. 8, *Taxodium* sp. (Fig. 36, Martin & Rouse, 1966) 30 μ.

Angiospermae (Figs. 9–16)

Fig. 9, *Betulaceae,* diameter of grain 22 μ – Fig. 10, *Betulaceae* (*Corylus*-type) 18 μ – Fig. 11, *Triatriopollenites* sp., 36 μ – Fig. 12, *Tricolpites* sp. Other flattened specimens are about 23 μ. The grains come very close to certain species of *Gunneraceae* – Fig. 13, Tricolporate pollen with faintly reticulate structure, 23 μ (cf. *Rhoipites* p. 268 in Srivastava, 1972) – Fig. 14, Triporate pollen, about 20 μ, cf. *Triporopollenites rugatus* (Pl. 1, Fig. F, Norton & Hall) – Fig. 15, *Liquidambarpollenites stigmosus* (*Periporopollenites stigmosus* Pl. 8, Figs. 1–8, Krutzsch, 1966) 28 μ – Fig. 16, Tricolporate grain, 28 μ. The faint striate pattern corresponds with that of *Tricolpopollenites striatus* (Pl. 20, Figs. 11, 12, Manum 1962).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An identification of the fossils further than to a generic level, was considered of little importance for our purpose, which was a dating of the embedding clayey deposit. The rock fragment came from a formation of sedimentary rocks yet unknown. No material for comparison is available from this area.

The flora as indicated by the fossils (selected grains are pictured in Plate 1) was one dominated by two groups of plants, the conifers and the angiosperms. Pteridophytic spores and older types of gymnosperm pollen are rare. However, it seems unjustifiable to judge from negative evidence in such a sparse assemblage.

Only a few works, mainly those of Groot & Groot (1962), Manum (1962), Martin & Rouse (1966), Norton & Hall (1967), Piel (1971) and Srivastava (1972) were consulted for comparisons.

Two-winged coniferous grains are sparse, three taxa belonging to the *Podocarpacea* and *Pinaceae* (Figs. 1 and 2). The most frequent pollen grains are of taxodiaceous affinities and might be assigned to the following taxa: *Glyptostrobus* (Fig. 5), *Metasequoia/Sequoia* (Figs. 3 and 4), *Sciadopitys* (Figs. 6 and 7), and *Taxodium* (Fig. 8).

The angiospermous pollen is such as may be assigned to the *Betulaceae* or *Myricaceae* (Figs. 9 and 10), to *Hamamelidaceae* (Fig. 15), and *Juglandaceae*. There is also some tricolporate pollen (Figs. 13 and 14).

The assemblage seems to be related to the Arctotertiary floras, and a Danian age is proposed for this rock, which also indicates the maximum age of the deposit where the rocks was embedded.

Remarks on the material

Certain dinoflagellate cysts characteristic of some clay samples could not be recovered in any of the rock fragments. To detect a possible source of such fossils, erratics from grab- and dredge-samples from other areas near Frøyabanken were searched for sedimentary rocks. A coarse micaceous sandstone yielded by maceration an assemblage which also included such cysts. It may therefore be supposed that the material from which the core deposit was formed, also included rocks which have not been discovered by this investigation.

The core deposit clearly demonstrates what has been found earlier by other workers (Owens 1972): that one has to work very carefully when handling material from an area where redeposition may have taken place. If the material of our core had been completely disintegrated during the formation of this deposit, we should have had no possibilities of estimating the age of the rebedded rock material, in relation to the last formed deposit. In that case the lower part of the cores 324 and 325 would have been taken as material of Lower Cretaceous age, as the younger rocks form the minor part of the rebedded material.

Discussion and conclusions

In Fig. 6 and Fig. 7 is shown an assembly of sedimentological data of cores 324 and 325. The upper and lower parts of the two cores differ with respect to the following factors:

1. The colour is visually different.
2. The content of organic matter is negligible in the upper part, and about 3% in the lower part.
3. The grain size distribution of the upper part shows grading from fine to coarse material upwards, while the lower part has a more homogeneous composition with little variance throughout the section.
4. Rock fragments of fragile, sedimentary rocks are usual in the lower part, while the content of such rock fragments is negligible in the upper.
5. The clay mineral composition changes abruptly while passing the boundary between the two parts of the cores.
6. Shells and foraminifera are present in the upper part of the core, but not in the lower.
7. Distinct assemblages of plant fossils, dating from Middle Jurassic to Early Tertiary, are found in the rock fragments as well as in the finer material in the lower part of the cores.

THE UPPER PART OF THE CORES

The upper part of the cores consists of material which seems to be a rather usual surface deposit formed after the retreat of the ice from the area. The material in the basal parts could be expected to have been derived partly from the meltwater suspension of the retreating ice. According to Haldorsen (1973), however, material from the melting shelf ice has no strong influence on the composition of the core sediments. The presence of surface till deposits in the area around the sample sites suggests a washing out of fine material by waves and currents. The coarsening of the deposit upwards towards the surface, which seems to be a general phenomenom of similar sediments over a wide area, is of interest here, and may indicate a gradual shoaling of the sea due to a glacial-isostatic rebound of the crust, which counteracts the eustatic influence. Further work is needed to solve these questions.

THE LOWER PART OF THE CORES

The lower part of the cores has a very different origin from that of the upper part. Grain size, as well as lithological studies, show the sediment to be a mixture of rock types of various kinds and a matrix consisting to a great extent of silt and clay. From studies of the clay mineral composition it is shown that the mineralogical assemblage of the matrix is very similar to that of the rock fragments. As mentioned, the colloid fraction of the sediment is nearly identical to the composition of the black, fine-grained claystones and is probably composed through a disintegration of this black rock. It is reasonable that the matrix of the core material is derived from those rock types which are now present in the sediment as gravels and stones.

The fossil assemblage of the matrix is composed of members of the fossil assemblages recovered from the rock fragments, and was undpubtedly derived from them. The polymorphy of the lithology is also shown up clearly in the age-variety of the fossils, ranging from Middle Jurassic to early Tertiary.

The mixture of different rock types without any stratigraphical order, and the palaeontological evidence, show the deposit to consist of rebedded material derived from various sources. The final deposition must be younger than the youngest fossils found, i.e. Lower Tertiary, and it must be older than the upper section of the core, which is presumably Late Weichsel.

A sediment of this type was scarcely formed during the Tertiary. It rather represents a glacial till deposited by the inland ice during a stage of the Pleistocene, probably the Weichsel. From the seismic data and geomorphological studies (Figs. 3 and 4) it was shown that the site of cores 324 and 325 coincides with an area of very thin Quaternary cover, and has a position in a depression to the northwest of a very marked ridge, also with a presumably thin till-cover. The only till cover of greater thickness is found on the northwestern slope of the ridge and in the area northwest of the sampling site. The depression is obviously a result of selective glacial erosion of comparatively weak rocks, while the ridge to the south presumably consists of more resistant rocks.

It is therefore reasonable to assume that the material of the lower parts of the cores studied consists of material derived from the bedrock surface near the sampling site in the area to the southeast. With a westerly to northwesterly movement of the ice, rocks of Middle Jurassic to Lower Tertiary age, which are supposed to outcrop in the area, were picked up and redeposited. Because of the very fragile nature of most of the rock fragments, the transport is thought to have been short.

During this transport very little material with an origin from the mainland has been introduced in the sediment, and no fossils of Quaternary age have been found.

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Four Sediment Cores from the Continental Shelf Outside Trøndelag

SYLVI HALVORSEN

Haldorsen, S. 1974: Four sediment cores from the continental shelf outside Trøndelag. *Norges geol. Unders. 304*, 21–31.

Grain size analysis and clay mineral investigations have been carried out. The cores consist of an assemblage of sand, silt and clay, where the clay content is gradually decreasing from the bottom towards the top of the cores. The main mineral constituents of the clay fraction are illite, kaolin, mixed layer-minerals, chlorite, quartz and feldspar. The sediment is assumed to consist of material washed out from the till deposits at the shallower parts of the shelf. The kaolin content of the clay fraction varies between 10 and 30% and has probably been derived from the sedimentary rocks underlying the glacial deposits.

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Introduction

The present paper is the result of investigations of four sediment cores from the continental shelf outside Trøndelag, Western Norway (Fig. 1). The paper is a part of a cand.real. thesis presented at the University of Bergen (Haldorsen 1972). A few later laboratory investigations have been added. The work is a part of a regional investigation of the surface sediments on the Trøndelag shelf, carried out at the Geological Institute of the University of Bergen under the leadership of Professor H. Holtedahl.

The map (Fig. 1) shows the location of the Trøndelag shelf. The bottom topography is characterized by the two bank areas in the north and south, respectively named Haltenbanken and Frøyabanken, the most shallow parts of them situated 100–200 m below present sea level.

These two shallow bank areas are separated by a deeper region from which the four investigated cores have been collected (Nos. 304, 309, 324 and 350 in Fig. 1). The depth of this region is about 300 m. This deep region continues towards the northeast and southwest and separates the two bank areas from the skerry area. As can be seen from Fig. 1, the four cores have been collected outside the mouth of Trondheimsfjorden. The sampling localities lie between 10 and 90 km NW of the Island of Frøya. The depth along this northwestern-southeastern profile varies between 310 and 330 m.

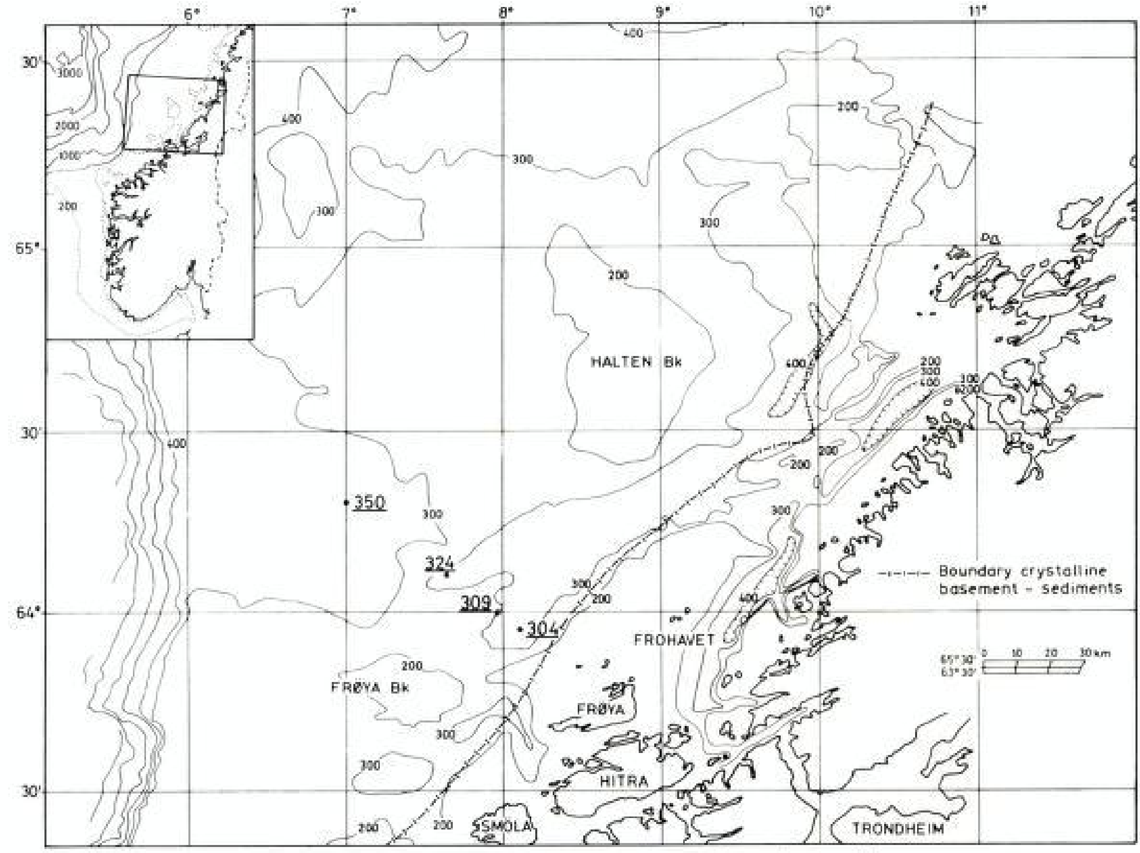

Fig. 1. Map of the shelf area outside Trøndelag. Underlined numbers refer to the localities of the investigated cores. Boundary between crystalline basement and sediments after Holtedahl & Sellevoll (1971, p. 46.)

Previous investigations of the area

Investigations of the Trøndelag shelf have been summarized by Holtedahl & Sellevoll (1971). This shelf area consists of a crystalline basement which is covered by several thousand metres of rather soft, sedimentary rocks of presumed Mesozoic and Tertiary age. The thickness of the Quaternary sediments varies from 250 m on the Haltenbank to about zero in the area from which the four investigated cores have been collected. The composition of the gravel fraction of the surface sediments indicates that the ice, at least once during the Quaternary, advanced across the Trøndelag shelf, leaving a glacial till which now covers the greater part of the surface in this area (Holtedahl & Sellevoll 1971, p. 47).

The lithological composition of till samples from the region where the four cores have been collected is of special importance. There is a considerable content of soft, unmetamorphosed rock fragments, which are not derived

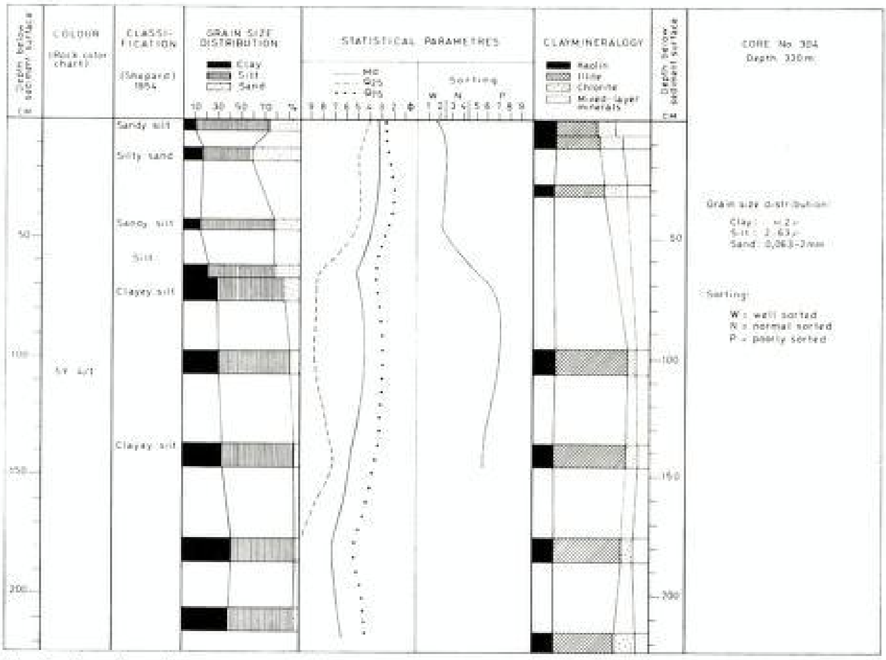

Fig. 2. Results of investigations from core No. 304.

from the coastal land areas. Fossil records indicate a Mesozoic age for some of this material (Holtedahl & Sellevoll 1971, p. 47).

Fig. 1 shows the assumed boundary between the crystalline rocks which form the coast areas, and the unmetamorphosed sedimentary rocks which cover the shelf area (Holtedahl & Sellevoll 1971, p. 46). This boundary is situated close to the coastal islands on this part of the Norwegian continental shelf.

Sampling procedure and description of the material

The examined material was collected with a gravity corer during 1969 on a cruise in the research vessel *Johan Hjort* belonging to the Institute of Ocean Research, Directory of Fisheries, Bergen. The examinations took place during 1970 and 1971. The material was kept in airtight PVC-tubes until the laboratory investigations were carried out.

On Figs. 2–5 are shown data from the four cores. The lengths vary from 60 cm for core No. 350 to 240 cm for core No. 309. The colour and texture are nearly identical for cores Nos. 304, 309, 350 and the upper part of core 324, while the lower 50 cm of core 324 consists of a sediment which differs from the upper 100 cm of the core with respect to colour, grain-size distribution and mineralogy (Fig. 4). This sediment is thought to be a till mainly composed of material derived from the Mesozoic and Tertiary bedrock. It is

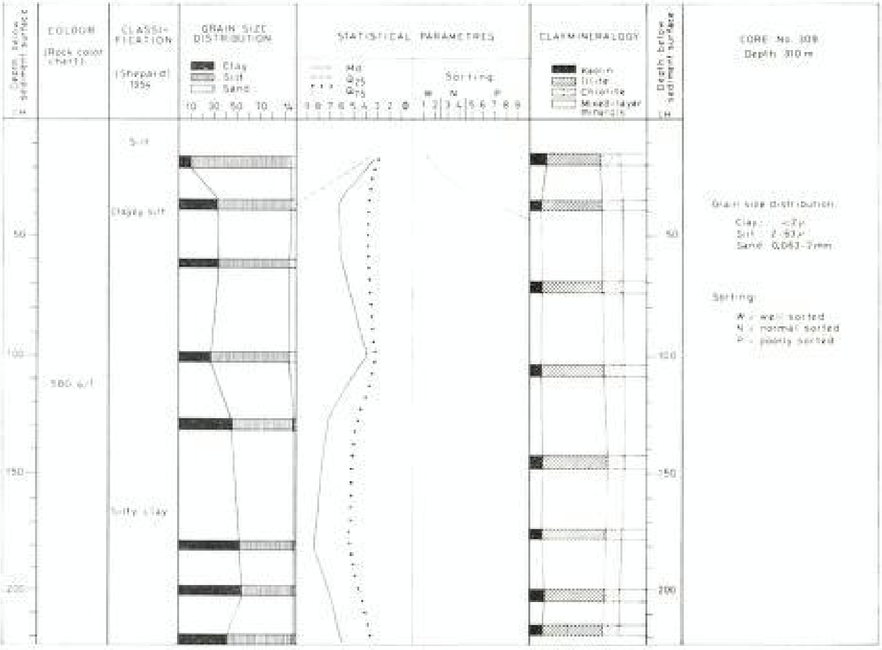

Fig. 3. Results of investigations from core No. 309.

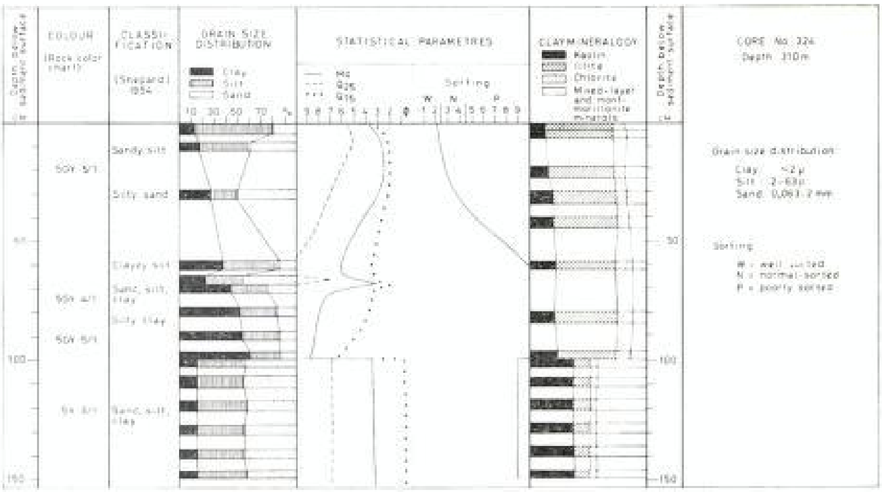

Fig. 4. Results of investigations from core No. 324.

discussed by Holtedahl et al. (1974) and will not be further described in this paper.

The colour of the cores is grey to bluish green and the colour symbols in Figs. 2–5 refer to the Rock Color Chart (Geological Society of America 1951). The cores consist mainly of silt and clay with variable proportions of

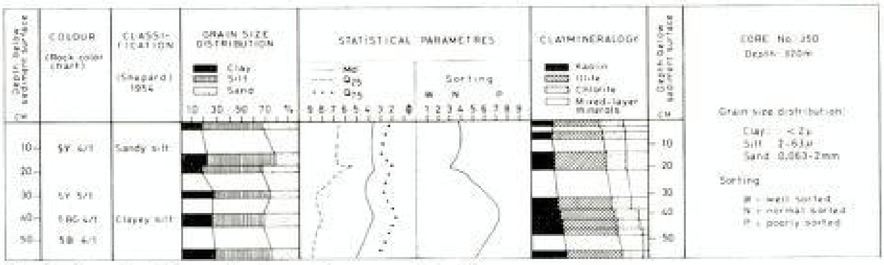

Fig. 5. Results of investigations from core No. 350.

sand. The material coarser than 2 mm consists of shell debris; the weight per cent of this fraction is negligible.

Foraminifera and shell fragments are found through all the cores, most frequently in the upper parts, while there are only small quantities in the deepest parts.

The shear strength values vary between 0.2 and 1.5 t/m^2 and the sensitivity is about 2–3. This rather soft sediment therefore shows no signs of overconsolidation.

The porosity values vary from 50 to 60%.

Laboratory methods and results of investigations

GRAIN-SIZE DISTRIBUTION

After removal of salt pore water from the samples, grain-size analysis was carried out by sieving and pipette methods. Samples were taken from each, tenth to twentieth cm through the cores, and about 10 g material was used for the pipette analysis.

The grain size distribution of the four cores is shown in Figs. 2–5. The size grades are mainly classified according to the system of Wentworth (1922); the boundary between clay and silt, however, is placed at 2μ (9 Θ-units). The quartiles Q_1 and Q_3 are the size values used by Pettijohn (1957, p. 37). The sorting is calculated according to Trask (1932).

There is a gradual increase in the clay content from the top towards the bottom of the cores, though the rate of this increase is not the same in all the cores. The greatest increase is found in core No. 324, were the clay content at the top of the core is 10% while the content of clay 100 cm below the sediment surface is about 60%. In this core there is a sand layer at about 20%. The least distinct increase in the clay content is found in core No. 350, which is also the shortest of the four cores. The clay content at the top of this core is about 20% while at the bottom there is about 30% clay.

There is a decrease in the sand content towards the bottom of the cores. The foraminifera in the cores are thought to be benthonic organisms found *in situ* and they have been separated from the sand fraction by using the method described by Feyling-Hansen (1958, p. 39). The weights per cent of the sand fraction in Figs. 2–5 are then calculated for the mineral material. The variation in the sand content is not as distinct as the increase in the clay content, with the exception of core 304. The upper 30 cm of this core consists of about 30–40% sand, while the sand content decreases to about 5% at the bottom. The lowest sand content is found in core 309, where it does not exceed 5% at any level.

The upper 30 to 50 cm of the cores consists of a well to normally sorted sediment, while the sorting is poor in the lower part of each core.

According to the classification of Shepard (1954), the upper part of the cores consists mainly of sandy silt and silty sand, the central part of clayey silt, and the bottom of the cores of a silty clay.

CLAY MINERALOGY

The clay fraction from eight levels in each core has been subjected to X-ray diffraction analysis. A Philips diffractometer with a Ni-filtered Cukα radiation and a goniometer speed of $\frac{1}{2}°2\Theta$ per minute was used. The samples were made by sedimenting an aqueous suspension on a glass slide and drying in air at room temperature. The mineral constituents were mainly identified according to the criteria used by Brown (1961). In addition, the 'slow scan' method of Biscaye (1964a) was used to identify kaolin minerals in the samples. The 'slow scan' speed was $\frac{1}{8}°2\Theta$ per minute. By this method the (002) reflection of kaolin at 3.58 Å can be separated from the (004) reflection of chlorite at 3.54 Å. Fig. 6 shows a 'slow scan' of the 3.5 Å peaks above the correspondng peaks on the 'normal scan' diffractogram from core 309, level 200 cm below the sediment surface.

The principal mineral constituents in the four cores are illite, kaolin, mixed layer minerals mainly of an illite/vermiculite type, chlorite, quartz and a proportion of feldspar. Fig. 6 shows the diffractometer tracings of untreated, glycerol-treated, heated and HC1-treated specimens from core 309, level 200 cm below the sediment surface. In addition to the treatments indicated in Fig. 6, a heating to 300°C was used to identify the mixed-layer minerals in some samples.

The semi-quantitative valuations of the mineralogical composition have been done using the methods of Gjems (1967) and Biscaye (1964b). The content of quartz and feldspar has not been estimated.

The kaolin and chlorite content was determined by treating the samples with a 6 N HC1, and then calculating the ratios between the 7 Å peaks on untreated and HC1-treated samples. The HC1-treatment is also used to determine whether the illite is of a di- or a trioctahedral type. The quartz reflection at 4.26 Å was used as an internal standard.

Figs. 2–5 shows the clay mineral composition of the four cores. The contents are given in the form of bars which show how the intensity ratios of the different clay minerals vary from sample to sample through the cores.

The illite content varies between 30 and 50% in the cores, and illite is

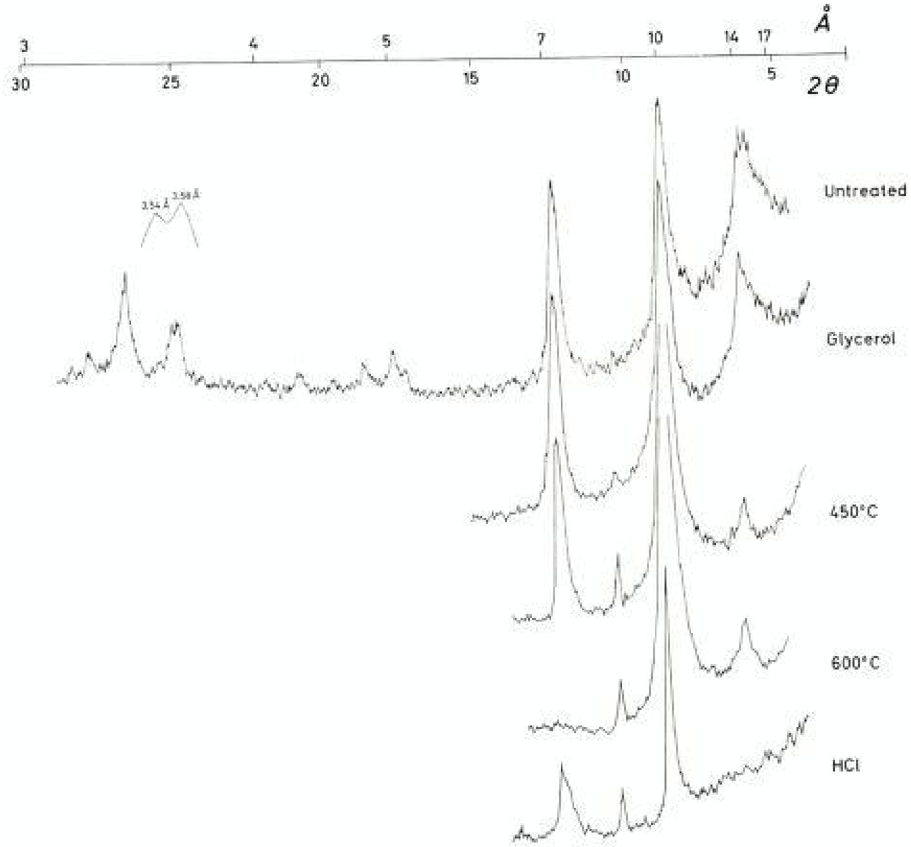

Fig. 6. X-ray diffractograms of core 309, level 200 cm below the sediment surface. 'Slow scan' of the 3.5 Å peak is traced above the corresponding peak of the 'normal scan' diffractogram.

therefore the main mineral group in the four cores. The intensity ratios between the first order reflection at 10 Å and the second order reflection at 5 Å is 1:5 to 1:8, which should indicate a proportion of trioctahedral illite (Bradley & Grim 1961), but the 10 Å reflection, however, is only slightly reduced by the strong HC1-treatment. The illite is therefore thought to be mainly of a dioctahedral type.

The kaolin content varies between 10% at the top of the cores and 20–30% at the bottom. Core 309 has the lowest kaolin content. The highest values are found in core 350, where a distinct increase is also found in the kaolin content towards the bottom of the core.

The chlorite has weak (001) and (003) reflections and strong (002) and (004) reflections. An increase is observed in the intensity of the (001) reflection on heated specimens for three samples (core 304, level 97–107 cm; core 325, level 95–100 cm; and core 325, level 55–58 cm). The low ratio between the (001) and the (002) reflections seems to be rather usual for chlorites in the clay frtction of marine sediments (Biscaye 1964b, pp. 35–

36). The chlorite content varies between 10 and 20%, and no systematical variations are found with respect to depth below sediment surface.

The content of mixed layer minerals varies between 5 and 20%, the highest values being found in the top of the cores.

Discussion and conclusions

SOURCE MATERIAL

The main surface sediment on the continental shelf outside Trøndelag is glacial till (Holtedahl & Sellevoll 1971, p. 44). Besides a mineralogical study of the sand fraction (Bjerkeli 1972), lithological investigations of this till material have until now been restricted to a description of the gravel and stone fraction. A clear dominance is found of crystalline rock types derived from the mainland in the east (Holtedahl & Sellevoll 1971, p. 34). No systematic investigations have been carried out to examine the clay fraction of the till or the composition of the soft sedimentary rock fragments.

One till sample from the area where the four cores have been collected has, as mentioned, a special composition. It is composed of material which most probably is derived from the underlying rocks. Rock fragments from this sample have been subjected to X-ray diffractometer analysis. The most common rock types were silt- and claystones. They showed a kaolin content varying between 60 and 80%.

When the ice advanced across the Trøndelag shelf during the Pleistocene, the soft sedimentary bedrocks were exposed to erosion. These rocks seem to consist partly of silt- and claystones, which are easily disintegrated. The finest fractions of the till have thus been enriched by the minerals from these silt- and claystones. If the rock types which have been analysed are representative of the composition of the eroded bedrocks, it is reasonable to presume that the clay material of the till deposits contains a great part of kaolin minerals.

With the exception of the lower part of core No. 324, the sediment described from the four cores is definitely not till material. This is clearly seen from the grain size distributions and from the distribution of the different foraminifera species through the cores. No systematic analysis has been carried out of the foraminifera in the cores, but a gradual change was observed from a fauna dominated by *Nonion labradoricum, Elphidium incertum clavatum,* and *Virgulina loeblichi* at the bottom, to a fauna represented by *Uvigerina peregrina, Höglundina elegans, Hyalinea balthica, Nonion barleeanum* and *Bulimina marginata* at the top, indicating a climatic change from cold to warmer.

The clay mineral analysis of the four cores showed a kaolin content varying between 10 and 30%. Berry & Johns (1966) have investigated sediment core samples from the North Atlantic Ocean and conclude that the clay minerals are mainly derived from terrestrial sources. Biscaye (1964b) has drawn the same conclusions from investigations of deep-sea cores from the Atlantic

Ocean. The formation of clay minerals *in situ* on the ocean bottom seemed to be of little importance.

The kaolin content of the investigated material cannot be explained by any significant transport of this mineral from the land areas during Postglacial time. Gjems (1967, p. 404) postulates that the occurrence of kaolin in the Scandinavian soils is restricted to places where this mineral is also found in the neighbouring bedrocks. In Norway such kaolin-bearing rocks have very restricted local occurrences and are not of any regional importance. It must be expected, however, that weathering products formed in Preglacial time had another mineralogical composition than most of the surface sediments found in Norway today. The greater part of those old weathering products were removed from the land areas during the Pleistocene and were deposited somewhere outside the Norwegian coast. Some part of that material may be found in the surface sediments on the continental shelf today. The shelf areas have, however, been exposed to glacial erosion, and the old weathering products have most probably been transported further out. Large masses of fresh rock material have been removed from the adjacent land areas and it is not probable that the pre-Quaternary weathering products have any strong influence on the composition of the present shelf surface sediments.

No samples have yet been collected from the shelf inside the boundary between the crystalline basement and the soft sedimentary rocks (Fig. 1). A sediment core collected in the outer part of Orkdalsfjord west of Trondheim (Fig. 1) did not contain any kaolin. Another core taken just outside the mentioned rock boundary, NW of the Island of Frøya, has been analysed and showed a clay mineral composition similar to the material described in this paper. It is therefore most likely that the sedimentary rocks of presumably Mesozoic or Tertiary age, which compose the base for the Quaternary sediments, have been the source material for the kaolin in the sediment cores.

The highest kaolin content found in the clay fraction of the cores studied is about 30%. If a kaolin content of about 60–80% is representative of the sedimentary bedrocks, at least one half of the clay fraction of the most kaolin-rich horizons in these cores consists of material derived from the local bedrocks.

THE TRANSPORT MECHANISM AND TIME OF DEPOSITION

The development of the foraminiferal fauna may indicate that the deposition of the lower parts of the cores took place under more arctic conditions than the deposition of the surface sediments. Suspended material from the melting shelf ice could then be expected to have a strong influence on the material which was first deposited. However, the clay mineral composition of the core material casts doubt on this hypothesis. When the front of the shelf ice was situated inside the boundary between the sedimentary rocks and the crystalline basement (Fig. 1), the suspended material from the meltwater presumably did not contain any significant quantity of kaolin minerals. The mentioned core which is sampled near this boundary west of Frøya has about the same grain size distribution and clay mineral composition as the four investigated cores and is undoubtedly deposited in the same way. It contains about 20–30% kaolin from the bottom to the top. Consequently the main source of the core material does not seem to be suspended material from the meltwater.

Holtedahl & Sellevoll (1971, p. 47) mention that clay and silt material winnowed out from the more shallow parts of the shelf might have been deposited at deeper parts of the area. The material described in this paper may be of such a type. The main part of the core sediments is then redeposited till material washed out from the shallower parts of the shelf. This hypothesis can explain the variations in texture and why the core material contains so much kaolin.

During the Pleistocene the sea level at the Trøndelag shelf showed great changes (Holtedahl 1971). The magnitude of the current- and wave-erosion at the different parts of the shelf was therefore more or less extensive. Calculations of the sea level changes during the Weichselian and Postglacial times are complicated because the isostatic factor is unknown.

What is known, however, is that the shallow parts of the shelf were exposed to erosion. The finest fractions of the till material were winnowed out from these areas.

A determination of the content of foraminifera in the coarse fraction of the cores showed that there was a large increase in the ratio of foraminifera-shells/mineral-grains from the bottom towards the top of the cores, which cannot only be explained by an increase in the frequency of living organisms. The rate of sedimentation seems to have been decreasing during the time of deposition, and this may be explained by decreased erosion of the till material. The eroding power may have been less extensive, or there was also a decrease in the amount of material available for erosion.

The quantitative changes of the erosion and the mechanisms of the transportation can to some extent explain the vertical variation in the grain size distribution. The different size fractions were not transported in the same way. Clay and silt were transported in suspension down to the deepest parts of the shelf area and were deposited there, while the greater parts of the sand and possibly the coarsest part of the silt fraction were transported along the bottom. The bottom transport was a much slower way of transportation than the transport in suspension, and as a result, clay and silt were thereby enriched in the sediments first deposited. When the erosion diminished, the transportation of clay and silt from the shallow areas decreased, while the sand and coarse silt were still in transportation along the bottom down to the deeper parts of the area, giving a higher content of these size fractions towards the top of the cores.

The time of deposition has not been exactly determined. As mentioned, no systematic investigation of the foraminifera content has yet been carried out. The fauna at the bottom of the cores, however, points to a late Weichselian age with arctic conditions. The changes in the fauna may indicate that the environment gradually became more boreal and the deposition of the upper part of the cores took place during Postglacial time. It has not been possible to determine whether the sedimentation is still going on. An investigation of the foraminifera content may possibly answer this question.

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Petrography of the Gula Group in Hessdalen, Southeastern Trondheim Region, with Special Reference to the Paragonitization of Andalusite Pseudomorphs

PER BØE

Bøe, P. 1974: Petrography of the Gula Group in Hessdalen, Southeastern Trondheim region, with special reference to the paragonitization of andalusite pseudomorphs. *Norges geol. Unders. 304,* 33–46.

Al-rich pelites from Hessdalen, SE Trondheim region, Central Norway, belonging to the Cambrian Gula Group, are described petrographically. The schists carry abundant porphyroblasts of staurolite, garnet, kyanite and pseudomorphs after andalusite. X-ray diffraction analysis has shown that the white mica of the pseudomorphic mineral assemblages is paragonite with a little muscovite.

It is proposed that the andalusite pseudomorphs are relics from a contact metamorphic aureole associated with pretectonic to early syntectonic emplacement of deep-seated, sub-surface gabbroic bodies, indicated by geophysical evidence. The subsequent high-pressure metamorphism of lower almandine-amphibolite facies, tentatively correlated with an early fold phase F_1, inverted the andalusite porphyroblasts to aggregates of kyanite. The formation of paragonite occurred during a retrogressive metamorphic phase, as a pseudomorphosis of the kyanite in the altered andalusite porphyroblasts.

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Introduction

The area under consideration is situated in the northern part of Hessdalen, a western tributary valley to the upper Gauldal valley in the county of Sør-Trøndelag (Fig. 1). A recent article on the geology of the Røros district embraces the Hessdalen area (Rui 1972). In this work the stratigraphy of the south-eastern Trondheim region is correlated with that of the Meråker district to the north, following Wolff (1967). It is also shown that the lithostratigraphic sequence is inverted, as is the case in the Meråker area.

The stratigraphic succession in the eastern Trondheim region has been correlated with that occurring in the western part of this rather extensive eugeosynclinal area of the Norwegian Caledonides (Wolff 1967). From various evidence it is now generally accepted that the Gula Group (named Gula Schist Group by Wolff 1967, and Gula Group by Wolff 1973) is the oldest unit of the Lower Paleozoic stratigraphic succession in the Trondheim region; this is followed by the volcanic Støren Group, the Lower and Upper Hovin Groups and the Horg Group (Roberts et al. 1970).

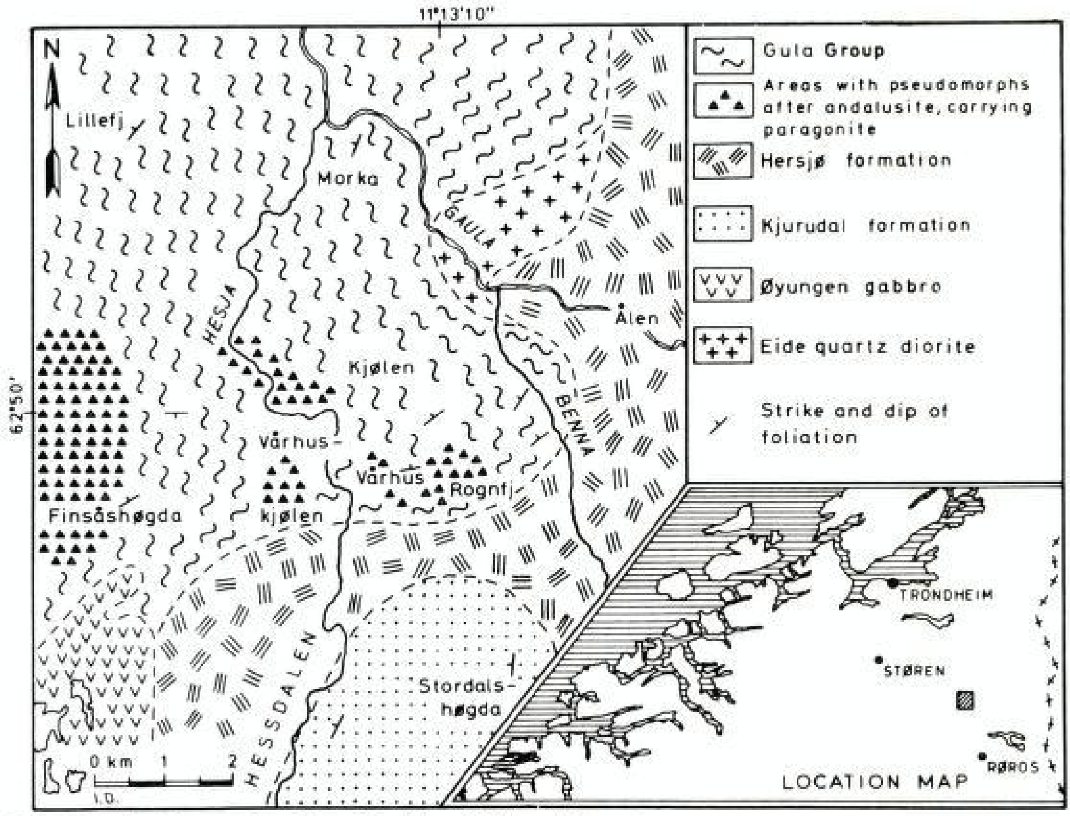

Fig. 1. Geological map of northern Hessdalen, SE Trondheim region.

Geological setting

In Hessdalen the metasediments of the Gula Group constitute the youngest part of this group, which occurs extensively in the central part of the Trondheim region. Volcanic rocks of the Hersjø formation, a supposed Støren Group equivalent, are lying tectonically below the mica schists of the Gula Group. The Hersjø formation is itself overriding the Kjurrudal formation, which is regarded as a Hovin Group equivalent (formation named after Rui, 1972). The Al-rich schists in Hessdalen, with numerous occurrences of staurolite and Al_2SiO_5-polymorphs, form a southern continuation of the so-called Drøya schists in Haltdalen, a few kilometres to the north in Gauldalen (Vogt 1941). Further to the north they are probably represented by the Heinvola zone in Tydal (Kisch 1962) and the zone with 'Selbu millstone' (Carstens 1929). To the south of the studied area similar rocks are found on the mountain Hersjøfjell (Birkeland 1967).

The occurrence of andalusite and andalusite pseudomorphs in Hessdalen has long been known. In 1868 Th. Kjerulf's co-worker Knut Hauan recorded andalusite on the western banks of the river Hesja, and in 1873 he found the mineral at Vårhus (diaries of Knut Hauan, NGU archives). It may be assumed that the reported crystals of andalusite actually were pseudomorphs of the mineral with their orginal shape unchanged. Hauan also observed glacial striae on these pseudomorphs partly weathered out of the schist in the Vårhus-Rognfjell area.

Tectonic structures

The folding deformation in the Hessdalen area seems to be divisible into two main episodes. An early fold phase, F_1, probably folded the sediments and volcanics in tight or isoclinal folds overturned to the east, with the formation of a distinct axial plane foliation. The schists split along this foliation, which mostly coincides with primary bedding on a mesoscopic scale. The F_1, foliation originally had a general NNE-strike with westerly dip, as seen in southern Hessdalen outside the present map area (Birkeland 1967, Bøe 1971). There are few mesoscopic folds of this episode to be seen in Hessdalen.

A later folding phase F_2 has refolded the earlier folds and foliation along east-west axes. The later phase is especially well marked in northern Hessdalen by the eastward extension of the Gula Group on Rognfjell, in the shape of a large and fairly open synform (Fig. 1). Lineations belonging to this second episode, defined chiefly by crenulations but also by mineral orientations and mullions, have directions within the sector 285°–315°, using a 400° scale. Axes of mesoscopic folds from the Hersjø and Kjurrudal formations in the southern part of the map (Fig. 1) have directions within the same sector, with a concentration around 310°.

Description of the mica schists

Mica schists of the Gula Group within the present area are brownish grey and usually fine-grained with an indistinct lamination. Small segregations of quartz of syntectonic origin are common, but not numerous. On weathered surfaces the schists have a rusty appearance, probably a result of disseminated sulphides. Graphite is observed in some places. Porphyroblastic minerals are common, and up to 3–4 cm in size. The porphyroblasts give a knotted appearance to the foliation surfaces.

The texture of the schist matrix is typically lepidoblastic, usually with biotite defining the foliation. In thin-sections, the schists may display microfolds, sometimes with the development of fracture cleavage and strain-slip cleavage. Some modal compositions, based on volumetric analysis of selected specimens, are given in Table 1.

Quartz and sodic *plagioclase* are completely recrystallized to granoblastic grains, which are slightly elongated within the foliation. Both these minerals have a fresh appearance with even extinction. The plagioclase lacks twinning.

Table 1. Modal analyses of mica schists of the Gula Group from Hessdalen, Sør-Trøndelag.

Localities: 1. Vårhus
2. Vårhus
3. Vårhus
4. Morka
5. Finsåhøgda
6. Rognfjell
7. Finsåhøgda
8. Finsåhøgda

	Mica schist	Staurolite-mica schist				Andalusite-mica schist		
	1	2	3	4	5	6	7	8
Staurolite porphyroblasts	–	8	5	7	9	3	–	–
Andalusite pseudomorphs	–	–	–	–	–	18	27	30
Quartz	51	28	21	33	33	37	22	19
Plagioclase		8	14	9	8	–	22	13
Biotite	44	49	50	46	43	39	33	32
Muscovite	x	x	9	2	5	x	1	1
Chlorite	1	5	x	–	x	1	4	4
Garnet	–	–	x	2	x	x	–	–
Kyanite	–	–	x	x	x	x	–	x
Tourmaline	–	x	x	x	x	x	x	x
Apatite	–	–	x	x	x	x	x	–
Orthite	x	x	x	x	x	–	–	x
Rutile	x	x	x	x	–	x	x	x
Zircon	x	x	x	x	x	x	x	x
Opaques	x	x	x	x	x	x	x	x
	100	100	100	100	100	100	100	100
An-content of plagioclase			25–28	28		25–30		25

The contents of quartz listed in Table 1 were determined by means of DTA-analyses.

Biotite forms small parallel-oriented flakes with irregular outline. The darkest absorption colour is yellowish brown. The refractive index measured on flakes is: $n_y \sim n_z = 1.624$. Maximum interference colour is green of the 3rd order.

White mica appears in small amounts in the matrix, usually parallel to the foliation, but it is also seen growing across this regional foliation. A third occurrence is that within pseudomorphs after andalusite (see below). The white mica of the matrix seems to have a higher maximum interference colour (transition 2nd to 3rd order) than that in the andalusite pseudomorphs. In all probability the white mica in the groundmass is a muscovite.

Chlorite may be present in quite appreciable amounts, though the mineral is generally an accessory. Fan-shaped aggregates are seen, together with individ-

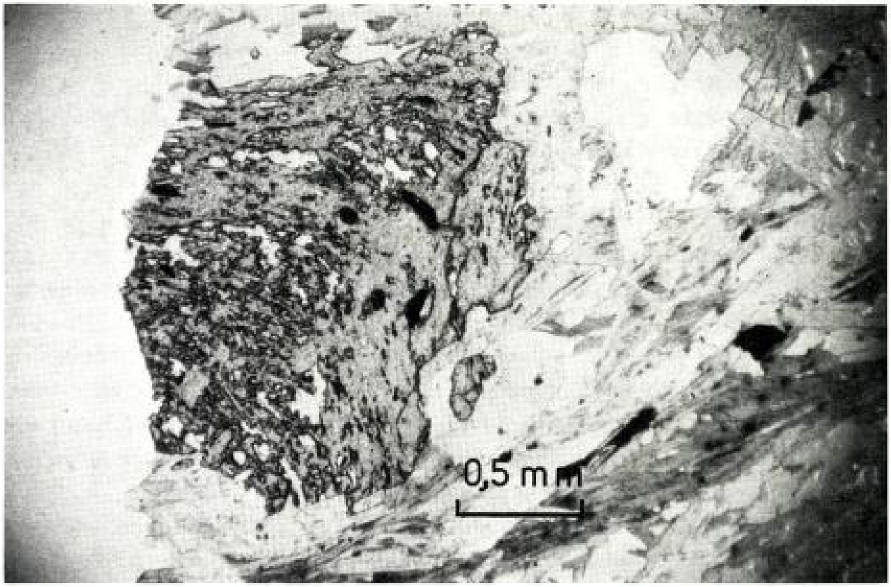

Fig. 2. Rotated syntectonic porphyroblast of staurolite. Plane polarized light. Vårhus.

ual flakes, often in intimate intergrowth with biotite. The chlorite is biaxial, is:$2V_Z \sim 15°$:$n_X \sim n_Y = 1.675$. Optical data indicate an Mg-rich ripidolite (Trøger 1971, p. 118).

Orthite, partly metamict, is usually the only epidote mineral present. In a few specimens, however, orthite occurs within fresh clinozoisite. *Tourmaline* may be present as small idioblastic prisms, with yellow-green absorption colours along the ω direction. *Apatite* is likewise observed as very small idioblastic grains. Opaque minerals in the schists comprise sulphide and oxide ore minerals, as well as graphite.

Staurolite, garnet and kyanite occur as porphyroblasts. In addition, andalusite was very likely initially developed as single-crystal porphyroblasts.

Staurolite occurs as idioblastic dark brown prisms up to 2 cm in size, which occasionally weather out on the exposed surfaces of the schist. Penetrative cross twins are fairly common. The staurolite prisms usally lie within the F_1 foliation planes. Under the microscope, staurolite is seen to be markedly poikiloblastic, the inclusions (mostly quartz) making up 50% or more of the crystal volume. The included grains are of distinctly smaller size than the present groundmass grains, but the textural relations between porphyroblasts and matrix are obscured by a later deformation of the matrix. It seems possible that this later small-scale deformation may have rotated the staurolite porphyroblasts somewhat after their growth. In two specimens, staurolite porphyroblasts possess curved inclusion trails indicating probable syntectonic growth (Fig. 2). In some sections, the staurolite gives the appearance of pushing aside the matrix foliation. Summing up, these various observations would seem to point to the conclusion that staurolite had a rapid, early F_1, syntectonic growth.

Measurements of refractive indices and axial angle indicate that the mineral is an Fe-rich variety (Trøger 1971).

Garnet is generally present as idiomorphic poikiloblasts, less than 0.5 cm in size. Only in one small area, at Morka, have larger garnets (2 cm) been found. Curved trails of inclusions are occasionally seen within the garnet porphyroblasts. Staurolite is sometimes included in these garnets. In most cases, garnet has grown by volume replacement, cutting the matrix foliation, though sometimes the porphyroblasts appear to push aside the matrix foliation to some degree. According to Misch (1971), where porphyroblasts are cutting the foliation and at the same time pushing it aside, this is an indication of late syntectonic to post-tectonic growth.

A garnet from Morka has been analysed chemically. This is shown to be a pyralspite with the following computed molecular composition: 63% almandine, 20% grossularite, 10% spessartite, and 7% pyrope.

Kyanite is found in several forms, indicating different modes of formation. Om Rognfjell, lenticular segregations occur (10–15 cm in length) containing approximately equal amounts of quartz and ice-blue kyanite, the latter in 2–3 cm-long prisms. Some paragonite has been indentified in these lenses by its X-ray diffraction pattern. In addition, the lenses carry a little staurolite, and occasional crystals of green apatite. These lenses are probably of hydrothermal origin, the necessary components for the mineral formation having been derived from some distant source.

A second type of kyanite occurrence is that of pseudomorphs after what is presumed to have been andalusite, especially the larger ones. This kyanite, present as slightly bent, unorientated needles, sometimes arranged in a dendritic pattern, is the result of polymorphic inversion from andalusite. A third type of kyanite is present as scattered porphyroblasts in the schist, and was possibly formed at the expense of biotite.

A particular occurence of kyanite from Finsåhøgda deserves special mention. Here the kyanite is consentrated in small (0.5 cm) aggregates in intimate intergrowth with sillimanite of fibrolite type. A few kyanite grains are completely pseudomorphosed to sillimanite mats, this clearly being a prograde replacement feature. Most of the kyanite growth is regarded by the writer as syntectonic with respect to the F_1 fold phase.

Lime-silicate rocks

Interbedded in the pelitic schists are lenses and thin layers of lime-silicate rocks. The texture of these rocks is either massive or banded with alternating

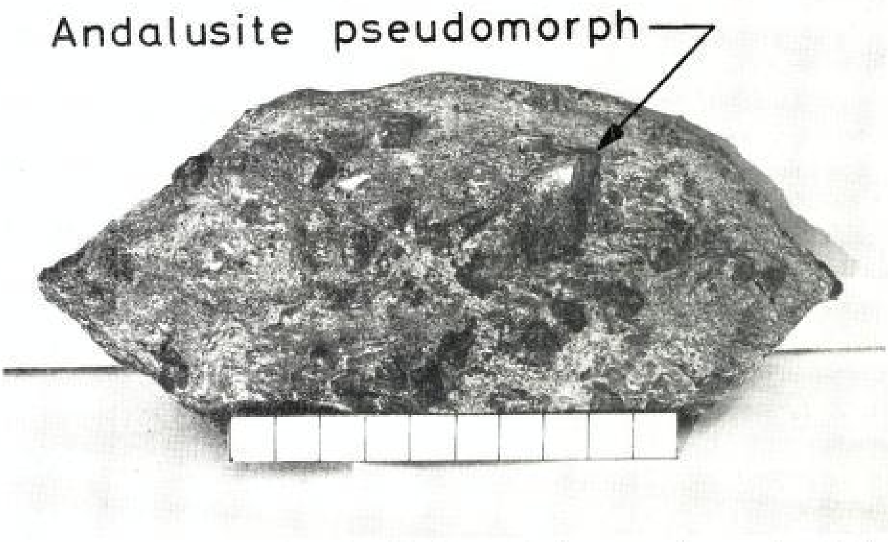

Fig. 3. Specimen of schist from the Gula Group showing one well-preserved andalusite pseudomorph, together with several staurolite idioblasts (dark bodies). Length of scale is 10 cm. From Vårhus.

biotite-rich and amphibole-rich bands. The mineral assemblages consist of plagioclase, scapolite, actinolitic amphibole, diopsidic pyroxene, clinozoisite, orthite (mostly included in clinozoisite), sphene, rutile, biotite and calcite.

The banded lime-silicate rocks conform petrographically to the lime-silicate gneiss described from the Gula Group by Goldschmidt (1915, pp. 8–21). These rocks are regionally metamorphosed calcareous sediments.

Pseudomorphs after andalusite

Pseudomorphs presumed to be after andalusite are a characteristic feature of the Al-rich pelites of northern Hessdalen. The pseudomorphs, of 1–2 cm average size, have been found in several areas (Fig. 1). They are generally light grey, with a darker brownish or bluish colour on fracture surfaces. The shape, and even the colour, of the bigger ones with sharp prismatic forms and rhombic or square cross-sections resemble that of idioblastic andalusite. In the present writer's view there can be little doubt that these light-coloured pesudomorphs were once individual andalusite crystals (Fig. 3).

Microscopic examination has shown that the andalusite is generally completely transformed to different mineral assemblages, in spite of good preservation of andalusite morphology in many cases. The pseudomorphs are easily seen within the schist matrix, with sharp borders between pseudomorphs and matrix. The foliation of the schist is in most cases wrapping around the pseudomorphs; only in a few cases is there a partial deflection of the schistosity with truncation of especially the biotite. It would appear that the andalusite formation was pretectonic to early syntectonic. This is in agreement with evidence found by Birkeland & Nilsen (1972).

Rognefjell and Vårhus are the localities where the largest pseudomorphs have been found. Locally these are quite abundant, and on Rognefjell the writer has found pseudomorphs projecting up to one cm out of the schist as a result of postglacial weathering. The largest pseudomorph measures 5 cm in length, though its prismatic shape is somewhat deformed.

In upper Gauldalen, pseudomorphs have been found containing some relict andalusite. Andalusite crystals showing little alteration have also been reported from this district (Birkeland & Nilsen 1972). In the river Hesja the writer found an erratic boulder of schist with pseudomorphs containing patches of relict andalusite. In the collections at the Geological Institute, Norges Tekniske Høgskole, Trondheim, there are specimens of brown schist with partly pseudomorphosed andalusite. Some of the specimens were found as erratics by J. H. L. Vogt in the Holtsjøen area, some 10 km to the north-east of the present area. One specimen is from Hessdalen, collected by R. Jakobsen Sørby.

It is clear that, in upper Gauldalen, the andalusite shows different degrees of alteration from very litle change to complete replacement. In Hessdalen, however, the impression is that the andalusite crystals are all completely altered to multiphase, multicrystal pseudomorphs (classification according to Spry 1969, p. 91).

The pseudomorphs in the three modal-analysed specimens (Table 1, Nos. 6–8) all show complete alteration. In these particular specimens the pseudomorphs, which are about 0.5 cm in size, have elliptical outlines and sharp borders against the matrix. The dominant replacive minerals are white mica (ca. 50%, mainly paragonite) and chlorite (30–40%); some individual grains of quartz are present as well as the accessories biotite, apatite, tourmaline and ore minerals. It is likely that quartz and some of the accessories are primary inclusions in the originally poikiloblastic andalusite. The micas show no directional growth and display a mesh-like texture.

The size of the white mica is on the average 200 μ, maximum 400 μ. Shapes are rather irregular, with a tendency to elongated flakes. The chlorite, of similar size, is pale green with a faint pleochroism. Its optical properties include $2V_Z = 15°$; $n_{xy} = 1.616$; normal interference colours. It is probably the same phase of chlorite growth as that occurring in the matrix. The size of quartz and other mineral grains is in the range 10–100 μ.

Thin-sections of the above-mentioned 5 cm-sized pseudomorph from Vårhus exhibit a different mineral assemblage. Andalusite is again lacking, but on the other hand kyanite is present, irregularly distributed. In some places kyanite occurs in a dendritic pattern as slightly bent needles, while in other areas of the thin-sections kyanite is observed as scattered grains embedded in white mica (Fig. 4). White mica is quantitatively (50%) the most important mineral besides kyanite. Chlorite is absent, and the amount of quartz is less

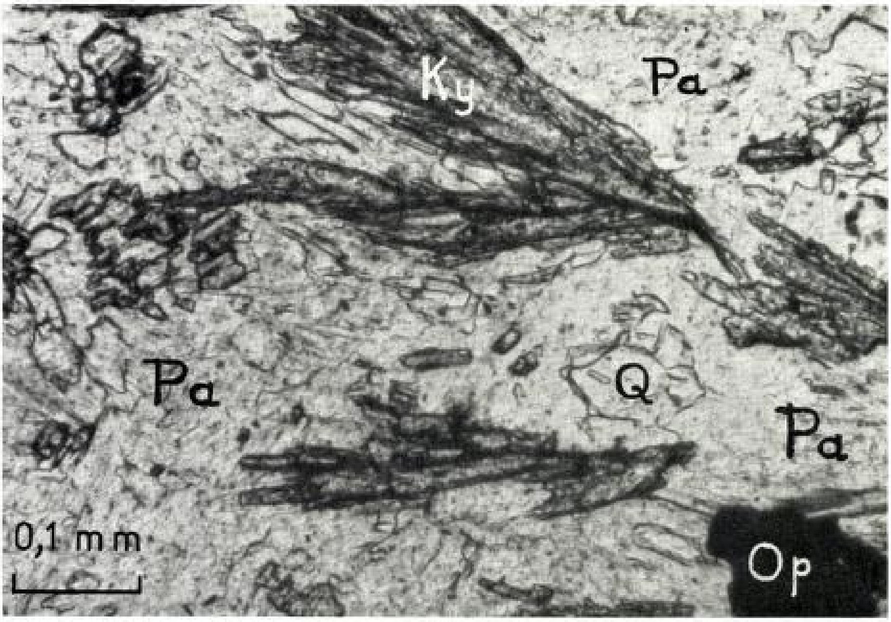

Fig. 4. Photomicrograph of part of a 5 cm long pseudomorph from Vårhus. Kyanite (Ky) is partly altered to a uniform mixture consisting mostly of paragonite (Pa) with a little muscovite. Q and Op are grains of quartz and opaque minerals, respectively.

than 10%. The mutual kyanite-white mica relationship seems to indicate that white mica replaces the kyanite. This presumed formation of the white mica, i.e. paragonite, from kyanite is more advanced in some parts of the pseudomorph, however, than in others.

Kyanite may be detected with the naked eye in hand specimens of some pseudomorphs. As a general rule the larger pseudomorphs carry kyanite.

Examination of paragonite

The larges pseudomorph found (described above) has been crushed and the white mica separated, with a rather poor result. This material, together with unseparated material from other pseudomorphs, has been analysed by X-ray diffraction, using CuKα-radiation. The goniometer was manually operated, with fixed time countings of impulses. The results are given in Table 2. Specimen 1 is poorly separated material, and specimens 2–6 unseparated. The four strongest and best defined reflections obtained in all runs are the basal reflections shown by specimen 1. There is practically no difference in the basal spacing of paragonite from different localities as shown by the d (002) values, indicating a constant Na-content of paragonite from the area. Specimens 2–6 all have clear, well defined reflections for the other three planes, (004), (006) and (0010), with values in very close agreement with those from specimen 1.

Table 2. X-ray diffraction data for paragonite from pseudomorphs after andalusite. For three specimens d (002) data for co-existing moscovite are listed.

			Paragonite	Muscovite
Spec.nos.	Localities	hkl	d	d
1	Vårhus	002	9.65	10.07
		004	4.82	
		006	3.21	
		0010	1.92	
2	Rognfjell	002	9.65	10.09
3	Rognfjell	002	9.64	
4	Finsåhøgda	002	9.65	
5	Vårhuskjølen	002	9.63	10.06
6	Vårhus	002	9.64	

In some specimens muscovite has been detected, chiefly by the (002) reflection, this showing a somewhat larger basal (002) spacing than paragonite (Fig. 5). There is reason to believe that small amounts of muscovite are always present in association with the paragonite.

Axial-angle measurements on specimen 1 have been carried out on a U-stage, giving 2V values in the range 46°–48° (10 measurements). This is a higher angle than reported earlier (Harder 1956, Neathery 1965, Deer et al. 1966).

Metamorphism

The porphyroblastic growth of andalusite presents a problem of its own, recently discussed by Birkeland & Nilsen (1972). These writers connect the andalusite growth in upper Gauldalen with contact metamorphism associated with gabbro intrusion.

The gabbro body situated closest to the present area is the Øyungen gabbro, with a surface outcrop of about 45 km^2, a few kilometres to the southwest (Fig. 1). The distance from the nearest contact of this intrusion to the areas with the most intensive andalusite formation at Vårhus and Rognfjell is 5 km. It does not seem very likely that the thermal influence of the Øyungen gabbro should have such a profound effect at this distance from the intrusion border. Any possible thermal effects from the Eide quartz-diorite may be discounted, as this is not a homogeneous intrusion but rather a concentration of quartz-diorite sills and dykes (Flatebø 1968).

If one considers the growth of andalusite in the Hessdalen area to be a contact metamorphic phenomenon, then one must necessarily postulate the subsurface presence of instrusive bodies. Geophysical evidence does, in fact, indicate the location of a deep-seated magnetic body in the area between

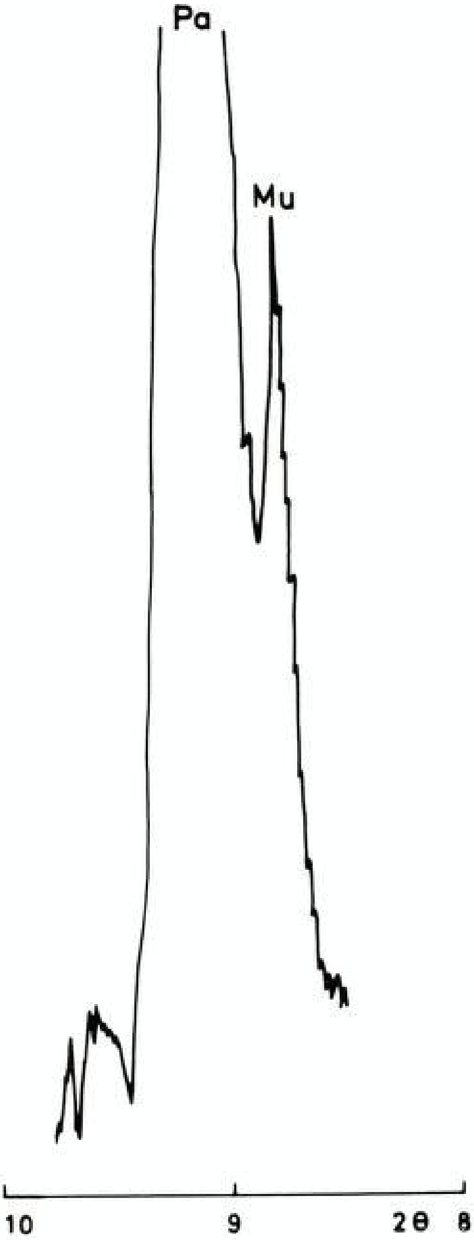

Fig. 5. Diffractometer traces over (002) peaks for co-existing paragonite and muscovite, using CuKα-radiation. Same specimen as in Fig. 4.

Finsåhøgda and Rognfjell (K. Åm, pers. comm.) The aeromagnetic map Haltdalen, issued by the Geological Survey of Norway, shows the presence of a marked but somewhat subdued magnetic anomaly along the eastern side of Hesja (Fig. 6). The cause of this magnetic anomaly is most likely a subsurface gabbroic instrusion carrying magnetite.

Exposed gabbros in the eastern Trondheim Region are known to have different magnetic properties. The Øyungen gabbro shows no magnetic anomalies,

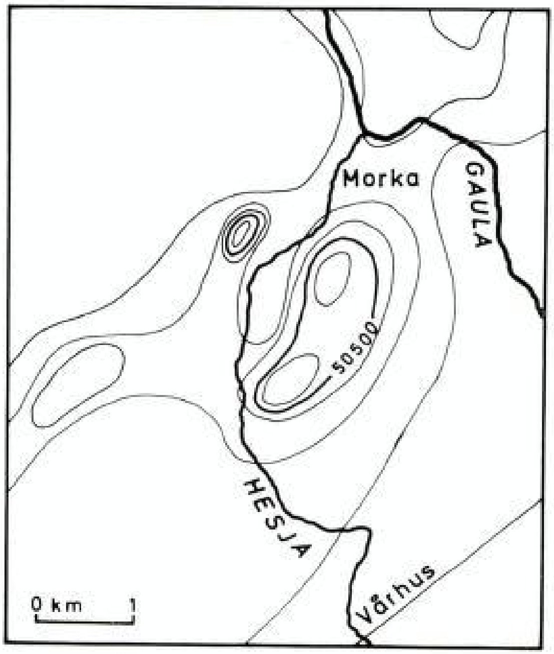

Fig. 6. Part of the aeromagnetic map Haltdalen (1620 I) showing the location of two magnetic anomalies on either side of the river Hesja. Intervals between isomagnetic curves are 100 gamma.

while the large Fongen gabbro lying some fifty kilometres to the north of the investigated area is markedly magnetic.

From the available evidence, it thus appears probable that the andalusite growth occurred in the contact aureoles of gabroic bodies, this perhaps giving some of the clues to the intensive andalusite porphyroblastesis. The relatively large size of the andalusite crystals suggests that a situation of steady heat flow may have occurred in the schists. The schists with pseudomorphs after andalusite thus seem to represent parts of a former contact aureole of hornblende–hornfels facies presumably lying above a zone of high-grade K-feldspar-cordierite-hornfels facies (Birkeland & Nilsen 1972). The vertical distance down to the presumed deep-seated gabbro could be 2–3 kilometres.

The contact, low-pressure metamorphism which is here proposed to be associated with gabbro emplacement at depth, was pretectonic to early syntectonic with respect to the F_1 deformation phase. This locally restricted metamorphism was followed by the regional high-pressure metamorphism broadly synchronous with the F_1 phase. The progressive regional metamorphism terminated in most parts of the area in the staurolite-almandine subfacies. In one part, Finsåhøgda, the sillimanite-almandine-orthoclase subfacies was probably imposed on the staurolite-almandine subfacies by a partial rise of temperature in the post-F_1/pre-F_2 static phase, the confining pressure remaining constant.

The paragonitization

The disorientated growth pattern of paragonite, sometimes in intimate intergrowth with chlorite, is indicative of a post-F_2 static formation of the mineral. The chlorite of the andalusite pseudomorphs is probably of the same type as that in the matrix, where chlorite certainly is a retrograde phase. It is very likely therefore, that even the white mica, including paragonite, crystallized during diaphthoresis.

Paragonite occurs either together with, or without, kyanite. A few thinsections of schist from outside the investigated area containing preserved primary andalusite display white mica; however, X-ray analysis has revealed this to be mainly muscovite, possibly with a little paragonite. Some kyanite is also observed, and it seems most likely that paragonite has formed at the expense of kyanite and not directly from andalusite. This means that, in general, andalusite in the first place inverted to kyanite as a response to prograde metamorphism. The formation of paragonite then proceeded as a transformation of kyanite during the waning phase of regional metamorphism. The pseudomorphs have thus acquired their present mineralogy by a two-stage transformation process. The formation of andalusite with subsequent pseudomorphosis to kyanite and later on to paragonite is thought to have progressed as a broadly continuous process during the main Silurian phase of the Caledonian orogeny.

It is the impression from the present investigation in the Hessdalen area that paragonite is exclusively connected with aluminium-rich milieux, deriving its sodium from matrix plagioclase. This appears to be valid for the pesudomorphs, as well as for the kyanite lenses on Rognfjell, and shows that the chemical conditions were not suitable for the formation of paragonite in the schist groundmass.

Acknowledgements. – The writer is indebted to Professor T. Strand for introducing him to the area. Thanks are also due to Professor Chr. Oftedahl and Dr. David Roberts for their critical comments and for correcting the English text. The field expenses were defrayed by Norges Geologiske Undersøkelse.

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Dome-bassin strukturer i grundfjeldet mellem Kolbotn og Bunnefjorden, Akershus

CLAUS ZETTERSTRØM

Zetterstrøm, C. 1973: Dome-basin structures in the bedrock between Kolbotn and Bunnfjorden. *Norges geol. Unders., 304,* 47–53.

Dome and basin structures in Precambrian gneisses east of the Oslo fjord have been mapped. A short description is given of the rock types and the main structure, the Gjersjø dome. The axial-plane of the youngest folding in the area strikes 70 degrees and dips about 35 degrees to the NW.

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Introduktion

Den foreliggende artikel viser resultaterne fra to måneders feltarbejde udført sommeren 1971 som en del af «Project Dybzone» og som en fortsættelse af et arbejde, der er brugt til forfatterens cand. scient. afløsningsopgave ved Københavns Universitet, (Zetterstrøm 1971). Områderne der er beskrevet 1971 og nu, ses på Fig. 1. Det eneste tidligere publiserede fra området er kortet fra Gleditsch (1952).

Feltarbejdet har afsløret en i området hidtil ukent dome-bassin struktur, hvori indgår de bjergarter, der er nævnt på kortet, Fig. 2, og i den følgende bjergartsoversigt.

Fig. 1. Områderne beskrevet af forfatteren 1971 og nu.

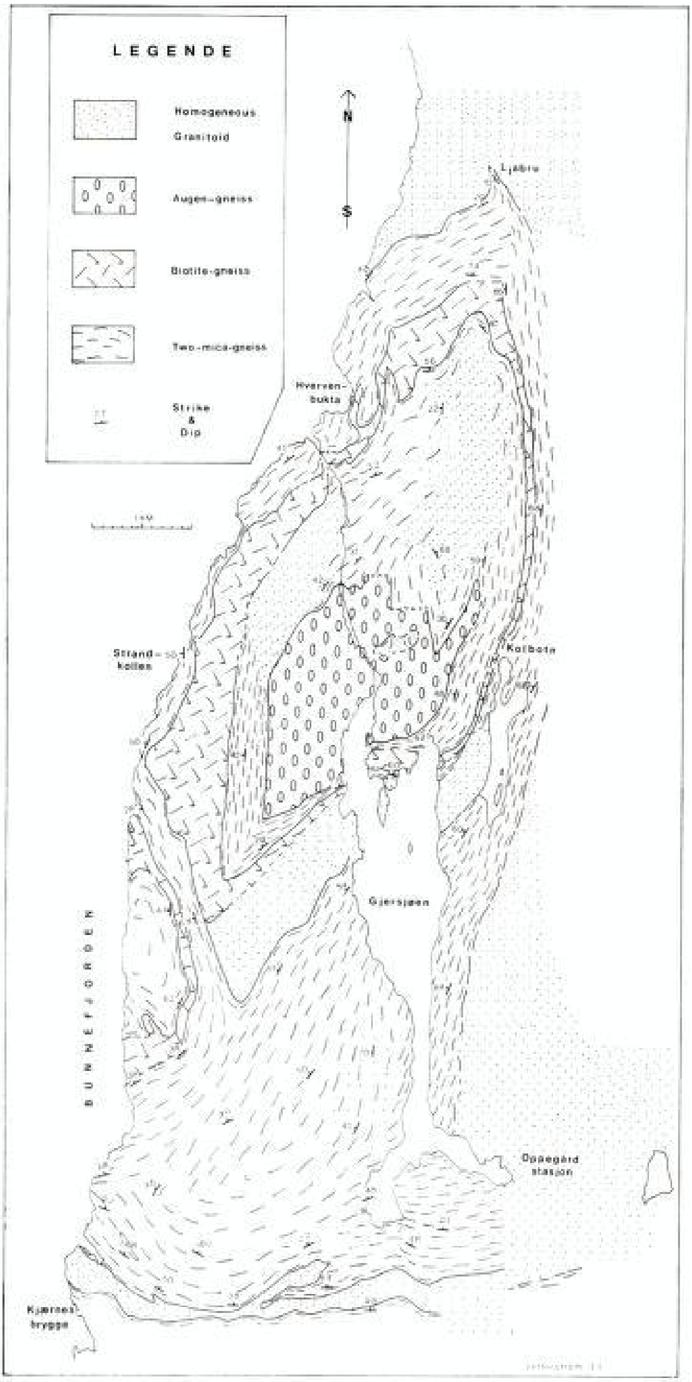

Fig. 2. Forenklet kort over grundfjeldet mellem Bunnefjorden og Kolbotn.

Bjergartsoversigt

Alle bjergarterne på kortet har granitoid sammensætning og har granat som accessorisk mineral. På kortet er ikke vist gange og legemer af metabasit og metadolerit, der formodes at svare til Moss-områdets metabasiske bjergarter, der er beskrevet af Berthelsen (1970).

De følgende bjergartsbeskrivelser bygger overvejende på feltiagttagelser.

TOGLIMMERGNEJS

Denne enhed består overvejende af finkornede kvarts-feldspat bjergarter med både biotit og lys glimmer som almindelige mørke mineraler. På forvitret overflade er bjergarten lysegrå mens den på friske flader har en brunviolet farvetone.

Glimmerrige og glimmerfattige bånd veksler, tykkelsen af de enkelte bånd varierer fra få cm til adskillige m. Enkelte dm brede amfibolitbånd ses i gnejsen. Kyanit eller hyppigere kyanit-pseudomorphoser af mikrokrystallin lys glimmer findes af og til i gnejsen. Pseudomorphoserne har en snavset grågrøn til gullighvid farve og et fedtet udseende.

Gnejsen indeholder flere steder zonare, 10–30 cm lange kalk-silikat legemer. Den centrale del af legemerne er gulbrun og indeholder granat, mens en ca. 2 cm bred grågrøn randzone indeholder »epidot» i stedet for granat. Toglimmergnejsen anses af Zetterstrøm (1971) for suprakrustal. Argumenterne er et højt (mere end 40% Vol.) kvarts i flere prøver samt tilstedeværelsen af kyanit og kalk-silikat.

BIOTITGNEJS

Mørkegrå, mellemkornet kvarts-feldspat gnejs med biotit som det almindelige mørke mineral. Gnejsen har ofte hvide enkelkrystal feldspatøjne med en diameter på ca. en cm. På velblottede steder ses det at gnejsen indeholder hektometer store legemer af homogene granitoide bjergarter. Disse bjergarter beskrives senere.

STÆNGELØJEGNEJS

Lys rødliggrå, mellem- til grovkornet biotitgnejs med sammensatte stænglede kvarts-feldspat øjne. Gnejsen har en dårlig, men nogle steder foldet foliation.

Stængeløjegnejsen fra Kolbotn-Bundefjords området viser stor lighed med stængeløjegnejser kortlagt af B. Hageskov længere mod syd. Ifølge Hageskov (personlig information) er disse sydlige stængeløjegnejser af intrusiv oprindelse.

HOMOGENE GRANITOIDE BJERGARTER

Denne enhed udgøres af biotitbærende granitiske til kvarts-dioritiske bjergarter med udpræget plutonisk udseende og med inklusioner af toglimmergnejs. De fleste af de homogene granitoider er mellemkornede, men fin- og grovkornede typer er ikke undtagelser.

GRÆNSERELATIONER

Grænsen mellem de forskellige bjergarter er normalt udformet som en få meter bred overgangszone, hvori ingen af bjergarterne viser typiske træk.

En anden type kontakt findes i den sydøstlige del af området, omkring Oppegård. Her danner en finkornet homogen granitoid en intrusiv breccie med toglimmergnejsen. Den breccierede zone kan blive over 1 km bred og optager det meste af det område, der på kortet er markeret som homogen granitoid øst for Oppegård station.

Andre steder i området er der mellem toglimmergnejs og en mellemkornet homogen grå granitoid en hektometer bred nebulitisk zone.

Gjersjø-domen og omliggende struktur

Områdets makrostruktur ses på kortet som et næsten rhombeformet mønster opbygget af vekslende gnejsbånd. I midten af strukturen findes stængeløjegnejs der successivt følges af toglimmergnejs, biotitgnejs og toglimmergnejs. I stængeløjegnejsen findes en karterbar inklusion af toglimmergnejs, måske en roof pendant? Både den nordvestlige og den sydøstlige flanke stryger nordøst, men den sydøstlige flanke hælder stejlere mod nordvest end den nordvestlige flanke gør. Den østlige – og den vestlige flanke stryger begge nord, den østlige flanke står stejlt, mens den vestlige hælder mod vest. Den resulterende rumlige figur er en næsten sukkertopformet dome, der synes vippet mod sydøst. Strukturen kaldes i det følgende for Gjersjø-domen. Syd for Gjersjø-domen danner foliationen i toglimmergnejsen en figur der meget minder om Gjersjø-domen. Vest for den sydlige spids af Gjersjø-domen findes en halvmåneformet struktur der markeres af et biotitgnejsbånd med overvejende vestlig hældning. Da strukturen mod vest afskæres af Bundefjorden kan det ikke sikkert afgøres om der er tale om en dome eller et bassin.

Forfatterens opfattelse af hele områdets makro-struktur ses på blokdiagrammet Fig. 3, her er den sidstnævnte struktur tegnet som et bassin.

Småstrukturerne i området er overvejende tætte til isoklinale folder af den type som ses på Fig. 4. Foldeakser og vertikaler fra disse småfolder er vist på Fig. 5. Af figurens stereogram ses at akserne med god tilnærmelse danner en storcirkel, der markerer at plan som stryger ca. 70° og hælder ca. 35° mod nordvest. De fleste af akserne dykker mod nordvest.

I den nordvestlige del af området er den dominerende småstruktur mode-

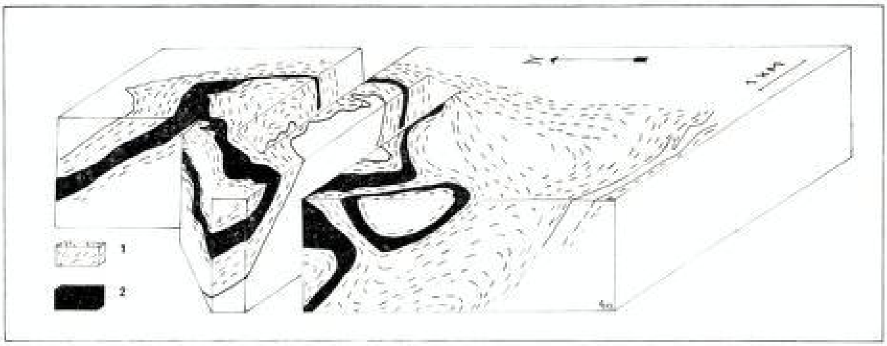

Fig. 3. Blokdiagram (isometrisk) der viser forfatterens opfattelse af områdets makrostruktur. 1. Toglimmergnejs 2. Biotitgnejs.

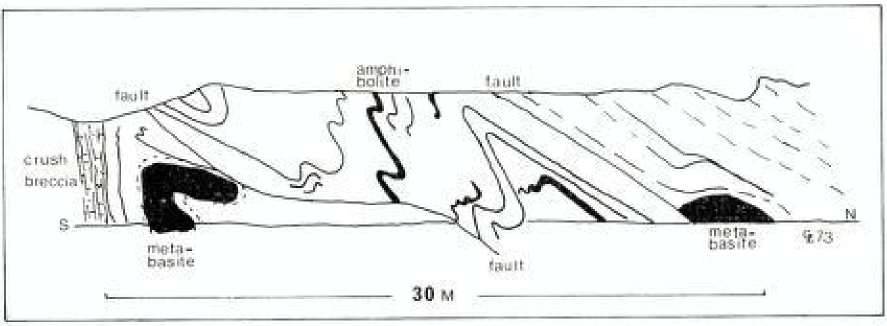

Fig. 4. Profil langs den nye E6 vest for Gjersjøens sydlige del. Folderne i profilet anses for at tilhøre den yngste generation.

rat hvælvede domer og bassiner. De ses i profilerne langs vejene, hvor de fremtræder som åbne folder og først nøjere undersøgelser viser, at der er tale om domer og bassiner. Omkring Hvervenbukta iagttages disse strukturer særdeles godt langs både den gamle og den nye E.6. Ved den offentlige badeplads syd for Strandkollen ses i kysten et 4 m langt bassin udstrakt i nord-syd retningen. Bassinet ses på Fig. 6, tegnet efter fotografi.

Tre forhold kan uddrages af det ovenstående:

1. Den dominerende struktur i området er en dome og bassin struktur.
2. Den yngste foldning i området producerer tætte til isoklinale folder med et aksialplan der stryger ca. 70° og hælder ca. 35°.
3. Den yngste foldnings aksialplan og de to nordøst strygende flanker i Gjersjø-domen er stort set paralelle.

Dome og bassin strukturen kan være dannet både ved diapirisme (Wegmann 1930) og ved dobbeltfoldning (Ramsay 1962). Er strukturen dannet ved dobbeltfoldning vil flere forskellige sæt folder kunne danne den. Hvilken af de mulige løsninger, der er den rigtige, må afgøres af det regionale mønster, efter at hele regionen er færdigkarteret.

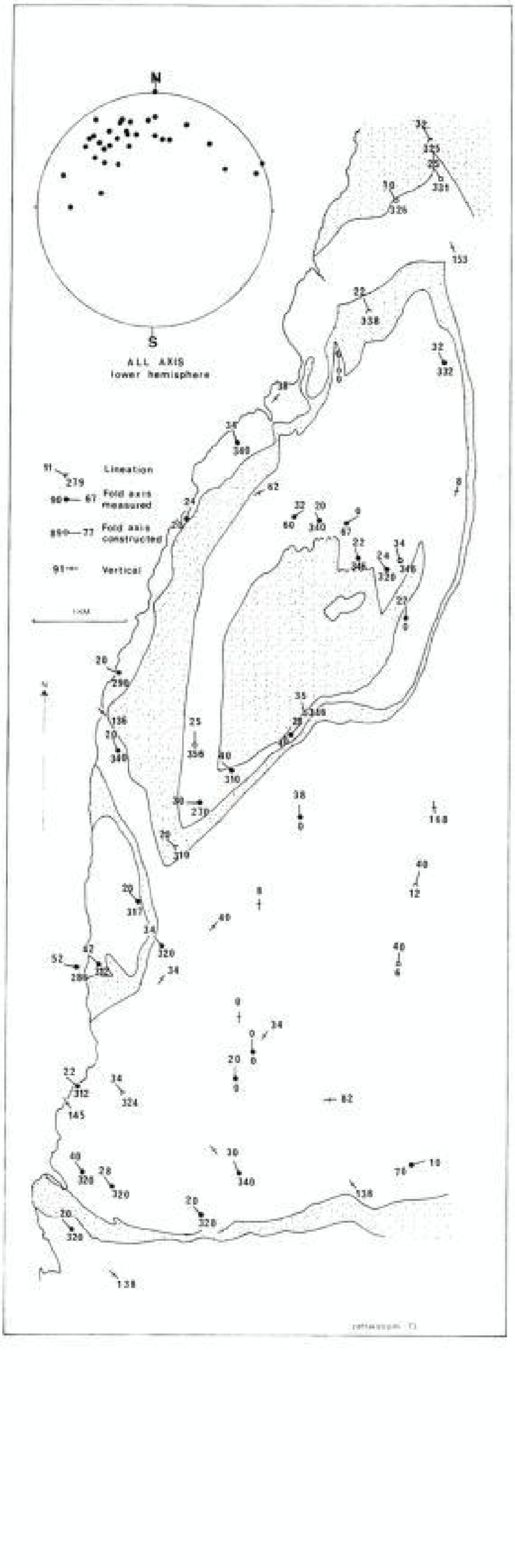

Fig. 5. Forenklet kort med alle målte foldeakser og vertikaler fra småfolder indtegnet. På figuren er indsat alle småfoldeakserne plottet på Lambert net. Stængeløjegnejs, biotitgnejs og homogene granitoider er vist prikket.

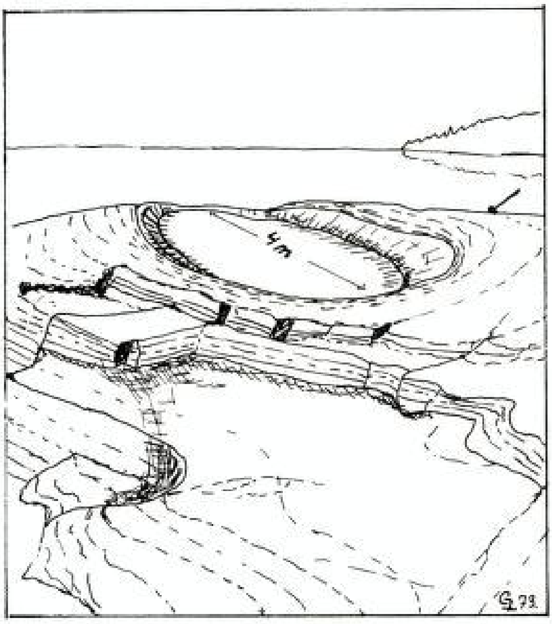

Fig. 6. Bassin i toglimmergnejs ved den offentlige badeplads syd for Strandkollen. Tegnet efter foto.

Efterord. Jeg takker professor dr. S. Skjeseth for lærerige ekskursioner og diskusioner under feltarbejdet og professor dr. A. Berthelsen for hans hjælp og kritik under udarbejdelsen af manuskriptet.

Statens naturvidenskabelige Forskningsråd, København og Norges Geologiske Undersøkelse har støttet projectet økonomisk.

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New Fossil Finds from the Cambro-Silurian Meta-sediments on Hardangervidda

ARILD ANDRESEN

Andresen, A. 1974: New fossil finds from the Cambro-Silurian meta-sediments on Hardangervidda. *Norges geol. Unders. 304*, 55–60.

The occurrence of Actinoceroid cephalopods (*Ormoceras (?)* sp.), brachiopods (*Orthis* ss.), and trilobites (*Ptychopyge* sp.) in a crystalline limestone overlying bluish quartzite on Hardangervidda indicates that Orthoceras Limestone of the Lower Ordovician Asaphus Series (Etage 3c) is present. The underlying quartzites are correlated with stage 3a–3b in the Oslo Region.

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Introduction

Hardangervidda (Fig. 1) is, outside the Oslo Region, one of the largest areas in Norway where Cambro-Silurian sediments of eastern facies (foreland facies) are exposed. The stratigraphy and structure of these rocks are not very well known, partly because of the inaccessibility of the area, and partly due to the intense deformation and lack of fossiliferous beds. Even though the fossils described in this paper are badly preserved, making identification of species in some cases uncertain and in other cases impossible, they give some information about the Cambro-Silurian stratigraphy.

The earliest contribution to the geology of Hardangervidda was made by Dahll (1861), who reported fossiliferous beds with *Dictyonema flabelliforme* (2e in the stratigraphic sequence of the Oslo Region) from Holberget (Fig. 1). Later, Brøgger (1893), after more detailed mapping, established a stratigraphic sequence for the rocks overlying the Precambrian basement. In this sequence all the rocks above the Precambrian basement were assumed to be in a normal succession. The subdivision he established was, from the base upwards: 1, Alum shale; 2, Quartizite; 3, Crystalline limestone (marble); 4, Phyllites; 5, Various crystalline rocks.

The *Dictyonema flabelliforme* reported from Holberget (Dahll 1861) was found in the upper part of the alum shale, indicating a Cambrian to Lower Ordovician age for this unit. Brøgger (1893 p. 80) correlated the crystalline limestone (3, above) with the Orthoceras Limestone, mainly on the basis of the occurrence of 4a fossils in phyllites overlying quartzite and limestone in Gausdal, some 150 km farther northeast. He also assumed that the phyllites of division 4 represented the lower part of the Silurian, while the crystalline rocks of division 5 were thought to be of upper Silurian age or younger.

Later, Reusch et al. (1902) suggested that division 5 represents a Caledonian nappe of Precambrian rocks. This hypothesis has since been generally accepted, and has been confirmed by recent mapping and geochronologic

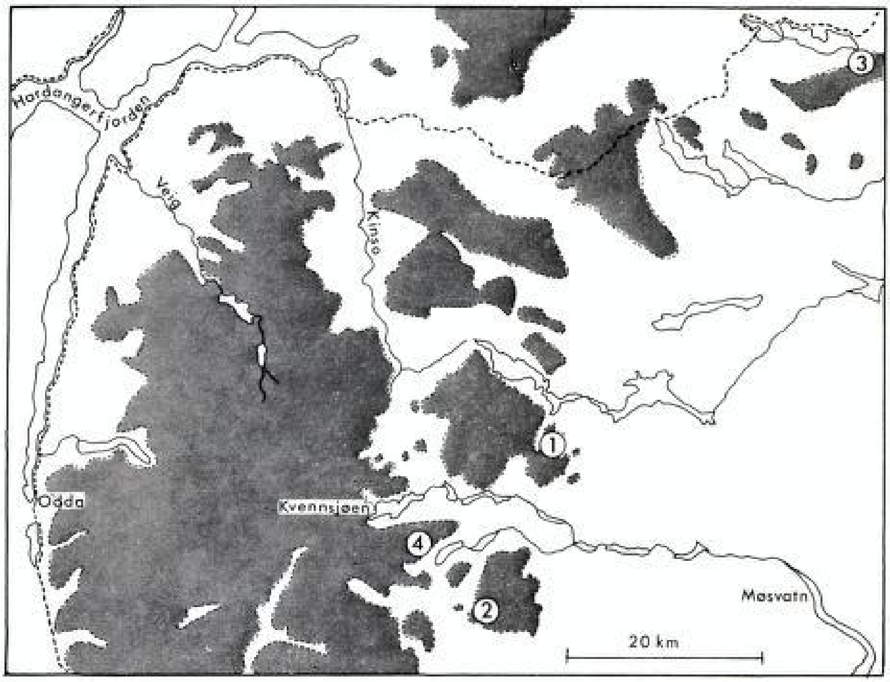

Fig. 1. Simplified geological map of Hardangervidda showing distribution of Cambro-Silurian rocks (grey) and known fossil localities. 1 = Holberget, 2 = Dvergsmednuten and Setenuten, 3 = Ustaoset, 4 = the two localities described in this publication (3 km south of Kvennsjøen.)

work (Naterstad et al. 1973, Andresen et al. in press). A subdivision into autochthonous and allochthonous Cambro-Silurian was made in the publication of Naterstad et al. (1973).

Rekstad (1903) discovered a new graptolite locality at Dvergsmednuten (Fig. 1), and Størmer (1940) has described the material from both Holberget and Dvergsmednuten. *Obolus* sp. was also described in the material from Holberget. The graptolite material has also been described by Bulman (1966). In addition to the described graptolite material from Holberget and Dvergsmednuten, O. Liestøl has collected *Dictyonema flabelliforme* at Setenuten, 3 km east of Dvergsmednuten.

Goldschmidt (1925) and Størmer (1925) described Lower Cambrian beds and fossils from Ustaoset. All the known fossil localities from Hardangervidda are plotted in Fig. 1.

Fossil localities and geological setting

The two new fossil localities are a few kilometres south of Kvennsjøen (Figs. 1 and 2). The fossils at both localities occur in isolated beds of crystalline limestone downfolded into the stratigraphically underlying bluish quartzite.

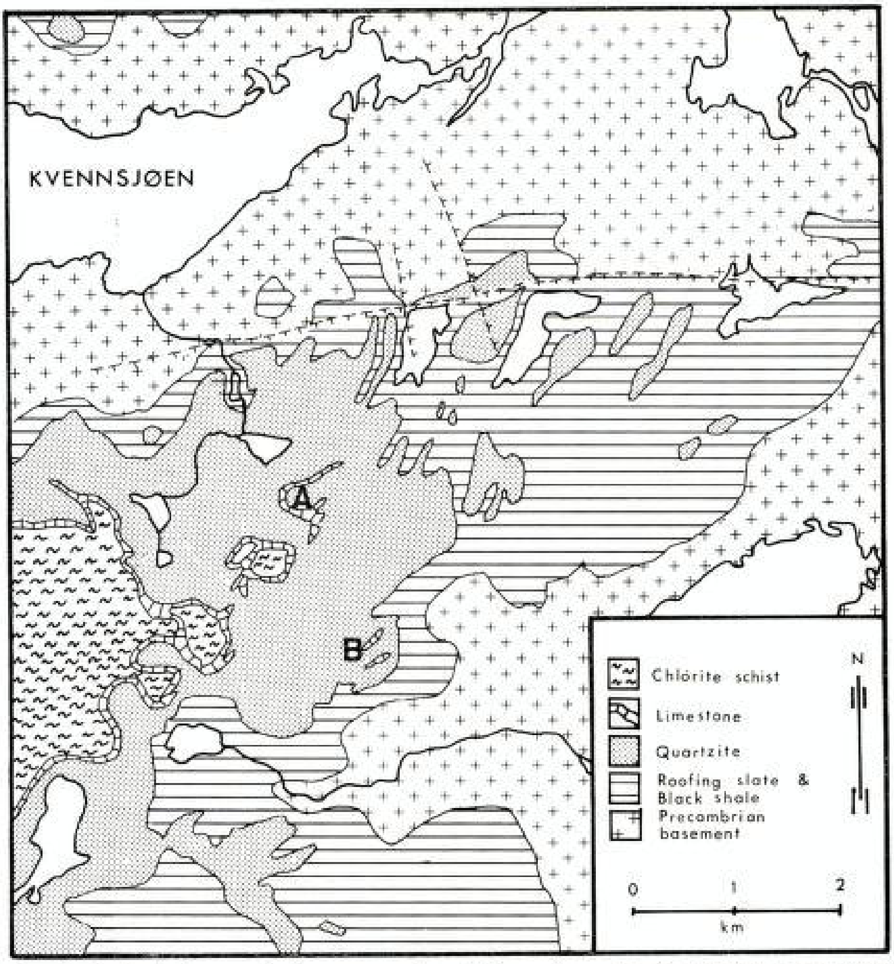

Fig. 2. Geological map of the area south of Kvennsjøen, showing the two new fossil localities (A and B). Note that the limestone (Orthoceras Limestone) has been traced as a continuous layer for several kilometres.

The fossiliferous beds correspond to division 3 of Brøgger (1893); thus they are younger than the earlier described fossiliferous beds from Holberget and Dvergsmednuten (Etage 2e). At both localities the limestone unit shows variable thickness due to isoclinal folding but is usually from 3–10 m thick. On the basis of lithologic variations, the limestone unit can be subdivided into three parts. The lowermost part is composed of a calcareous sandstone, always less than 0.5 m thick. Clastic grains are mainly quartz with average grain-size about 1 mm. Above this zone is a rather pure crystalline limestone (marble), 3–6 m thick. A 3–7 m thick zone of white mica/chlorite-rich marble makes up the uppermost part of the unit. Pure marble beds are also sometimes found within this upper unit.

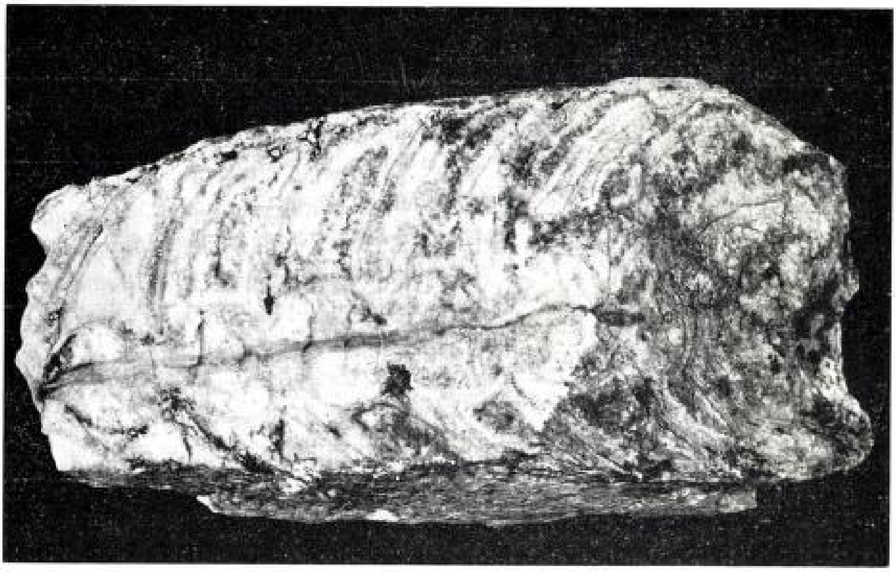

Fig. 3. Longitudinal section through the siphuncle of Actinoceroid cephalopoda (*Ormoceras* (?) sp.) from locality A. Length of specimen 10 cm.

Fossils

All the described fossils are collected from locality A (Fig. 2); the single cephalopod observed at locality B was too strongly deformed and badly preserved for description and identification. The cephalopod from locality B was observed in the middle unit of pure limestone. At locality A fossils were found both in the calcareous sandstone and in the pure limestone.

A rich shelly fauna of brachiopods and trilobite fragments was found in a loose boulder belonging to the calcareous sandstone horizon. A single gastropod and a larger number of small rodlike bodies about 1 mm across and 1–2 cm long were also observed in the same bed. Even though the trilobite fragments are strongly deformed and sheared, one of them shows a trilobite pygidium of Asaphid type. The overall elongated outline, relatively flat, somewhat pleural field, and long tapering rachis, faintly ringed, suggest *Ptychopyge* sp. rather than *Asaphus*. Associated with the trilobite fragments were several brachiopods of genus *Orthis* ss. Some of these are well preserved and rather like several *Orthis* of *callitramma* type from 3c. The gastropod is of the planispiral type and about 1 cm across. Further identification is not possible.

A cephalopod was found in the pure limestone overlying the calcareous sandstone with its shelly fauna at locality A (Fig. 3). polished section parallel to the siphuncle shows a 60 mm long specimen with five chambers and with diameter varying from 48 mm to 36 mm, giving an apertural angle of 12°. The siphuncle extension has a height equal to its length and the siphuncle itself is ventrally placed, with a distance from the centre of the siphuncle to the wall equal to 3/10 of the width of the couch. The data are sufficient to identify this as an Actinoceroid type cephalopod, but the lack of finer structures makes a precise definition of genus uncertain. Earlier descriptions of Actinoceroid cephalopods from the Lower Ordovician of the Fennoscandian-/Baltic Shield (Troedsson 1926) include species which strongly resemble the present specimen. Of these the *Ormoceras oelandicum* from the Platyurus Limestone (Upper Red Orthoceras Limestone) shows especially great similarities. It is therefore concluded that the cephalopos from Hardangervidda is an Actinoceroid cephalopod, *Ormoceras(?)* sp.

Discussion and conclusions

The occurrence of *Ormoceras(?)* sp., *Ptychopyge* sp. and *Orthis* ss. in the limestone above the bluish quartzite on Hardangervidda indicates that the limestone is equivalent to the Orthoceras Limestone of the Lower Ordovician Asaphus Series (Etage 3c). The *Ptychopyge* sp. indicates 3c age generally, while *Ormoceras*(?) sp. indicates the upper part of the Orthoceras Limestone. From the rather restricted number of fossils found to date, it is difficult to correlate the lithologic variation observed in the Orthoceras Limestone on Hardangervidda with the subdivision ($3c\alpha$, $3c\beta$, $3c\gamma$) of the Oslo Region. The pure limestone with *Ormoceras*(?) sp. may, however, correspond to the Endoceras Limestone ($3c\gamma$). The calcareous sandstone below, and possibly also the upper part of the quartzite, should then be correlated with $3c\alpha$-β while the white mica/chlorite rich limestone above should represent the transition zone between the Endoceras Limestone and the Upper Didymograpthus Shale (Etage $44a\alpha_{1-2}$).

Bjørlykke (1965) described a distinct change in mineralogy and chemistry of shales in the Oslo Region lying below and above the Orthoceras Limestone. The shales above (4a) have a higher chlorite/illite ratio and a higher content of Mg. This change in chemistry and mineralogy is even more pronounced on Hardangervidda, as the shales or schists above the limestone unit are chlorite schists, while those below are black shales. This is further evidence in support of the proposed correlation.

Since *Dictyonema flabelliforme* (2e) occurs just below quartzite (Holberget and Dvergsmednuten) and Orthoceras Limestone (3c) has now been identified above, the massive bluish quartzite and underlying roofing slate must be restricted to stage 3a–b.

Acknowledgements. – Professor T. Strand and Dr. D. Bruton are thanked for help with identification of fossils. The work was carried out as a part of the Hardangervidda–Ryfylke project, NAVF grant D. 4031–19, with amanuensis J. Naterstad as project leader.

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Sammenligning av sprøhet og flisighet for borkjernemateriale og utskutte bergartsprøver

ERLING SØRENSEN & THOR L. SVERDRUP

Sørensen, E. & Sverdrup, T.L. 1974: Comparison of brittleness and flakiness numbers in borehole material and blasted rock samples. *Norges geol. Unders. 304*, 61–72.

Brittleness and flakiness (Swedish impact test) in borehole cores from 7 rock-types have been investigated and compared with the results noted in material blasted from the same localities. The bore-hole material seems to give more favourable results than those from the blasted rock.

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Forord

Da forfatterne i 1966 gjorde en orienterende undersøkelse parallell til denne (Sverdrup & Sørensen 1966,) kom vi frem til følgende konklusjon: «De fremkomne data viser såvidt markert begunstigelse av borkjernemateriale både hva sprøhet og flisighet angår, at en skal være meget varsom med å benytte borkjernemateriale ukritisk for bedømmelse av bergarters anvendbarhet i faste veidekker.»

Undersøkelsene er hittil begrenset til ett felt, men på grunn av resultatene har institusjonen funnet det nødvendig å fortsette arbeidet også i andre områder, såvel i massive som skifrige bergarter».

De utførte diamantboringer er denne gang i sin helhet bekostet av NGU. Det er benyttet 32 mm kjerne. O. Gausdal ledet boringen, og Fr. Chr. Wolff har sammenfattet det geologiske kartet (Fig. 1) på basis av karter av H. Ramberg, Chr. Oftedahl m.fl. Vi vil benytte anledningen til å takke samtlige medarbeidere for den hjelp vi har mottatt for å få undersøkelsen gjennomført.

Innledning

Bakgrunnen for undersøkelsen er gitt tidligere (Sverdrup & Sørensen 1966). De orienterende resultatene den gang var kun basert på en forekomst, Kalvå, Ørlandet i Sør-Trøndelag fylke. Følgende data kom den gang frem (Tabell 1).

Tabell 1. Begunstigelse i % av sprøhet og flisighet for borkjernemateriale.

	Fraksjon	Begunstigelse	Begunstigelse slått 2 ganger	
Flisighet	8–11,3 mm	2,05 %	2,88 %	(Sverdrup & Sørensen 1966)
Flisighet	11,3–16 mm	3,76 %	1,55 %	»
Sprøhet	8–11,3 mm	4,72 %	10,29 %	»
Sprøhet	11,3–16 mm	11,14 %	15,53 %	»
Flisighet	8–11,3 mm	7,5 %	4,4 %	(Jøsang 1967)
Sprøhet	8–11,3 mm	16,8 %	3,7 %	»

Vi fant at det var to faktorer som ville begunstige borkjernematerialet:

1. Kjernens form, med krumme flater i forhold til utskutt materiale.
2. Sjokk i bergart på grunn av skyting.

Jøsang (1967) har gjennomført en liknende undersøkelse ved Veglaboratoriet. Han har analysert borkjernematerialet, men har ikke hatt håndstykkeprøver fra samme lokalitet. Som referansemateriale har han plukket ut biter av boremateriale som ikke hadde krumme (diamantbor) flater. Også han kom frem til at borkjernematerialet ga gunstigere resultat enn materiale uten krumme flater. Jøsangs resultater er meget interessante da dette materiale ikke er skuddpåvirket. Sjokkeffekten kommer således her ikke inn i bildet.

For fraksjon 8–11,3 mm har Jøsang følgende prosentvise forbedring av materialet (Tabell 1).

Ved den utvidete undersøkelsen som denne gang har funnet sted, er det prøvetatt på ialt 6 steder og i 7 forskjellige bergartstyper (Fig. 1). Metoden for prøvetaking er beskrevet tidligere (Sverdrup & Sørensen 1966).

Utførelse av sprøhets- og flisighetsanalyse (fallprøve)

Fallprøvens målsetting er å få et mål for steinmaterialets kornform (flisighet) og dets motstand mot mekaniske påvirkninger (sprøhet). I grove trekk utføres følgende operasjoner:

Etter at steinmaterialet er knust 2 ganger i kjeftknuser med 12 mm åpning, blir det grovsiktet på ASTM kvadratsikt 5/16″ (8 mm), 7/16″ (11,3 mm) og 5/8″ (16 mm). Materialet splittes, og det siktes ut 2 parallelle prøver av fraksjonen 8–11,3 mm og 11,3–16 mm. For at prøvens volum skal være konstant, veier man ut mengde avhengig av spesifikk vekt. Utgangspunktet er 500 gram stoff med sp.v. 2,65. Vekten øker eller minsker ca. 10 gram ved variasjon i sp.v. på 0,05. Man benytter formelen:

$$\text{Innveid mengde } \frac{500 \cdot \text{sp.v.}}{2 \cdot 65}$$

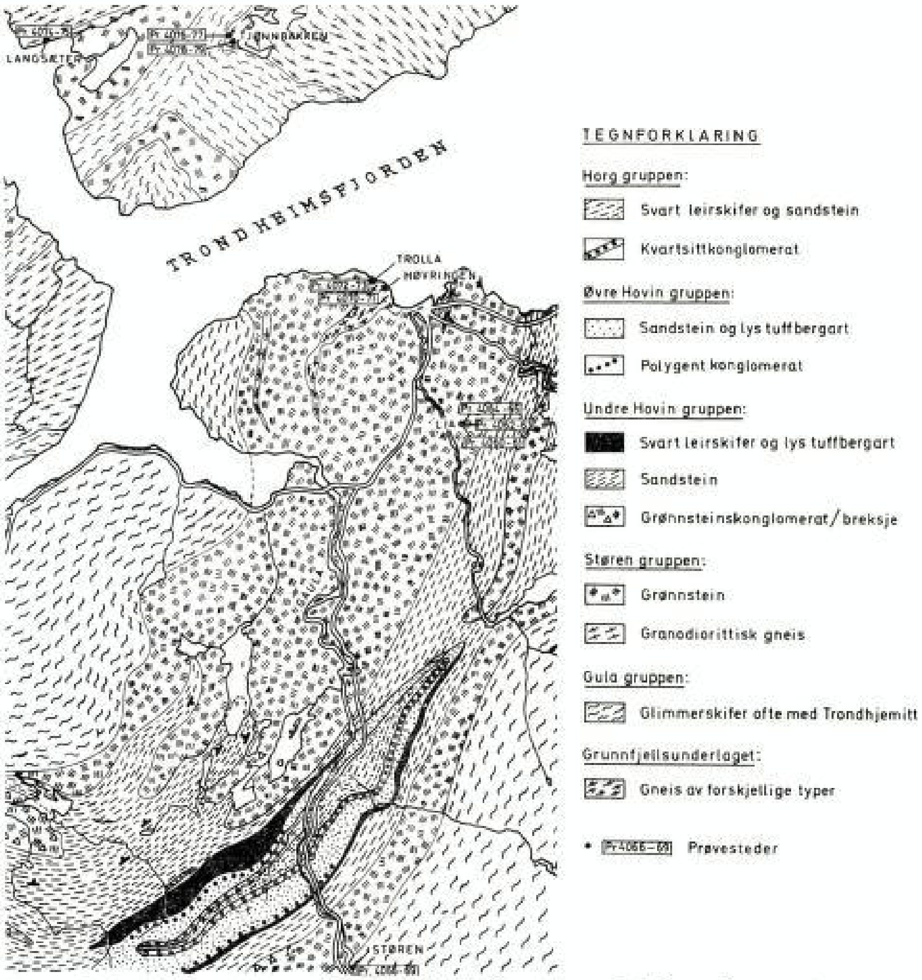
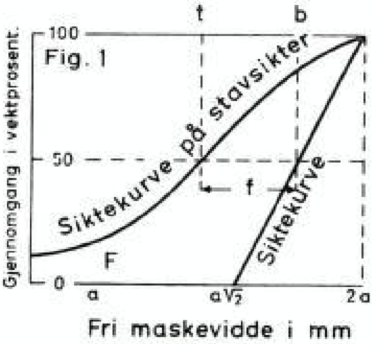


Fig. 1. Geologisk kart (sammenstilt av F. C. Wolff) med prøvelokaliteter inntegnet.

De to fraksjonene (8 – 11,3 mm og 11,3 – 16 mm) siktes på stavsikt, og av de prosenttall man får for hver siktmengde leses flisighetstallet av på et nomogram.

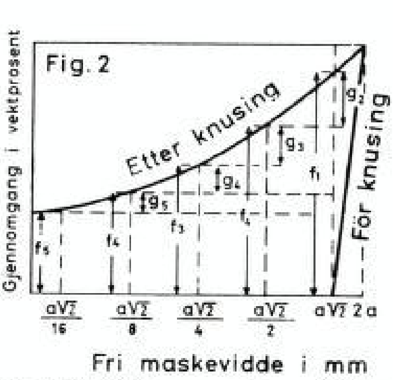
De utsiktede prøvene fylles løst opp i en stålmorter, denne plasseres under det automatiske fallapparatet, og et 14 kg's lodd faller 20 ganger ned på steinmaterialet fra konstant høyde 25 cm. Materialets pakningsgrad blir så angitt. Prøven siktes på kvadratsikt. Sprøhetstallet er da den del som er nedknust til under sin opprinnelige kornstørrelse. Konstantenes definisjon er vist på fig. 2. Har man igjen nok materiale fra hver fraksjon, blandes dette til en ny prøve, såkalt omslagsprøve. Da omslagsprøven har vært 2 ganger gjennom fallapparatur-testen, vil den normalt gi en bedre flisighet og sprøhet enn utgangsmaterialet. For mere utførlig beskrivelse henvises til Selmer-Olsen (1949).

Konstantenes definisjon:



Flisighetstall: $f = \frac{b}{t}$

(i logaritmisk skala blir $f = b - t$)
hvor b er steinenes gjennomsnittlige bredde
og t " " " tykkelse
Se fig. 1



Sprøhetstall: $s = f_1 = g_2 + g_3 + g_4 + g_5 + f_5$

hvor f_1 f_2 f_3 f_4 og f_5 er de mengder (i %) som går gjennom hver enkelt av de 5 sikter, og g_2 g_3 g_4 og g_5 er de mengder (i %) som ligger igjen på de 4 underste av de 5 sikter steinprøven blir siktet på etter knusing. Forholdet mellom disse sikters maskevidde er 1:2. Forsökene blir i alm. utført med 2 av de 3 kornfraksjoner: 5,6–8,0 mm, 8,0–11,3 mm eller 11,3–16,0 mm hvor forholdet mellom fraksjonsgrensene er $1:\sqrt{2}$.
Se fig. 2

Fig. 2. Definisjon av sprøhets- og flisighetstall.

Resultater av fallprøvene

Figurene 3–12 viser alle resultatene av fallprøvene på borkjerner og utskutt materiale. Tabell 2 viser borkjernematerialets begunstigelse/eventuell svekkelse i % sett i relasjon til utskutt materiale.

Resultatene er forsåvidt bemerkelsesverdige da bergartstypen synes å ha liten innvirkning på resultatene. Lillefraksjonens flisighet er den fraksjon som har minst spredning, mens stofraksjonens sprøhet varierer sterkt fra prøve til prøve. Et naturlig trekk ved bergartene indikeres av Fig. 13. Usikkerhetsfaktoren synes større for sure bergarter enn for basiske hva angår sprøhet.

En trondhjemittisk bergart fra Trolla skiller seg ut fra de øvrige. Her er borprøveanalysen dårligere enn analysene for utskutt materiale. Hva årsaken til dette er, er vanskelig å si. Følgende observasjoner foreligger for denne prøven: Borhullene er påsatt i en sur bergart som er meget sterkt forskifret. Bergarten har et fall på ca. 10°, og hullene er satt vertikalt. Slipstudiene viser at bergarten har en meget liten holdfasthet parallelt lagningen (forskifringen). Borkjernene skjærer således forskifringsplanet, med liten holdfasthet, nesten loddrett. Dette kan være årsaken til at borkjernene her får ekstremt

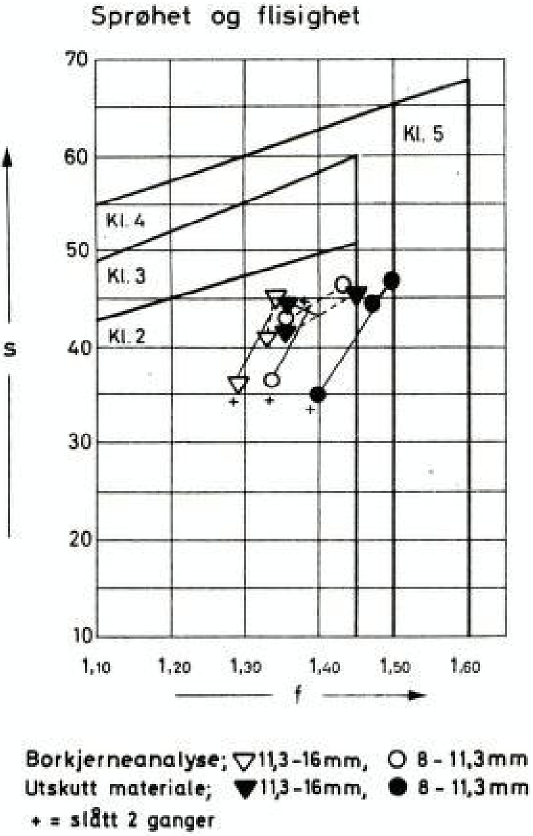


Fig. 3. Finkornet grønnstein, Lia (Bh. 1). Prøve 4060 (borkjerner) – 4061 (utskutt materiale).

lav holdfasthet. Vi var dessverre ikke oppmerksom på forholdet før kjernematerialet var nedknust, så vi har ikke kunnet kontrollere dette. Om det er dette forhold som er avgjørende, viser det klart at en må være meget varsom med hvordan en plasserer et borhull i forhold til lagning, oppknusing og forskifring, om materialet senere skal nyttes for fallprøveanalyser.

Konklusjon

Fallprøveanalysene er idag en standardisert metode for å vurdere en bergarts anvendbarhet for faste veidekker. Bergartene grupperes i klasser etter sprøhet- og flisighetstall. Grensene er helt klare; for eks. kan en ikke anvende en bergart for oljegrus hvis den har flisighet større enn 1,45.

Grupperingen er basert på overflateprøver og/eller håndstykkeprøver. Dagens utvikling tilsier at slike forekomster i økende grad blir undersøkt ved diamantboring av forekomsten. Ved analyse av borkjerner må en tydeligvis gå meget varsomt til verks. Borkjernematerialet bør i hvert enkelt tilfelle vurderes i relasjon til «dagprøven».

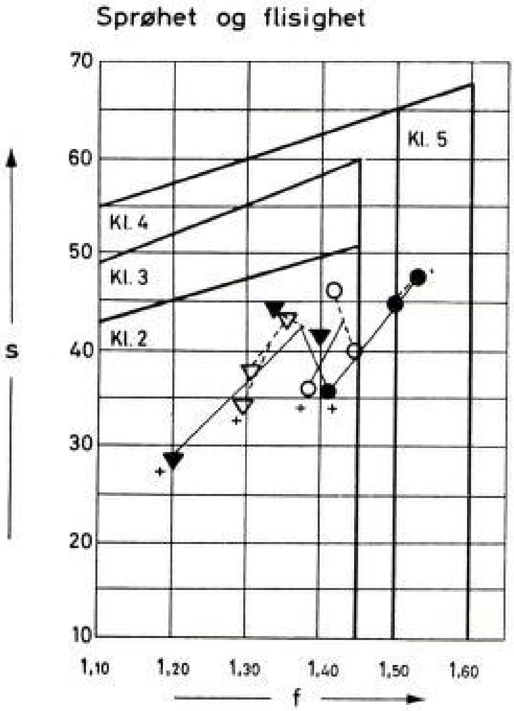


Fig. 4. Finkornet grønnstein, Lia (Bh. 2). Prøve 4062 (borkjerner) – 4063 (utskutt materiale). Symboler som på fig. 3.

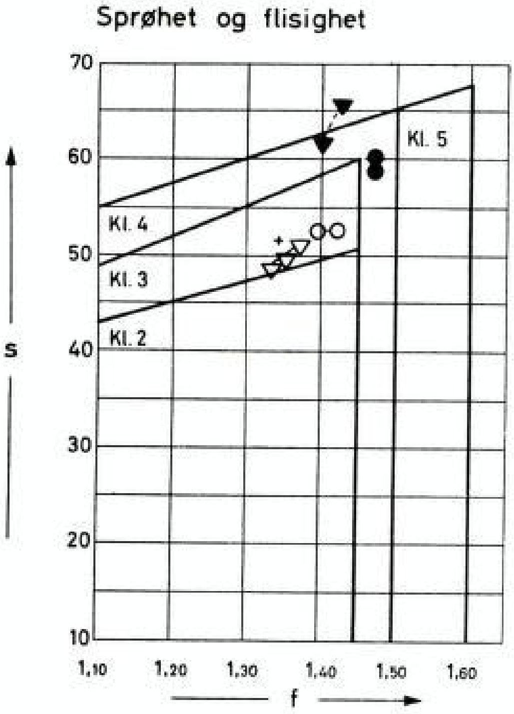
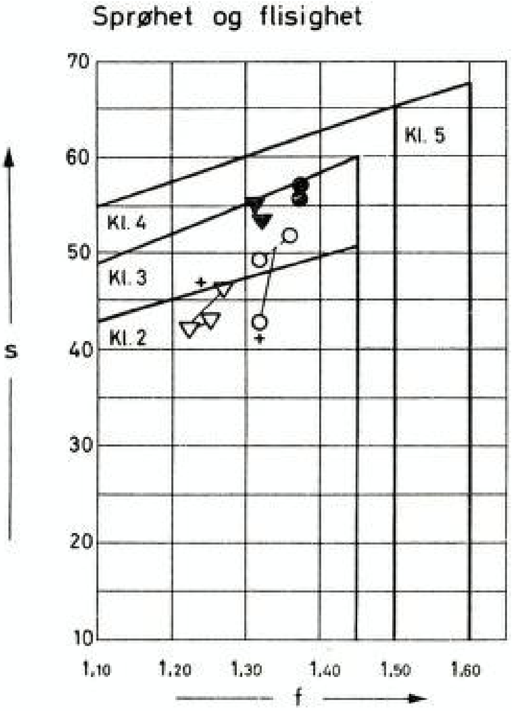


Fig. 5. Finkornet keratofyr, Lia (Bh. 3). Prøve 4064 (borkjerner) – 4065 (utskutt materiale). Symboler som på fig. 3.

Fig. 6. Trondhjemitt, Støren (Bh. 4). Prøve 4066 (borkjerner) – 4067 (utskutt materiale). Symboler som på fig. 3.



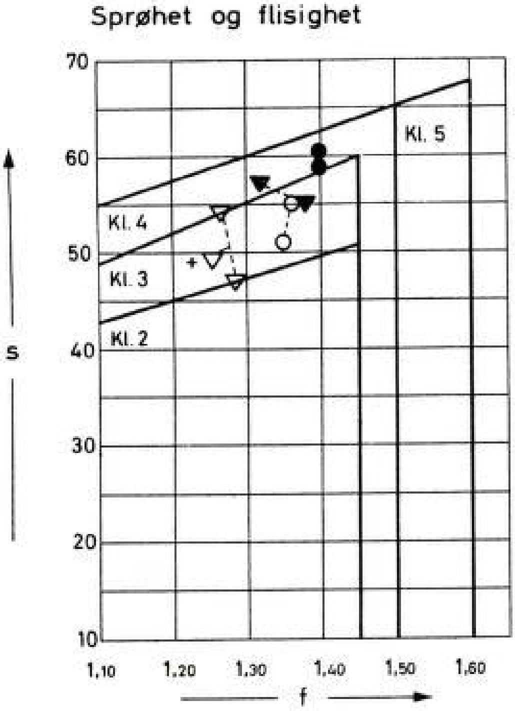


Fig. 7. Trondhjemitt, Støren (Bh. 5). Prøve 4068 (borkjerner) – 4069 (utskutt materiale). Symboler som på fig. 3.

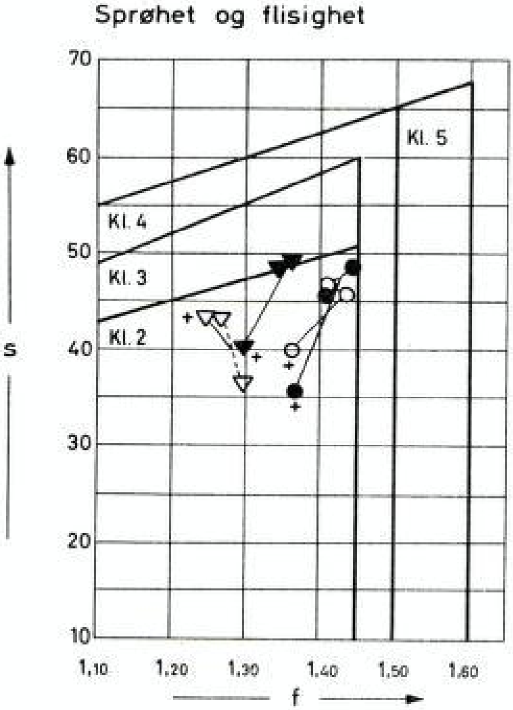


Fig. 8. Trondhjemittisk bergart, Høvringen (Bh. 6). Prøve 4070 (borkjerner) – 4071 (utskutt materiale). Symboler som på fig. 3.

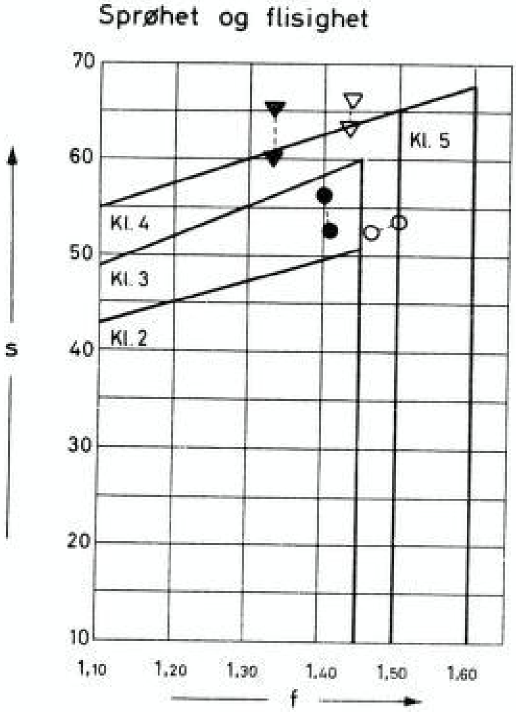
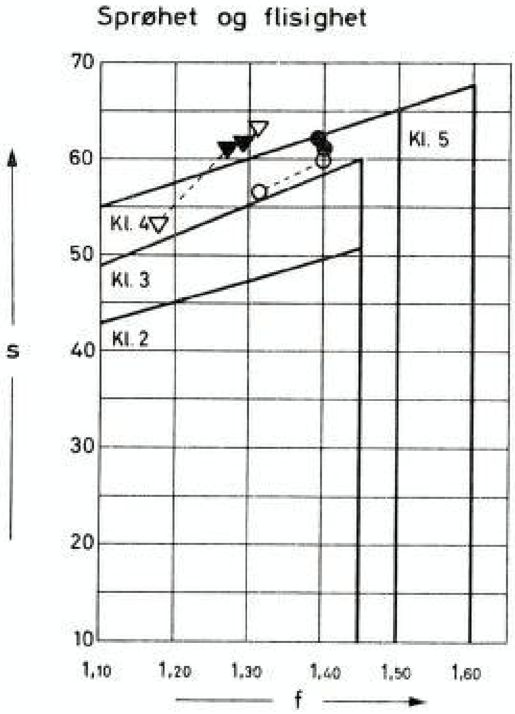


Fig. 9. Trondhjemittisk bergart, Trolla (Bh. 7). Prøve 4072 (borkjerner) – 4073 (utskutt materiale). Symboler som på fig. 3.

Fig. 10. Kvartsmonzonittisk gneis, Langseter (Bh. 8). Prøve 4074 (borkjerner) – 4075 (utskutt materiale). Symboler som på fig. 3.



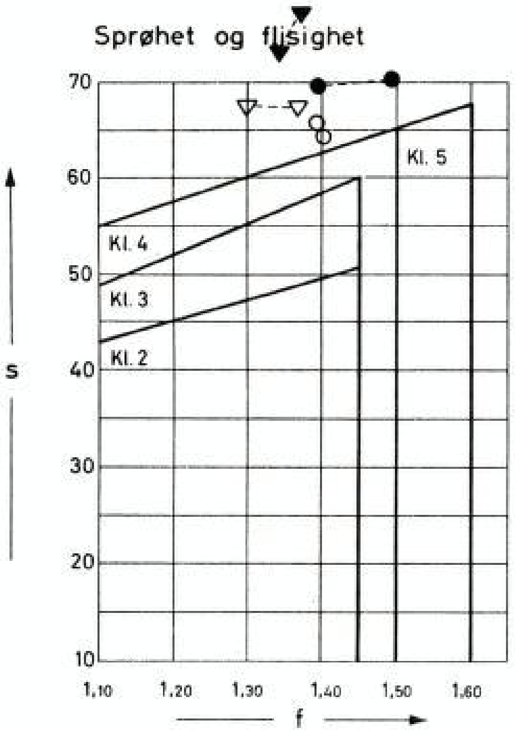


Fig. 11. Rød gneis, Tjønnbakken (Bh. 9). Prøve 4076 (borkjerner). – 4077 (utskutt materiale). Symboler som på fig. 3.

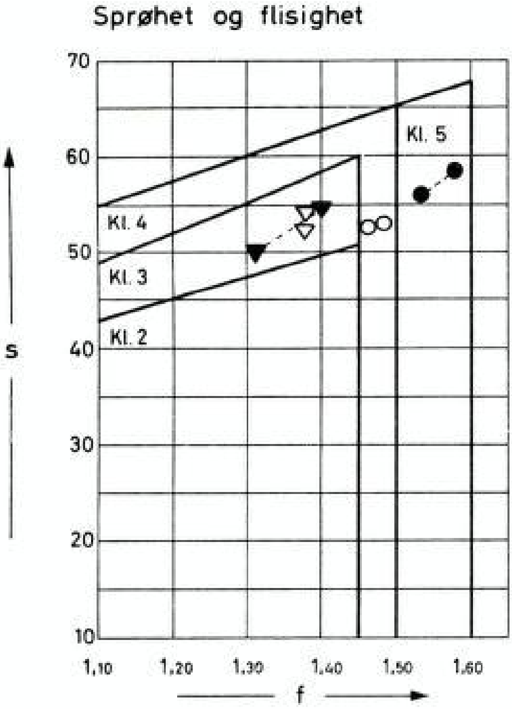


Fig. 12. Amfibolitt, Tjønnbakken (Bh. 10). Prøve 4078 (borkjerner) –4079 (utskutt materiale). Symboler som på fig. 3.

Av de fremkomne data synes det som en bør feste seg ved fraksjon 8 – 11,3 mm. Her er feilmarginen minst, og det er denne fraksjons fallprøveresultater som er utslagsgivende ved bedømmelse av asfalttilslagsmateriale.

Hvorvidt det er bergartens krumme overflate eller sjokk som er mest utslagsgivende, er vanskelig å avgjøre. Jøsangs (1967) undersøkelser viser samme tendens som våre. Disse prøvene var ikke utskutt, og bergarten hadde således ikke vært utsatt for sjokk. Om denne ene undersøkelse kan legges til grunn, synes det som den vesentligste årsak til kjernematerialets gode egenskaper er de krumme flatene.

Tabell 2 har også enkelte tall for materiale slått 2 ganger. Grunnlaget her er for dårlig til at en kan trekke noen konklusjoner.

Boringer utført med større kronediameter enn de som er anvendt for det analyserte materiale vil ventelig gi resultater som ligger nærmere de data en får fra utskutte prøver.

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Tabell 2. Begunstigelse/svekkelse av sprøhet og flisighet for borkjernemateriale i % sett i relasjon til utskutt materiale

Prøve	Lokalitet	Prøve-type	Bergart	Fraksjon	Begunstig-else	Svekkelse	Begunstigelse slått 2 ganger	Svekkelse slått 2 ganger
4060	Lia	Bh 1.	Finkornet grønnstein	Flisighet 8 –11,3 mm	6,08 %		4,2 %	
4061	»	utskutt	» »	» 11,3–16 mm	6,52 %			2,3 %
4062	»	Bh 2	» »	Sprøhet 8 –11,3 mm	4,34 %			0,8 %
4063	»	utskutt	» »	» 11,3–16 mm	6,48 %		1,1 %	
4064	Lia	Bh 3	Kvartskeratofyr	Flisighet 8 –11,3 mm	4,76 %			
				» 11,3–16 mm	5,63 %			
4065	»	utskutt	»	Sprøhet 8 –11,3 mm	10,36 %			
				» 11,3–16 mm	23,94 %			
4066	Støren	Bh 4	Trondhjemitt	Flisighet 8 –11,3 mm	2,88 %			
4067	»	utskutt	»	» 11,3–16 mm	6,72 %			
4068	»	Bh 5	»	Sprøhet 8 –11,3 mm	10,52 %			
4069	»	utskutt	»	» 11,3–16 mm	15,91 %			
4070	Høvringen	Bh 6	Trondhjemittisk bergart	Flisighet 8 –11,3 mm	0,7 %		0,0 %	0,0 %
				» 11,3–16 mm	5,2 %			
4071	»	utskutt	Trondhjemittisk bergart	Sprøhet 8 –11,3 mm	1,92 %		3,8 %	11,5 %
				» 11,3–16 mm	18,44 %			8,7 %
4072	Trolla	Bh 7	Trondhjemittisk bergart	Flisighet 8 –11,3 mm		5,0 %		
				» 11,3–16 mm		7,5 %		
4073	»	utskutt	Trondhjemittisk bergart	Sprøhet 8 –11,3 mm	2,4 %			
				» 11,3–16 mm		2,8 %		
4074	Langseter	Bh 8	Kvartsmonzonittisk gneis	Flisighet 8 –11,3 mm	2,86 %			
				» 11,3–16 mm	3,88 %			
4075	»	utskutt	Kvartsmonzonittisk gneis	Sprøhet 8 –11,3 mm	5,35 %			
				» 11,3–16 mm	5,24 %			
4076	Tjønnbakken	Bh 9	Rød gneis	Flisighet 8 –11,3 mm	3,47 %			
				» 11,3–16 mm	2,21 %			
4077	»	utskutt	»	Sprøhet 8 –11,3 mm	6,72 %			
				» 11,3–16 mm	10,71 %			
4078	Tjønnbakken	Bh 10	Amfibolitt	Flisighet 8 –11,3 mm	5,77 %			
				» 11,3–16 mm		1,4 %		
4079	»	utskutt	»	Sprøhet 8 –11,3 mm	6,67 %			
				» 11,3–16 mm		2,8 %		

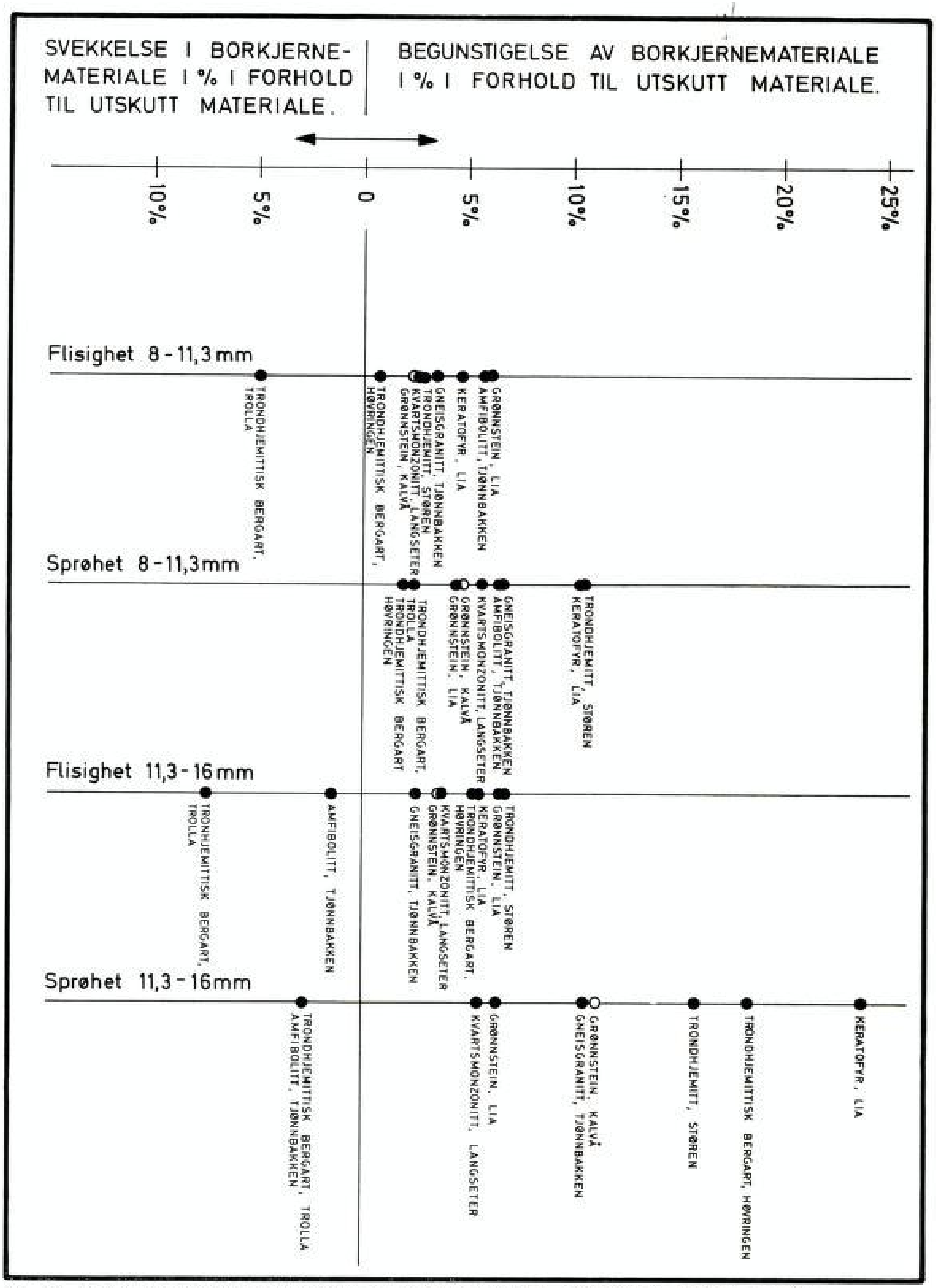

Fig. 13. Prosentvis svekkelse/begunstigelse av borkjernemateriale i forhold til utskutt materiale.

Some Naturally Heavy-Metal Poisoned Areas of Interest in Prospecting, Soil Chemistry, and Geomedicine

J. LÅG & B. BØLVIKEN

Låg, J. & Bølviken, B. 1974: Some naturally heavy-metal poisoned areas of interest in prospecting, soil chemistry, and geomedicine. *Norges geol. Unders. 304*, 73–96.

Occurrences of naturally lead-poisoned soil and vegetation have been found in 5 different areas in Norway where deposits of galena occur in the bedrock, namely at Snertingdal, Galå near Rena, Nordre Osen, Nord-Aurdal, and Stabbursdalen. In the initial stages of lead poisoning at these locations *Vaccinium spp.* are replaced by *Deschampsia flexuosa*. Where lead poisoning is more advanced, the field characteristics are: abnormal, dying or deficient vegetation; apparently high stone content at the soil surface; a poorly developed or deficient bleached layer in podzol areas. Samples from lead-affected patches show average lead contents of up to 2.5% in soil and up to 400 ppm in vegetable dry matter, corresponding approximately to 400 and 70 times, respectively, the contents found at 'background stations'.

Elements other than lead can also be toxic to the vegetation. At a copper-bearing mineral deposit at Karasjok, average Cu contents of 7400 ppm and 330 ppm were found in soil and vegetation, respectively, from patches with abnormal or deficient vegetation. At the Tverrfjellet pyrite deposit at Hjerkinn poisoning symptoms of soil and vegetation are also pronounced but there the cause of poisoning is probably more complex.

Feeding experiments show that a natural high lead concentration in hay can result in an increased lead content in rabbit liver, kidneys, and bones already after 4 weeks.

The investigations indicate that (1) natural heavy metal poisoning of soil and vegetation in connection with sulphide mineralization in bedrock is more common than earlier expected; (2) searching for heavy metal poisoned areas may be an effective prospecting method, and the registration of special plant communities seems to be more effective in this connection than looking for rare indicator plants; (3) certain features of the natural geochemical environment may be noxious to animals.

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Introduction

In an earlier publication (Låg et al. 1970) an occurrence of naturally lead-poisoned soil at Kastad, Vardal, was described. Analyses of soil samples showed high lead concentrations (up to ca. 10% Pb in dry matter). Vegetation samples also had high lead contents (nearly 0.4% Pb in dry matter). The lead poisoning at Kastad is due to natural processes, the lead deriving in solution from a nearby occurrence in bedrock and being deposited in the humus-rich parts of the soil where the lead-bearing groundwater emerges at

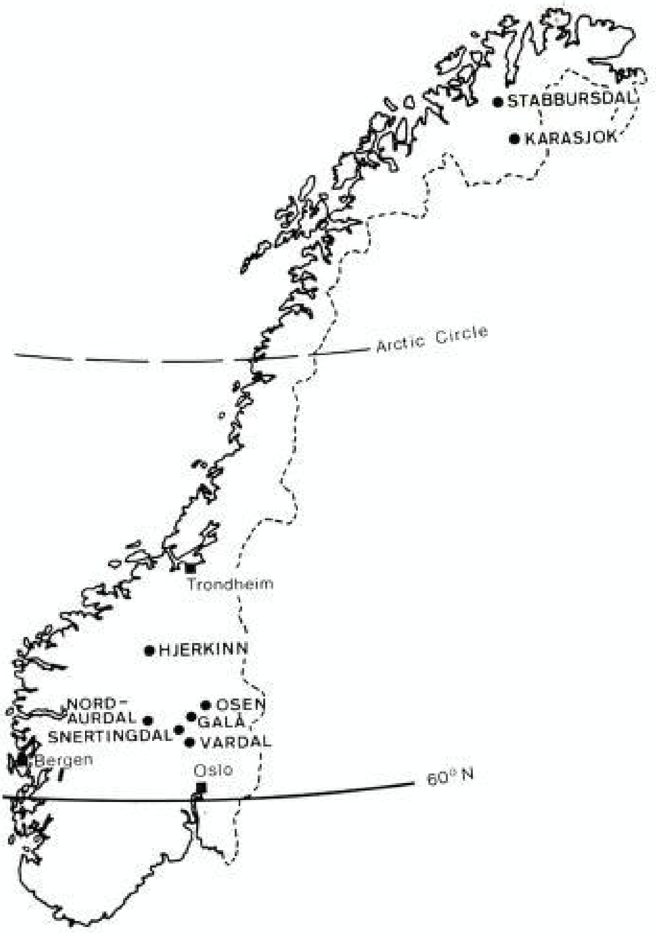

Fig. 1. Location of occurrences of naturally heavy metal poisoned areas.

the surface. Following up this example from Kastad, the present authors subsequently investigated other areas to see if similar poisoning phenomena could be demonstrated. Suitable bedrock lead occurrences are those found in recent years by Norges geologiske undersøkelse (NGU), since they have not as yet been disturbed by mining operations. The investigations have shown that lead poisoning can be demonstrated in connection with every one of the occurrences so far studied; these are at Nøssmarka in Snertingdal, Galå near Rena, Skavern in Nordre Osen, Kalvetjern in Nord-Aurdal, and Krokvann in Stabbursdalen (Fig. 1). The surveys have been directed towards indicating possible poisoning phenomena in the field, and thereafter sampling and analysing to determine the nature of the poisoning.

The observed field characteristics of lead poisoning are:

1. Abnormal, dying or deficient vegetation.
2. Apparently high stone content at the soil surface in morainic regions.
3. Poorly developed or deficient bleached layer in podzolic areas.

Fig. 2. Area of strong lead poisoning, Nøssmarka, Snertingdal. Scant vegetation of *Deschampsia flexuosa*. The light patch in the middle of the picture is barren soil with stones.

The normal ground-cover vegetation in the investigated areas includes plenty of *Vaccinium myrtillus* and *V. vitis-idaea.*In the initial stages of lead poisoning such species are replaced by *Deschampsia flexuosa.* This is one of Norway's most widespread plant species, and it grows especially at the expense of *Vaccinium* species in places where trees have been felled and the ground-cover vegetation in the forest thus receives more light. In lead-poisoned areas *D. flexuosa* dominates even in relatively dark, dense forests. The *Vaccinium* species which survive show symptoms such as stunted growth, discoloration of the leaves and lack of fruit. Other common plants species, such as *Trientalis europaea* and *Dryopteris linnaeana*, also show similar signs of retarded growth, though several of the larger species of fern appear to be fairly normal.

With comparatively weak lead contamination *Deschampsia flexuosa* grows profusely but rarely sets ears. With increasing contamination this species also becomes more and more stunted and discoloured before disappearing completely. Where lead poisoning is most advanced the ground is barren, the largest area so far observed being up to 100 m^2. These barren patches occur in the lowermost parts of the terrain, which are periodically influenced by percolating water. In regions with morainic soil material the patches apparently have an unusually high stone content at the surface, which in fact is a sign both of exposed ground due to lack of vegetation and of a real increase in coarse-grained mineral material because the finer particles are eroded faster than normal. When the poisoning is so strong that the ground cover vegeta-

Fig. 3. Area of moderate lead poisoning, Nøssmarka, Snertingdal. Vegetation of *Deschampsia flexuosa.* Light patches are stones and/or barren soil.

tion is killed off, the frequency of dead or stunted specimens of trees of Norway spruce in the adjacent area is also strikingly high.

As the poisoning hampers the plants' normal growth, the production of humus is correspondingly small. The normal podzolization processes with development of a bleached layer are therefore retarded.

On the basis of these observations, during our field work (in all cases in podzol regions) we have divided the lead poisoning into three classes:

Class 1. Strong poisoning. (Fig. 2).

The ground-cover vegetation of higher plants is totally absent over areas from 0.1 m^2 to several tens of square metres. The soil lacks a bleached layer.

Class 2. Moderate poisoning. (Fig. 3).

The normal vegetation, which in the investigated areas often consists of *Vaccinium spp.* and ferns, is replaced by *Deschampsia flexuosa* which shows stunted growth and discoloration. Some barren patches measuring ca. 0.1 m^2 or less may be present. The soil lacks the bleached layer.

Class 3. Weak poisoning. (Fig. 4).

The ground-cover vegetation is dominated by *Deschampsia flexuosa,* without *Sphagnum spp.,* where one should expect to find *Vaccinium spp.* and ferns. Sporadic specimens of such plants within the *D. flexuosa* areas show discoloration and stunted growth. The bleached layer is either weakly developed or absent.

Soil and plant samples were collected for laboratory analysis from the poisoned areas and from neighbouring normal ground. The results of the analyses have in all cases provided clear factual evidence of lead poisoning.

Fig. 4. Area of weak lead poisoning, Nøssmarka, Snertingdal. Profuse vegetation of *Deschampsia flexuosa.* Light patches are stones and/or barren soil.

Elements other than lead can also cause the poisoning of soil and vegetation. Poisoning phenomena have been observed at a copper occurrence at Karasjok and the Tverrfjellet pyrite deposit at Hjerkinn.

With high lead concentrations in vegetation there exists a possibility that animals which obtain their nourishment partly or wholly from such vegetation can be affected by harmful quantities of lead. To illustrate aspects of this geomedical problem we have carried out simple preliminary experiments whereby rabbits have been fed on *Deschampsia flexuosa* hay from lead-poisoned areas.

A brief account is given below of investigations of natural heavy metal poisoning of soil and vegetation which we have made subsequent to the publication of our studies on the Kastad area (Låg et al. 1970). Nøssmarka in Snertingdal has been studied in most detail, and the experiences from this area form the basis for the investigations in the other areas described in this account.

The poisoned areas

LEAD POISONING

Nøssmarka in Snertingdal, Gjøvik

A lead mineralization was discovered by NGU in Nøssmarka belonging to the farm Øvre Nøss in Snertingdal, Gjøvik (Bjørlykke et al. 1973); see Fig. 1. The mineralized area is situated on a gently inclined north-facing slope lead-

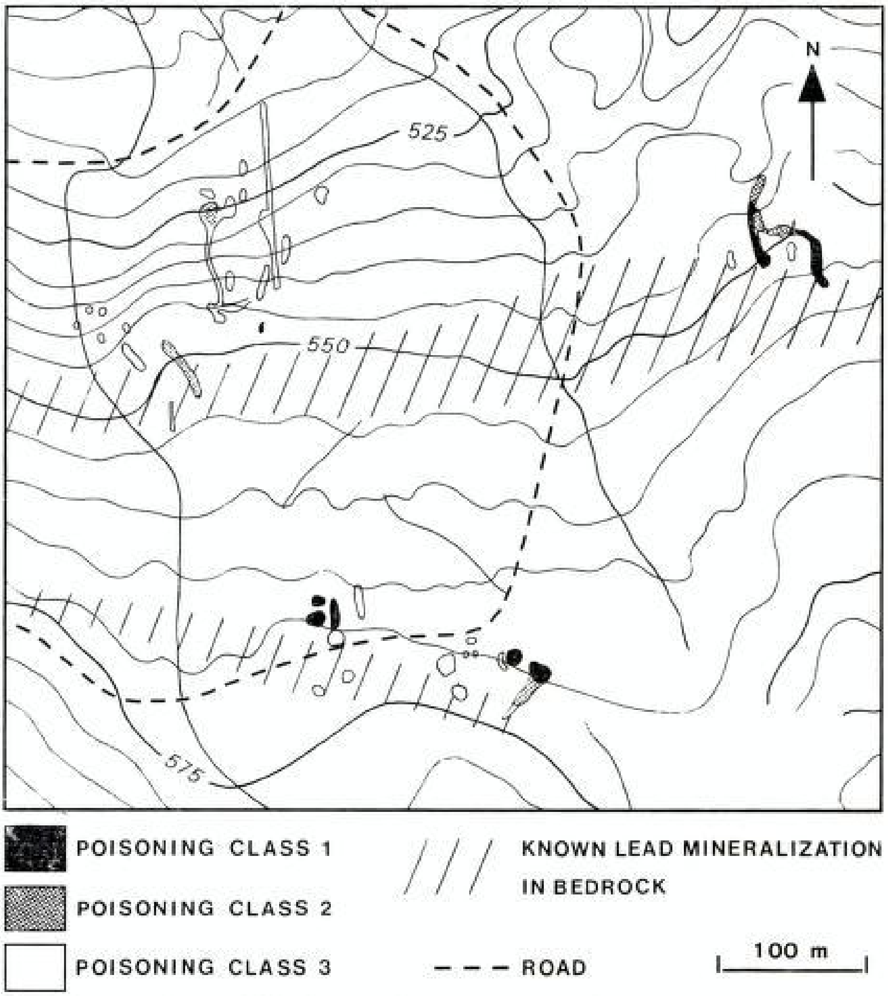

Fig. 5. Patterns of naturally lead-poisoned areas, Nøssmarka, Snertingdal.

ing down to the river Stokkelva at an altitude of ca. 500 m a.s.l., the annual precipitation and mean temperature being approximately 700 mm and 2°C, respectively. The thickness of the superficial deposits is variable, up to an estimated maximum of 10–15 m; a general average thickness is considered to be 1–2 m. These deposits consist mainly of morainic material, and the soil profile shows a normal podzol development with a bleached layer between 2 cm and 15 cm. Norway spruce is the prevalent tree while the ground-cover vegetation is generally of blueberry *(Vaccinium myrtillus)* type with or without ferns *(Dryopteris).*

The area has been investigated by different exploration methods, but none of these is thought to have contaminated the surroundings to any mentionable degree. The lead mineralization consists of galena disseminated in a quartzite which strikes approximately E–W and dips ca. 60° towards the north (Fig. 5). The mineralized zone is exposed in only a few places but was found to be about 2 km long with an optimum grade of 1% Pb over 15–20 m; hand specimens may show up to 6% Pb.

The poisoned areas which have been found so far (Fig. 5) occur as patches in the low parts of the terrain (where groundwater or percolating water periodically reaches the surface) forming irregular patterns which follow the natural drainage system down-slope from the lead-mineralized bedrock. Often the patches have developed into a fan-shaped form, with the most pronounced poisoning at the apex of the fan where the groundwater issues at the surface.

Vegetation samples were collected of species which either grew upon or had parts of their root systems in the poisoned areas. *Deschampsia flexuosa* was collected from all the patches, and *Dryopteris linnaeana, Trientalis europaea, Vaccinium myrtillus, V. vitis-idaea, Sorbus aucuparia,* and *Betula pubescens,* wherever this was possible. Only the exposed parts of the plants were sampled and care was taken not to contaminate the specimens with soil material during the sampling process. Before the vegetation samples were put into paper bags, they were sprayed thoroughly with distilled water on a nylon sieve in order to remove dust. As a rule two soil samples were taken for every sample of vegetation, one at a depth of 2–5 cm and another at a depth of 20–25 cm. Each soil sample was made up of at least 10 subsamples taken over the whole area from which the vegetation sample had been collected. For comparison, vegetation and soil were also sampled at 4 background stations in the surrounding area. The analytical results of this sampling correspond fairly well with those found in the literature (see for example Brooks 1972, Hawkes & Webb 1962, Lounamaa 1956). The collected samples were dried at 105°C and the metal content of the dry material was determined by atomic absorption in the diluted solution after ashing at 430°C and digestion of the ash with hot nitric acid.

Tables 1 and 2 give a summary of the analytical results, briefly commented upon in the following paragraphs:

The lead poisoning is confirmed since the soil samples show a lead content 100–400 times higher than normal (Table 1), an increasing content from poisoning class 3 (100–200 times the normal) to poisoning class 1 (about 400 times the normal) (Table 1), and no clearly abnormal contents of elements other than lead (Table 2).

The lead content in the soil-poisoned areas is higher at a depth of 2–5 cm than at 20–25 cm (Table 1), the average values being 1.9% and 0.69% and the maxima 4.2% and 3.6%, respectively.

The ash content of the soil samples from the poisoned areas is high, this being pronounced at a depth of 2–5 cm beneath the barren patches, where it is approximately twice that of the normal (Table 1, Fig. 6). This high ash content confirms that the poisoning prevents normal growth, since the production of humus must have been low. Our earlier investigations (Låg et al. 1970) and work by Szalay (1969) and Szalay & Szilagi (1968) has sug-

Table 1. Ash, lead content and pH in dry matter of soil; ash and lead content in dry matter of vegetation from Nossmarka, Snertingdal

	Class	N	Ash %	Pb ppm	pH
Soil samples, depth 2–5 cm, barren areas	1	9	66.1	24,500	4.5
Soil samples, depth 20–25 cm, barren areas	1	8	93.5	9,900	4.8
Soil samples, depth 2–5 cm, background stations	BG	15*	33.3	57	4.0
Soil samples, depth 20–25 cm, background stations	BG	16*	92.5	26	4.6
Deschampsia flexuosa, leaves	2–3	23	4.8	99	
Deschampsia flexuosa, leaves	BG	6	5.4	3	
Corresponding soil samples, depth 2–5 cm	2–3	23**	47.3	17,200	4.4
Corresponding soil samples, depth 20–25 cm	2–3	22**	94.0	4,700	4.7
Trientalis europaea, above surface	2–3	3	8.0	184	
Trientalis europaea, above surface	BG	3	7.7	10	
Corresponding soil samples, depth 2–5 cm	2–3	3	49.8	19.000	4.3
Corresponding soil samples, depth 20–25 cm	2–3	3	88.8	10,800	4.7
Dryopteris linnaeana, above surface	2–3	3	8.9	253	
Dryopteris linnaeana, above surface	BG	4	8.7	4	
Corresponding soil samples, depth 2–5 cm	2–3	3	25.2	17,500	4.3
Corresponding soil samples, depth 20–25 cm	2–3	3	92.3	8,200	4.7
Dryopteris spp., (mainly filix-mas.)	2–3	3	10.0	410	
Dryopteris spp., (mainly filix-mas.)	BG	4	6.9	6	
Corresponding soil samples, depth 2–5 cm	2–3	3	47.5	23,300	4.5
Corresponding soil samples, depth 20–25 cm	2–3	3	94.7	4,000	4.9
Vaccinium vitis-idaea, stem	2–3	2	3.4		
Vaccinium vitis-idaea, stem	BG	2	2.8	6	
Vaccinium vitis-idaea, leaves	2–3	3	2.9	64	
Vaccinium vitis-idaea, leaves	BG	2	3.6	2	
Corresponding soil samples, depth 2–5 cm	2–3	3	68.0	23,200	4.5
Corresponding soil samples, depth 20–25 cm	2–3	3	89.7	12,800	4.8
Vaccinium uliginosum, above surface	2–3	1	1.3	78	
Vaccinium uliginosum, above surface	BG	1	2.0	9	
Vaccinium myrtillus, stem	2–3	6	2.9	159	
Vaccinium myrtillus, leaves	2–3	6	4.9	40	
Vaccinium myrtillus, whole plant	BG	3	3.7	4	
Corresponding soil samples, depth 2–5 cm	2–3	6	50.8	20,200	4.5
Corresponding soil samples, depth 20–25 cm	2–3	6	91.8	6,400	4.6
Betula, second year twig	3	2	1.6	78	
Betula, second year twig	BG	4	2.0	14	
Betula, first year twig	3	2	2.4	65	
Betula, first year twig	BG	4	3.2	9	
Betula, leaves	3	2	4.7	14	
Betula, leaves	BG	3	5.6	5	
Corresponding soil sample, depth 2–5 cm	3	2	54.5	14,800	4.4
Corresponding soil sample, depth 20–25 cm	3	2	95.5	2,800	4.8
Sorbus aucuparia, second year, twig	3	2	2.3	22	
Sorbus aucuparia, second year, twig	BG	4	2.3	4	
Sorbus aucuparia, first year, twig	3	2	3.2	19	
Sorbus aucuparia, first year, twig	BG	4	2.8	4	
Sorbus aucuparia, leaves	3	2	7.0	6	
Sorbus aucuparia, leaves	3	4	6.0	4	
Corresponding soil samples, depth 2–5 cm	3	2	44.3	7,800	3,9
Corresponding soil samples, depth 20–25 cm	3	2	93.1	2,300	4.7

Figures indicate arithmetic means.

Each soil sample for analysis (composite samples) consists of 10 subsamples. Classes 1–3: Very strong to weak lead poisoning (see text). BG: background. N: Number of composite samples.

* pH: Average of 3 samples

** pH: Average of 8 samples

Table 2. Ash and metal contents in dry matter (105°C) of soil samples from Nøssmarka, Snertingdal

	N	Ash %	Ag ppm	Cd ppm	Co ppm	Cr ppm	Cu ppm	Fe %	Mn ppm	Ni ppm	V ppm	Zn ppm
Barren patches, depth 2–5 cm	9	66.1	<1	0.9	10	14	15	1.1	1300	12	17	44
Background samples, depth 2–5 cm	15	33.3	<1	0.8	3	5	7	0.3	400	5	7	57
Barren patches, depth 20–25 cm	8	93.5	<1	0.9	18	25	18	2.0	120	27	22	64
Background samples, depth 20–25 cm	16	92.5	<1	0.8	11	24	10	2.3	240	20	30	31

Figures indicate arithmetic means.
Each soil sample for analysis (composite samples) consists of 10 sub-samples.
N: Number of composite samples.

Table 3. Ratio of ash, Fe, Mn and Pb of lead poisoned versus background soils, Nøssmarka, Snertingdal

				Poisoned/background			
		Depth cm	N_p/N_b	Ash	Fe	Mn	Pb
Soil, poisoning class	2–3	2–5	23/15	1.4	3.5	2.4	300
» » »	2–3	20–25	22/16	1.0	0.9	3.6	180
» » »	1	2–5	9/15	2.0	4.2	3.2	430
» » »	1	20–25	8/16	1.0	0.9	4.9	380

N_p : Number of samples from poisoned areas.
N_b : Number of samples from background areas.

gested that lead is associated with the organic part of the soil. Lead is probably so strongly bound to humus (Chowdury & Bose 1971) that humus-rich soil may not be toxic to plants until the lead content becomes fairly high. With a steady supply of more lead than is carried away, however, sooner or later lead concentrations in the soil-water will become restrictive for natural plant growth. The rate of humus production is then reduced and the breakdown of humus may occur faster than the supply of new organic matter. This situation will probably facilitate a comparatively rapid and accelerating poisoning of the soil, since the amount of humus required to fix the lead diminishes simultaneously as lead is being brought in. Because of this process, lead poisoning may probably occur within a relatively short space of geological time.

The lead poisoning also influences the distribution of Fe and Mn during the podzolization processes, even though the two elements respond differently. As can be seen from Table 3, contents of both Fe and Mn are high in

Table 4. Lead content in vegetation in relation to lead content of corresponding soil. Nøssmarka, Snertingdal

		N	%Pb in veg/Pb in soil	
Soil depth, cm			2–5	20–25
Betula pubescens, leaves	P	2	0.36	14
	B	4	21	39
Betula pubescens, first year twig	P	2	0.39	2.9
	B	4	38	39
Betula pubescens, second year twig	P	2	0.64	6.8
	B	4	61	61
Sorbus aucuparia, leaves	P	2	0.10	0.28
	B	4	7.5	18
Sorbus aucuparia, first year twig	P	2	0.35	0.86
	B	4	8.1	20
Sorbus aucuparia, second year twig	P	2	0.34	1.0
	B	4	7.9	14
Vaccinium myrtillus, leaves	P	6	0.26	1.3
Vaccinium myrtillus, stem	P	6	0.95	5.3
Vaccinium myrtillus, whole plant	B	3	6.0	12
Deschampsia flexuosa, leaves	P	21	0.68	3.1
	B	6	5.4	10
Dryopteris linnaeana	P	3	2.1	4.6
	B	4	9.2	31
Dryopteris spp. (mainly filix-mas)	P	3	3.5	22
	B	4	9.9	27
Trientalis europaea	P	3	1.0	6.3
	B	4	22	49

N: Number of vegetation samples, number of soil samples.
P: Poisoned area.
B: Background area.

the topsoil (upper 2–5 cm) of the poisoned areas, whereas Fe is fairly normal but Mn still high at a depth of 20–25 cm.

The high lead content in the soil of the poisoned areas is also reflected in several plant species. *Dryopteris spp.* show the highest average lead content (70–80 times normal) and deciduous trees the lowest (1–7 times normal). Leaves of *Deschampsia flexuosa* have an average lead content of about 30 times the normal, while the lead content of the exposed part of *Trientalis europaea* is approximately 20 times the normal value. In the *Vaccinium* species the lead content is generally higher in the stems than in the leaves; plants from the poisoned ground contain from 10 to 40 times more lead than normal.

The lead content of the vegetation in relation to that of the soil is shown in Table 4. It is clear that the different species take up the available lead in different amounts. There is no simple relationship between the lead content of a species and lead content in the soil, or the ability of the species to

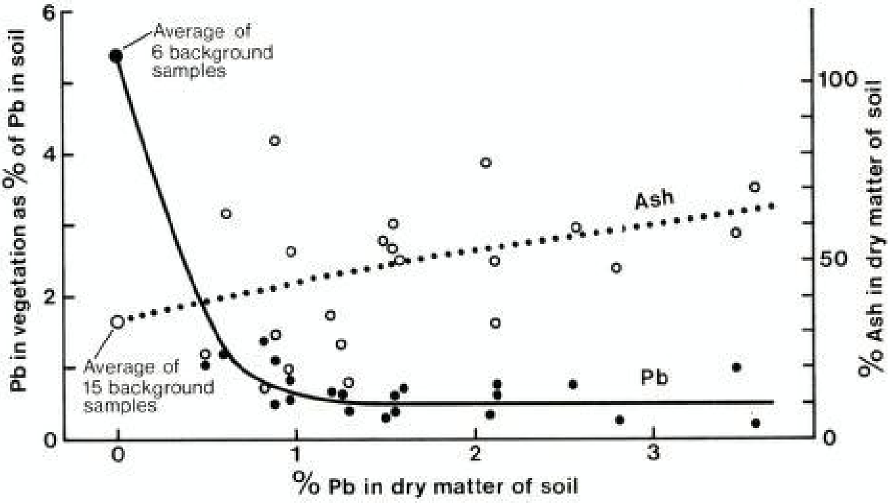

Fig. 6. Lead content in soil (depth 2–5 cm) versus (1) ash in soil (right hand ordinate, open circles, dotted line) and (2) lead content in *Deschampsia flexuosa* as percentage of lead content in the corresponding soil (left hand ordinate, closed circles, continuous line). Data from Nøssmarka, Snertingdal. See also Table 4.

tolerate high lead concentrations in the soil. Consequently, the lead content of a species may not be reliable as a direct indication of its lead tolerance.

The response of the species *Deschampsia flexuosa* to various lead contents in the soil is illustrated in Fig. 6, where the ratio 'Pb in plant/Pb in soil' is plotted against 'Pb in soil'. It can be seen that when the lead content of the topsoil increases from 60 ppm (normal) to 1% (high), the ratio 'Pb in plant/Pb in soil' decreases from a normal range of 5–6% down to 0.6%. From then on the ratio is more or less constant with an increasing lead content in the soil. The increasing ash content towards the right in Fig. 6 seems to indicate that the content of organic matter in the soil decreases with an increasing lead content in the soil.

This may indicate that a defence mechanism of *D. flexuosa* combined with a restricted availability of Pb in the soil, effectively counteracts poisoning of the plant due to large quantities of lead in the surroundings, up to ca. 1% Pb in the soil's upper layer corresponding to a tolerable content of ca. 60 ppm in dry matter of the plants. Above this concentration the lead content of the plants increases more or less proportionally with the lead content of the soil until poisoning takes effect and kills off the plants.

The Galå area, Åmot in Hedmark

In 1970 NGU discovered a lead deposit outcropping in small tributary streams on the south side of the Galå river, ca. 20 km north of Leiret, Elverum (Fig. 1). The type of lead mineralization is similar to that found at Nøss-

Table 5. Ash, heavy metals and pH in dry matter of soil; ash and heavy metals in dry matter of vegetation from lead poisoned patches in the Galå area, Åmot in Hedmark

	N	Ash %	Cd ppm	Cu ppm	Ni ppm	Pb ppm	Zn ppm	pH
Soil samples, depth 2–5 cm	2	54.0	0.7	6	9	6,400	40	4.1
Soil samples, depth 20–25 cm	2	94.8	0.8	9	21	8,300	65	4.6
Betula, composite/leaves and twigs	1	1.8	0.2	5	3	62	157	
Sorbus aucuparia, leaves	1	7.2	0.1	4	5	18	22	
Vaccinium myrtillus, leaves	2	4.9	trace	7	3	73	29	
Vaccinium myrtillus, stem	2	2.6	0.1	6	2	32	50	
Deschampsia flexuosa	2	4.5	0.1	4	4	51	32	

Figures indicate arithmetic means.
N: Number of samples.

marka, Snertingdal, but at present its extent and grade is unknown (Bjørlykke et al. 1973).

The climate and other general surroundings are similar to those at Snertingdal. Superficial deposits of glacial material are somewhat irregular with great thicknesses in some of the depressions. Symptoms of poisoning of the soil and vegetation were observed at localities near to lead-mineralized outcrops, where the superficial cover is moderate. The occurrences of poisoning in the Galå area are analogous to those in Snertingdal, the affected patches being found in relatively low terrain, where water may appear at the surface in wet periods. The normal vegetation of blueberry, ferns and other herbaceous plants of these patches is stunted or absent; instead *Deschampsia flexuosa* prevails (poisoning class 3). In a few places *D. flexuosa* is also lacking, so that small barren spots are present (poisoning classes 1–2). Soil and vegetation were sampled as described earlier (p. 79), except that in this case the plants were not washed after picking. The analytical results (Table 5) confirm that lead poisoning has occurred as the lead content is relatively high, while contents of the other analysed elements are moderate.

Skavern, Nordre Osen, Åmot in Hedmark

Several hundred blocks of a local galena-bearing quartzite occur at Skavern, ca. 4 km east of the northern end of Osensjøen, Åmot in Hedmark (Fig. 1). The lead mineralization, which has also been proved in outcrops and in drill holes, is similar to that already described.

The climatic conditions are much the same as in the Snertingdal and Galå areas. A fairly thick and coarse-grained superficial cover (of glacial origin) occasions a relatively deep groundwater level, which has promoted the formation of well-developed podzolic soils, and a forest where pine often prevails over spruce. The ground-cover vegetation is dominated by *Vaccinium myrtillus, V. vitis-idaea* and *Calluna vulgaris*. The poisoning symptoms are similar to

Table 6. Ash, heavy metals and pH in dry matter of soil; ash and heavy metals in dry matter of vegetation from lead poisoned patches at Skavern, Nordre Osen, Åmot in Hedmark

	Class	N	Ash %	Cd ppm	Cu ppm	Ni ppm	Pb ppm	Zn ppm	pH
Soil samples, depth 2–5 cm	1	2	44.1	0.9	126	37	97,000	416	5.5
Soil samples, depth 20–25 cm	1	2	86.6	1.2	130	40	40,000	496	5.4
Soil samples, depth 2–5 cm	2–3	7	48.7	1.9	55	42	48,000	360	4.9
Soil samples, depth 20–25 cm	2–3	7	91.2	1.5	69	50	19,000	588	5.4
Betula pubescens, leaves	2–3	2	3.8	0.4	3	4	32	363	
Betula pubescens, first year twig	2–3	1	1.8	0.1	3	3	71	337	
Betula pubescens, second year twig	2–3	1	1.7	0.1	3	2	89	345	
Vaccinium myrtillus, leaves	2–3	4	4.6	trace	5	4	19	45	
Vaccinium myrtillus, stem	2–3	4	2.7	trace	6	4	61	994	
Deschampsia flexuosa	2–3	7	4.2	0.2	3	5	99	41	
Ptilium crista-castrensis	3	1	4.5	0.3	6	12	3,600	93	

Figures indicate arithmetic mean.
N: Number of samples.
Classes 1–3: Strong to weak lead poisoning (see text).
Range 5–208 ppm.

those found at Nøssmarka and Galå. The presence of *Deschampsia flexuosa* indicates poisoning of classes 2 and 3, and barren patches also signify a more complete poisoning. The symptoms of poisoning appear down-slope from the lead mineralization, just above swampy areas, i.e. at places where the groundwater is present close to or at the surface as distinct from the predominating terrain of deep groundwater level.

Some comments on the analytical results from soil and vegetation samples of the Skavern area (see p. 79 for methods; also Table 6), are as follows:

1. Of the elements Cd, Cu, Ni, Pb and Zn only lead occurs in possible toxic concentrations, being 5–10% at a depth of 2–5 cm and 2–4% at a depth of 20–25 cm in the soil of the areas of poisoning. Soil patches designated poisoning class 1 have a higher lead content than those from classes 2 and 3.
2. The high lead content of the soil is reflected in the vegetation; *Deschampsia flexuosa,* for example, shows 99 ppm lead in dry matter. In a sample of the moss species *Ptilium crista-castrensis* 3600 ppm of lead was detected, the corresponding lead content of the soil being 3.5% at a depth of 2–5 cm and 1.3% at 20–25 cm. Occasional samples of moss species from lead-poisoned patches in other areas also show high lead contents. These examples and the fact that *Sphagnum spp.* are as a rule absent from lead-poisoned soil – even though the topography and water regime might be favourable for their growth – suggest that a poor ability to reject lead is a feature common to mosses.

3. The zinc content of both soil and plants is relatively high at Osen compared with that in the Nøssmarka and Galå areas, probably because the lead mineralization at Osen is more zinc-rich than that in the other areas.

Table 7. Ash, heavy metals and pH in dry matter of soil; ash and heavy metals in vegetation from poisoned areas at Kalvtjern, Nord-Aurdal

	Class	N	Ash %	Cu ppm	Ni ppm	Pb ppm	Zn ppm	pH
Soil samples, depth 2–5 cm	1–3	7	49.7	26	11	973	33	4.6
Deschampsia flexuosa	2	1	5.6	3	4	37	22	
Colloidal precipitations in stagnant water downslope from poisoned patches		4	48.6	7	14	2,246	69	

Classes 1–3: Strong to weak poisoning (see text).
Figures indicate arithmetic means of N samples.

Kalvetjern, Nord-Aurdal

During a regional survey in 1971 NGU discovered a strong geochemical anomaly at Kalvetjern, Nord-Aurdal (Fig. 1), with a lead content in the stream sediments up to nearly 1%. The drainage basin of the anomalous streams lies at ca. 1000 m above sea level, which in that part of Norway is just above the timber line. Precipitation is estimated at around 600 mm per year and the mean temperature close to 0°C. The overburden, which is mostly of glacial origin, is generally very thin and contains an unusually high frequency of surface boulders. Most of these boulders are of local origin, having been transported only short distances by the ice, while others are very likely more or less *in situ,* being products of frost action on the quartzitic bedrock. A thorough geological surface investigation (which considering the local conditions could be regarded as fairly complete) and some soil sampling along selected lines have been conducted in the area, but no lead mineralization was found apart from accessory galena. The bedrock is estimated to have an overall content of less than 100 ppm lead; nevertheless, poisoning of soil and vegetation is apparent. Some patches, several tens of square metres in extent, consist of barren soil. These patches seem to be connected with the occurrence of some rather large and irregular porphyroblasts of pyrite in the bedrock. Other features are similar to those described from the Snertingdal, Galå, and Nordre Osen areas. These were judged in the field to be patches of lead poisoning, a suggestion which we consider to be confirmed by the analytical results of the soil and vegetation samples (see Table 7).

In areas with frequent temperature variations around 0°C where the overburden is thin, frost action could result in the development of innumerable joints and fissures in the bedrock. The possibilities for the extraction of

Fig. 7. Naturally lead-poisoned area near Krokvann, Stabbursdalen, Alta. Light patches in the front are stones in barren soil.

heavy metals from this mechanically weathered rock are greater than normal because of the increased surface area of minerals exposed to water and air. With a low humus production there is only a restricted amount of loose material to tie up any lead brought into solution. A more than hundred-fold increase in lead concentration could occur within a few hundred metres due to solution, transportation in water and subsequent redeposition. The results from Kalvetjern show that under these conditions lead poisoning may occur even at relatively low lead concentrations in the bedrock. This might indicate that lead poisoning could be more common in certain districts than earlier expected.

Krokvann, Stabbursdalen, Alta

In 1971, during the follow-up of a stream sediment anomaly, an occurrence of lead mineralization was found in Stabbursdalen near Alta (Fig. 1). The area is situated at an altitude of 400 m a.s.l. some 40 km from the nearest fjord, which at this latitude (70°N) means a climate of a sub-arctic continental type. The mean temperature in the area is supposed to be well below 0°C, and the annual precipitation approximately 300 mm. The lead, which is present as irregular aggregates of galena in a quartzite, is thought to be closely related to the type of lead mineralization described earlier in this paper (p. 78). The superficial cover in the trea consists chiefly of morainic and glaciofluvial material of variable thickness. The soil belongs to a high-

Table 8. Ash, heavy metals and pH in dry matter (105° C) of soil; ash and heavy metals in dry matter of poisoned area at a lead occurrence near Krokvann, Stabbursdalen, Alta

	Class	N	Ash %	Cd ppm	Cu ppm	Ni ppm	Pb ppm	Zn ppm	pH
Soil samples, depth 2–5 cm	2–3	4	83.0	1.8	260	48	10,400	860	5.8
Betula pubescens, leaves	3	1	3.5	0.2	3	3	16	180	
Betula pubescens, first year twig	3	1	2.1	trace	6	2	9	110	
Betula pubescens, second year twig	3	1	1.3	trace	4	1	20	150	
Deschampsia flexuosa	3	1	4.9	trace	5	2	320	100	
Festuca ovina	3	1	4.7	trace	8	4	270	60	
Scirpus caespitosus	3	2	4.5	trace	8	6	385	90	
Scorpidium scorpidodes and other moss species	2–3	1	59.5	1.8	65	65	11,200	710	

Classes 1–3: Strong to weak poisoning (see text).
Figures indicate arithmetic mean of N samples.

mountain podzol type with a very thin bleached layer, often marked only by isolated white quartz grains beneath the humus cover, which is generally from 1 to a few cm thick. The vegetation is sparse, generally stunted birch with occasional taller birch on some south-facing slopes and a more ordinary mountainous ground-cover vegetation. (Fig. 7).

Because of the rather special vegetation the symptoms of poisoning in this area are less obvious than those demonstrable in the other areas further south. In small patches where the mineralized rock is exposed the vegetation is absent, but these patches can easily be confused with ground made barren by wind erosion, a common feature under these conditions. The vegetation pattern is nevertheless supposed to be lead affected, since in the vicinity of the mineralization the grass species *Deschampsia flexuosa* and *Festuca ovina* dominate totally at the expense of the normal plant cover with a more diverse variety of species. This suggestion was confirmed by high Pb and somewhat increased Cu and Zn contents of the soil samples (Table 8). The high percentages of ash show a low humus content, which promotes the occurrence of lead- and other metal-poisoning, perhaps even at only relatively moderate concentrations in the soil (see also p. 87). The lead content of *Deschampsia flexuosa* from the Stabbursdal areas (Table 8) is considerably higher than in corresponding samples taken further south in the country. It is, however, uncertain if this is a general trend since only one sample from Stabbursdalen was analysed. Another grass species, *Festuca ovina,* appears to have a similarly higher lead content, as also do *Scirpus caespitosus* and small patches of mosses collected at the edge of a stream just below the visible lead mineralization.

Fig. 8. Naturally copper-poisoned area in birch forest, Karasjok. Dark area in the middle right hand side of the picture is barren soil. Ground-cover vegetation in the left hand side consists mainly of *Juncus trifidus, Festuca ovina, Deschampsia flexuosa* and *Viscaria alpina.*

OTHER POISONED AREAS

Karasjok

South of the village of Karasjok (mean temperature – 2.6°C and annual precipitation ca. 300 mm, Fig 1) about 300 m a.s.l. in a dry and rather cool area, chalcopyrite and pyrite occur disseminated in a nearly flat-lying muscovite- and amphibole-bearing gneiss. Above the gneiss there is a concordant black schist rich in carbon and pyrrhotite. Both the gneiss and the schist are weathered down to approximately 0.5 m (B. Røsholt, geologist, A/S Sydvaranger, personal communication) The superficial deposits generally consist of a few metres thickness of morainic material, mostly of a fine-sand character; in the mineralized area, however, a thickness of 0.5–1 m is common. Among tree species birch *(Betula pubescens)* predominates with some pine *(Pinus silvestris),* and in the ground-cover vegetation *Vaccinium myrtillus* and *V. vitis-idaea* are abundant. Patterns of natural poisoning were observed in the field and these could be verified by chemical analyses of soil and vegetation samples (Figs. 8 and 9, Table 9). The poisoned areas may be recognized: (1) as open areas in the otherwise dense birch forest; these vary in size and form from small patches to areas several thousands of square metres in extent, often with long axes normal to the map contours; (2) through the ground-cover vegetation, where *Juncus trifidus, Festuca ovina, Deschampsia flexuosa* and *Viscaria alpina* predominate instead of the normal vegetation rich in various herb species, and *Vaccinium myrtillus* and *V. vitis-*

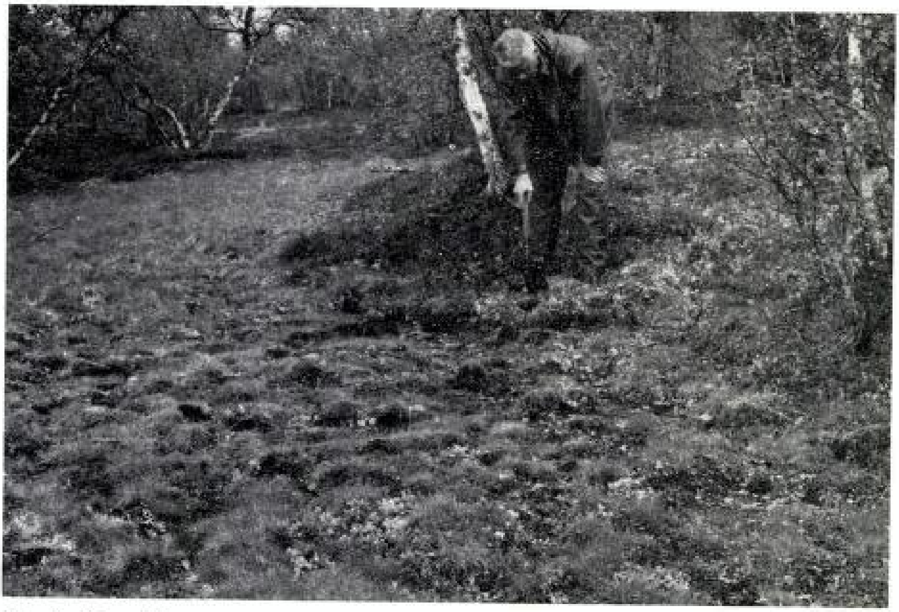

Fig. 9. Naturally copper-poisoned area in birch forest, Karasjok. Normal ground cover vegetation of *Vaccinium spp.* Vegetation of *Juncus trifidus, Festuca ovina* and *Deschampsia flexuosa* in copper affected area (open space)

idaea; (3) as barren areas up to several tens of square metres in extent at places where the water issues at the surface.

According to the results shown in Table 9 the contents of Cd, Ni, Pb and Zn lie within a more or less normal range for soils. The copper contents, however, are abnormal, being about 7000 ppm and 3000 ppm at depths of 2–5 cm and 20–25 cm, respectively. The corresponding ash percentages are 85% and 97%, indicating a comparatively low humus content, and consequently a limited ability to bind copper since the metal to a large degree is presumably

Table 9. Ash, heavy metals and pH in dry matter (105° C) of soil; ash and heavy metals in dry matter vegetation from poisoned areas at a copper occurrence in Karasjok

	N	Ash %	Cd ppm	Cu ppm	Ni ppm	Pb ppm	Zn ppm	pH
Soil samples, depth 2–5 cm	9	85.1	0.6	7,400	32	18	36	5.0
Soil samples, depth 20–25 cm	5	96.6	0.9	3,000	38	20	58	5.1
Betula pubescens, leaves	4	1.9	trace	7	6	4	102	
Betula, first year twig	4	1.2	trace	5	1	2	116	
Betula, second year twig	4	1.5	trace	12	4	3	178	
Deschampsia flexuosa	2	5.8	0.2	271	7	3	42	
Festuca ovina	3	3.9	trace	334	5	4	97	
Juncus trifidus	1	3.5	0.5	69	9	3	112	
Viscaria alpina	1	5.7	0.3	895	10	3	63	

Figures indicate arithmetic means of N samples.

Fig. 10. Naturally poisoned area at Tverrfjellet, Hjerkinn. Light patches in the front are stones and boulders in barren soil. In the background *Betula nana, Eriophorum vaginatum, Juncus trifidus,* and *Viscaria alpina* are frequent species of the vegetation.

bound in the organic part of the soil. Copper might therefore become accessible and toxic to plants even at moderate concentrations.

In the vegetation *Deschampsia flexuosa, Festuca ovina* and particularly *Viscaria alpina* have high copper contents. *Viscaria alpina,* often called the 'copper flower' in Scandinavia, has for a long time been known for its copper tolerance (Vogt 1939, 1942a, 1942b).

Tverrfjellet, Hjerkinn

The Tverrfjellet pyrite deposit is situated ca. 3 km west of Hjerkinn station (Fig. 1). The deposit was discovered towards the end of the 1950's and is now being mined, but the mining operations and technical installations have not disturbed the suboutcrop of the ore and the adjacent areas to any appreciable degree. The mineralization consists of massive pyrite with chalcopyrite and sphalerite in Lower Palaeozoic greenstones (Waltham 1968). The deposit is located at 1000 m a.s.l. in an area with about 300 mm annual precipitation and a mean temperature of 0°C.

The vegetation is sparse, consisting mainly of dwarf birch and juniper, *Vaccinium spp.* and mosses with a modest mixture of herbaceous plants. Morainic deposits and glaciofluvial material, often a few metres thick, constitute the overburden. In spite of the low mean temperature the ore, which is

Table 10. Ash, heavy metals and pH in dry matter of soil; ash and heavy metals in dry matter of vegetation samples from poisoned area at Tverrfjellet pyrite deposit Hjerkin

	N	Ash %	Cd ppm	Cu ppm	Ni ppm	Pb ppm	Zn ppm	pH
Soil samples, depth 2–5 cm	9	50.5	1.3	785	18	57	232	3.8
Betula nana, leaves	1	2.8	0.3	51	2	9	336	
Betula nana, stem	1	1.5	trace	46	1	9	456	
Deschampsia flexuosa	3	4.2	0.2	9	3	3	50	
Empetrum hermaphroditum	1	8.5	2.4	76	3	23	36	
Eriophorum vaginatum, dead plants	1	49.2	7.8	4,600	30	107	1,500	
Juncus trifidus	2	3.4	trace	25	2	8	187	
Paludella squarrosa with salt precipitations	1	17.4	3.5	2,700	10	30	520	

Figures indicate arithmetic means of N samples.

completely covered, has suffered an intense chemical weathering represented on the surface by clear subsidence phenomena and extensive precipitation of secondary iron oxides downstream from the suboutcrop of the ore. Where the rust-coloured deposits are particularly prominent vegetation is often completely absent, the surface then appearing as extensive red-brown barren areas. At the edges of such areas, the borders of which are often sharp (Fig. 10), *Eriophorum vaginatum, Juncus trifidus* and *Viscaria alpina* are frequent. These plant species have earlier been observed by Vogt and coworkers at mine dumps in the similarly mineralized Røros area, (Vogt 1939, 1942a, 1942b; Vogt & Braadlie 1942). Vogt and coworkers have also analysed samples of vegetation from this area (Vogt & Bugge 1943, Vogt, Braadlie & Bergh 1943). As a whole, Tverrfjellet appears to be a clear example of natural poisoning caused by the weathering products of the pyrite mineralization. High contents of copper, zinc and lead and sometimes also low pH have been demonstrated from stream sediments, soil and water in this area (Bølviken 1967, Mehrtens & Tooms 1973, Mehrtens et al. 1973).

Some of our analytical results from soil and vegetation are presented in Table 10. It is uncertain which of the elements are most effective in producing the poisoning. Under these rather difficult climatic conditions a combination of high contents of heavy metals and low pH values is probably the main cause. The low pH may also facilitate the solution of elements such as Al to toxic concentrations in the soil.

At high altitudes and in the far north in Norway the climate is decidedly unfavourable for plant growth. The vegetation in the investigated areas Nord-Aurdal, Stabbursdalen, Karasjok and Hjerkinn, would therefore be generally more vulnerable to metal poisoning than vegetation growing under more favourable climatic conditions.

Table 11. Lead content in organs of 4 rabbits (1–4), fed 4 weeks with hay of *Deschampsia flexuosa* with naturally high lead content (70 ppm Pb). Control group from same litter (5–8) received normal feeds (1–2 ppm Pb). Age at slaughter: 12 weeks

	Diet high in lead				Diet low in lead			
Rabbit No	1	2	3	4	5	6	7	8
Thigh-muscle	1	1	2	2	1	1	1	1
Thigh-bone	72	81	43	73	24	32	27	27
Liver	7	14	5	9	1	2	2	1
Kidney	12	10	9	16	2	2	2	1
Faeces	70	99	34	101	2	2	2	48
Urine	<1	<1	<1	<1	<1	<1	<1	<1

Figures indicate ppm lead in dry material (105° C) of organs.

Feeding experiments

Some of Norway's most common pasture grass species, *Agrostis, Deschampsia* and *Festuca,* are especially resistant to strong heavy-metal influence. It is not unlikely that lead which occurs naturally in lead-bearing grass may be fairly soluble and detrimental to herbivores, even to a greater extent than some of the artificially supplied lead which may occur principally as relatively stable compounds. In order to obtain some idea as to whether or not naturally high lead contents in vegetation can be taken up by animals, we have carried out tentative feeding experiments. Four rabbits were fed on a diet consisting of hay of *Deschampsia flexuosa* from naturally lead-rich patches in Nøssmarka, Snertingdal, and a control group of four rabbits from the same litter were simultaneously fed on a normal, lead-deficient diet. The rabbits' age at the start of the experiment was 8 weeks, and the duration of the experiment 4 weeks. After slaughter, the rabbits were dissected and a few different organs were analysed; Table 11 shows some of the results.

The lead-rich diet has produced higher lead contents in thigh bones, liver and kidneys, with lead-affected/normal ratios of 2.4, 5.8 and 6.7 respectively. For the thigh muscles the results are less conclusive, although a tendency in the same direction is indicated. The lead content of the faeces was, in most cases, about the same as that in the fodder; in urine the content of lead was below the detection limit of the analytical method. The results show that rabbits have the ability to allow some of the naturally supplied lead to pass undigested; with a continual supply of lead-rich fodder, however, ingested lead may be taken up by the organism at an increased rate producing concentrations higher than normal already after 4 weeks.

The experiments provide no definite data as to what will happen over the long-term with less drastic lead concentrations, but indicate nevertheless that the lead-metabolism of herbivores can be directly influenced by the habitat. It may, therefore, also be assumed that the lead-metabolism of human beings may to some degree be influenced by the local, natural, geochemical environment, and that this could have consequences for the state of health of population groups. Although our understanding of relationships between geochemical environment and health and disease is incomplete there does, however, appear to be a rapidly increasing interest in these important geomedical problems (see for example Bersin 1963, Cannon & Hopps 1971, 1972, Hemphill 1968, 1969, 1970, 1971, 1972, Hepple 1972, Låg 1972, Schormüller 1965–1970, Underwood 1971, Usik 1969, and Zaijk 1969).

Conclusions

Research on different aspects of natural heavy metal poisoning and other related phenomena may contribute to a better understanding of basic geochemical processes in the environment to the eventual benefit of subjects such as prospecting, geomedicine, and pollution. The investigations reported here will therefore be continued. The conclusions of the present work are somewhat preliminary and tentative but the main aspects may be summarized as follows:

1. Through the effect of natural processes lead and other heavy metals can be extracted from crystalline mineralizations in bedrock and overburden and thereafter transported over considerable distances.
2. When natural heavy-metal solutions during their transportation meet variations in the geochemical environment, e.g. pass through material with a relatively high content of humus, the heavy metals can be precipitated and thereby enriched to concentrations far greater than those at the place where they originated.
3. By these processes heavy metals derived from bedrock occurrences may be enriched in the soil downslope from the source to concentrations toxic to vegetation within relatively short geological periods, the degree of poisoning depending on many factors such as: the rate of neutralization of sulphuric acid produced during the oxidation of sulphides at the source; the amount and composition of humus in the soil; the thickness and composition of other parts of the overburden; the topography; the depth of the groundwater table; distance from the bedrock source; and climate and climatic variations during the time of transport.
4. Small areas with heavy-metal poisoning of soil and vegetation appear to be a rather common feature in Norway in connection with sulphide mineralizations in the bedrock. As the symptoms – atypical plant communities, stunted growth and barren areas – are often easily recognizable and the affected areas often of considerable size, searching for signs of natural poisoning may prove to be an effective prospecting method.
5. The typical vegetation indication of heavy-metal poisoning of the soil is not necessarily the occurrence of rare species. On the contrary, the most common grasses such as *Agrostis, Deschampsia* and *Festuca spp.* as well

as other widespread plants, e.g. *Dryopteris spp. Eriophorum vaginatum* and *Juncus trifidus* seem to be important indicators. Consequently, rather than looking for rare indicator species, the registration of special and unusual vegetation types should be an effective geobotanical tool for discovering anomalous metal contents in the soil. Stands of *Deschampsia flexuosa* without *Sphagnum spp.* growing in moist depressions in forest are a typical example of such a vegetation type characteristic of lead-rich soils.

6. A high metal content in the soil produces a high metal content in the vegetation growing upon it. Furthermore, a high metal content in feeds may result in high metal contents in the organs of herbivores. Since some of the most common grass species of normal pasture are amongst those showing pronounced heavy-metal tolerance, it seems quite possible that natural high contents of these elements in the habitat can cause high heavy-metal concentrations in the local herbivores, and perhaps also in the local carnivores and human beings. Some heavy metals are thought to be harmful to human beings even in very small amounts. It is consequently reasonable to consider the possibility that the heavy-metal status of the geochemical environment may in some cases affect the health and physical condition of human population groups.

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