Sub-till sediments at Rokoberget, southeastern Norway

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A dark, blue-grey, silty clay below till is described from a locality 230 m a.s.l. in the Rokosjøen depression east of Mjøsa. The sediment is glacially deformed but interpreted to represent a deposit from a period with a local lake-level at least 240-250 m above present sea-level. The depositional environments are complex and believed partly to have been a shallow fjord embayment, but glaciolacustrine conditions may also have been involved. The pollen flora of the sediment is reflecting a grass-dominated, treeless, interstadial vegetation. Two ^{14}C-AMS dates at c. 34 and c. 47 ka suggest a Middle Weichselian age for the sediments in the described *Rokoberget interstadial*. Similar glaciolacustrine/lacustrine/marine deposits may have been widespread in several periods, playing an important role as parent material for parts of the 'old blue tills' and overconsolidated sub-till sediments in the Mjøsa region. Possible correlations with other known interstadial deposits in southeastern Norway are discussed, but only fragments of the Weichselian development are known at the present time.

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Introduction

Since the description of the complex Gudbrandsdalen interstadial (Bergersen & Garnes 1971), some ten occurrences of interstadial sediments have been reported from the southern part of Central Norway. Three of these are situated in the Mjøsa region (Fig. 1): near Brumunddal (Helle et al. 1981), in Åstdalen (Haldorsen & Rappol 1990), and in the Lillehammer area (Olsen, unpublished).

During the summer 1990, a new locality with sub-till sediments was discovered and sampled in an extended slope excavation along a forest road at Rokoberget east of Mjøsa (Figs. 1 & 2). Preliminary investigations showed the presence of both pollen and macroscopic plant remains (J.O. Vigran pers. comm. 1990). In 1991 the section was therefore examined more closely, and both a partly diamictic sand and a lodgement till were recognised in the upper parts of the section. The sediment below the diamictons is a dark, blue-grey, silty clay affected by glaciotectonic deformation (Fig. 3).

The purpose of the present paper is to describe the sub-till sediments from Rokoberget, and thereby to contribute with another puzzle to the complex picture of Weichselian interstadials in Norway. It is our hope to throw some new light on the origin of the matrix of some of the 'blue tills' in the region. Possible correlations with similar sequences in surrounding areas will also be discussed.

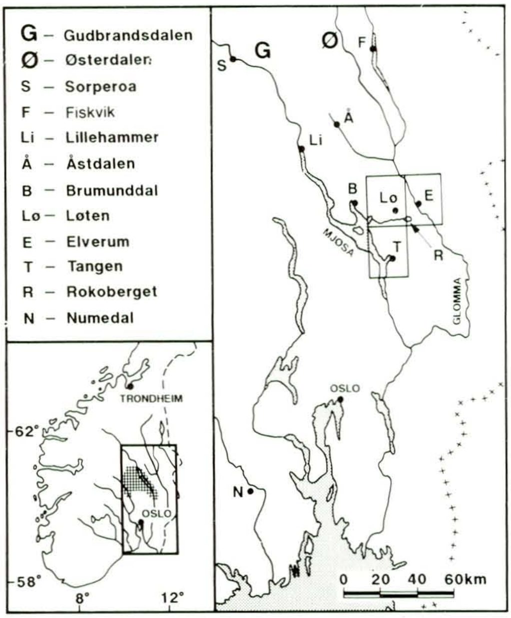

Fig. 1. Location map, southeastern Norway. Quaternary geological maps in scale 1:50,000 for the map-sheets Løten, Elverum and Tangen (Follestad 1973, 1974, Bargel 1983) are shown. The shaded area on the inset map indicates areas with fine-grained, blue-grey, lodgement till (after Olsen 1985a).

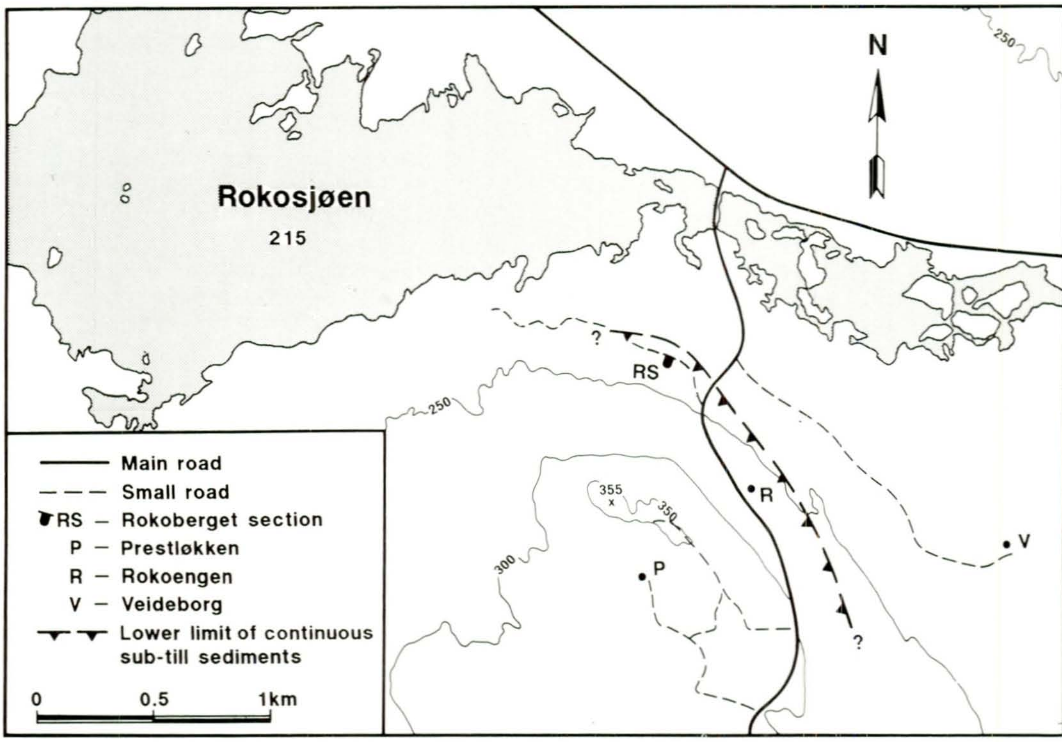

Fig. 2. Topography of the Rokoberget area and location, south of the forest road, of the described section (RS) at the northern end of a small ridge thought to be a drumlin. The dashed line indicates the extent of the sub-till sediments towards the north and east.

Physiography and geology

Topography and bedrock

The lake Rokosjøen (Figs. 1 & 2) forms the central part of a c. 30 km transverse depression between the two main N - S trending valley systems in southeastern Norway; the lake Mjøsa and Gudbrandsdalen in the west and Østerdalen with the river Glomma in the east.

The present water-level in Rokosjøen is c. 215 m, in Mjøsa c. 125 m and in the Glomma east of Rokosjøen c. 160 m (all values above present sea-level; a.s.l.). South of Rokosjøen, the hill Rokoberget has its highest point at 355 m a.s.l. (Fig. 2).

The local bedrock around Rokosjøen is dominated by Precambrian granites and gneisses. Rokoberget is underlain by one of several gabbro bodies forming low smooth hills. All these rock types are about 1,600 Ma. To the north and west the basement platform is overlain by younger sandstones and shales of Vendian and Cambro-Silurian age (Gvein et al. 1973).

Quaternary geology

The superficial Quaternary deposits east of Mjøsa in the vicinity of Rokosjøen (Fig. 1) have been mapped by NGU (Follestad 1973, 1974, Bargel 1980, 1983), and are of Late Weichselian and Holocene age.

In the valleys of the Glomma and other rivers there are glaciofluvial, fluvial and some aeolian deposits, while till is the dominant superficial sediment outside the river valleys. The gravel fraction (4 - 8 mm) in the till south of Rokosjøen is totally dominated by Precambrian rocks and quartzite/sandstone (Follestad 1973, Bargel 1983).

The investigated area south of Rokosjøen (Fig. 2) has a continuous till cover, partly of great thickness. In a road-cut, a till with a thickness of more than 2 m was described by Bargel (1980), before a new and deeper section was excavated in 1990.

The oldest recorded regional ice movement in the area (of supposed Weichselian age) is towards the south. The younger ice movements recorded during NGU's mapping have a slightly more southeasterly component (Follestad 1973, Bargel 1983).

Locality description

The investigated Rokoberget section lies south of Rokosjøen (Figs. 1 & 2) about 230 m a.s.l. It encompasses a cross-section through a small ridge which is elongated N-S or slightly towards NNW-SSE (Fig. 2). The ridge is interpreted as a possible drumlin made by erosion of the substrate during an ice movement towards the south.

Examination of exposures of granite in the area not far from the Rokoberget locality in 1991 revealed that the oldest ice movement recorded in the area is represented by crude grooves with a direction towards southeast or east-southeast. The subsequent ice movement left coarse striations directed towards the south. The younger, less pronounced, ice movement structures observed near the locality have a mainly southeasterly component, while the last ice movement in the Rokosjøen area was directed towards east-southeast. Striations from this phase are found as weak and thin striae on the topmost parts of bedrock exposures.

The ice movement that formed the suggested drumlin may therefore be that which produced the old coarse striation towards the south; alternatively it may correlate with a younger regional southerly ice movement that is not so well documented in this particular area.

The Rokoberget section is about 75 m long, up to 4 - 5 m high and can be divided into three main lithostratigraphical units (Fig. 3):

a) Glaciotectonised sub-till sediments.
  - Blue-grey silty clay.
  - Silt and sand.

b) Sand and gravelly sand.

c) Till.

The blue-grey silty clay is exposed at the base of the excavation. It is compact and the exposed part of the sediment has been strongly disturbed by glaciotectonics with structures (mainly folding) showing an ice movement from north-northwest to south-southeast. The clay is overlain by silt and sand that are also disturbed by glaciotectonic structures (Fig. 3).

In the western part of the section the sub-till sediments are overlain by a brownish dia-

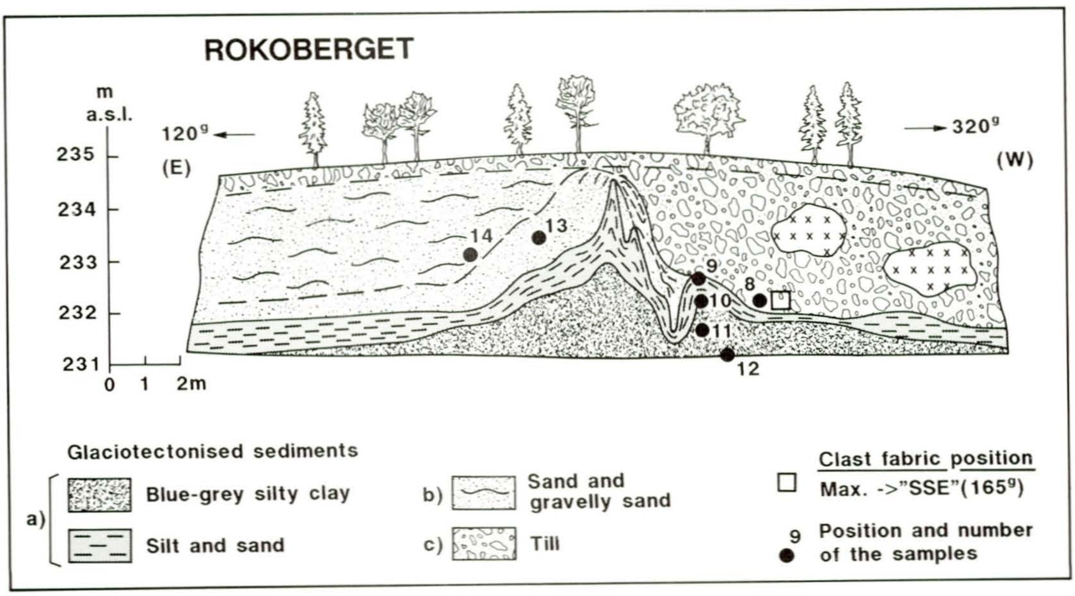

Fig. 3. The Rokoberget section, looking towards the south. The positions of the sample sites are indicated. The ¹⁴C-AMS dates are from samples nos. 9 and 12.

micton interpreted to represent a lodgement till (Fig. 3). The till contains local granite boulders up to more than 1 m^3 in size. A clast fabric analysis in the lower part of the till revealed a preferred orientation indicating an ice movement towards the south-southeast. This is in agreement with measurements of the axes of ten glaciotectonic folds in the underlying deformed sediments.

The eastern part of the section has a thin till cover (ablation till ?) but is dominated by sand and gravelly sand (Fig. 3). The sand has a somewhat deformed appearance, which may have been caused by either glaciotectonic deformation or deep frost action (permafrost), or by a combination of both processes.

The boundary between the units varies from distinct and sharp to indistinct and mixed. The chaotic deformation structures in the upper-middle part of the section (Fig. 3) make it difficult to decide on the relative age between the sand in the eastern, and the till in the western part of the section. The sand may grade laterally into a grey to brown-grey till with sand, gravel and some large boulders outside the section. Our present favoured interpretation, however, is that the sand is older than the till and thus constitutes the youngest part of the sub-till sediments. To test this hypothesis, more extensive field-work, including digging, is required.

In this work we have not given the units any formal or informal names, except for the lower unit which we have called the *Rokoberget interstadial sediments.*

Laboratory investigations

As the till in the section resembles the common, well-known, Quaternary deposits in the region (Follestad 1973, Bargel 1983), only the sub-till sediments have been subject to closer laboratory investigation in the present work and are described in more detail below. A search was also made for foraminifera (J.G. Verdenius pers. comm. 1990) and diatoms (B. Stabell pers. comm. 1992) in the clay but none was found.

Grain-size distribution

The grain-size distribution has been determined on selected samples from the Rokoberget section (Fig. 4). As a comparison, the grain-size distribution of the matrix-rich Jørstad Till from the Lillehammer area is also shown in this figure.

In Fig. 5, grain-size parameters are compared with Norwegian Quaternary sediments of known origin (after Selmer-Olsen 1954). The Jørstad Till samples group within the till field, whereas the Rokoberget samples indicate a complex depositional history. The silty clay from the Rokoberget interstadial sediments (sample 12) falls within the field for lacustrine sediments while the sand above (sample 13) may have several possible origins. The gravelly sand (sample 14) is clearly bimodal and the most probable explanation for the gravel content would seem to be ice rafting.

Mineralogy

Bulk samples of the silty clay from Rokoberget have been analysed by X-ray diffraction and differential thermal methods. Semi-quantitative evaluation indicates the following mineralogical composition: 40-50% quartz, 20-30% feldspar, 15-20% mica/illite, 10-15% chlorite and about 5% pyrite. This is a composition which resembles that of the Late Weichselian clays from the Østlandet area (Låg 1948, Selmer-Olsen 1977).

Geotechnical properties

In the section, the clay was very hard and probably partly dehydrated, a feature which adds to the uncertainty of some of the analyses.

The plastic properties gave the following values: Liquid limit, w_L = 29%; plastic limit, w_P = 23%, and plasticity index, $I_P = w_L - w_P$ = 6%.

The sediment was very sensitive to small changes in water content. The natural water content was measured to 13-14%. Although this may be too low due to drying, it is believed to be below the plastic limit.

The geotechnical properties of the clay indicate a sediment with a clay fraction of low activity (as confirmed by the mineralogical analysis) and with some organic material. Treatment with H_2O_2 gave no weight loss, while the loss-on-ignition at 1000°C was about 5% and at 550°C 2-3% in samples from the lowermost part of the sediments (sample no. 12 in Fig. 3).

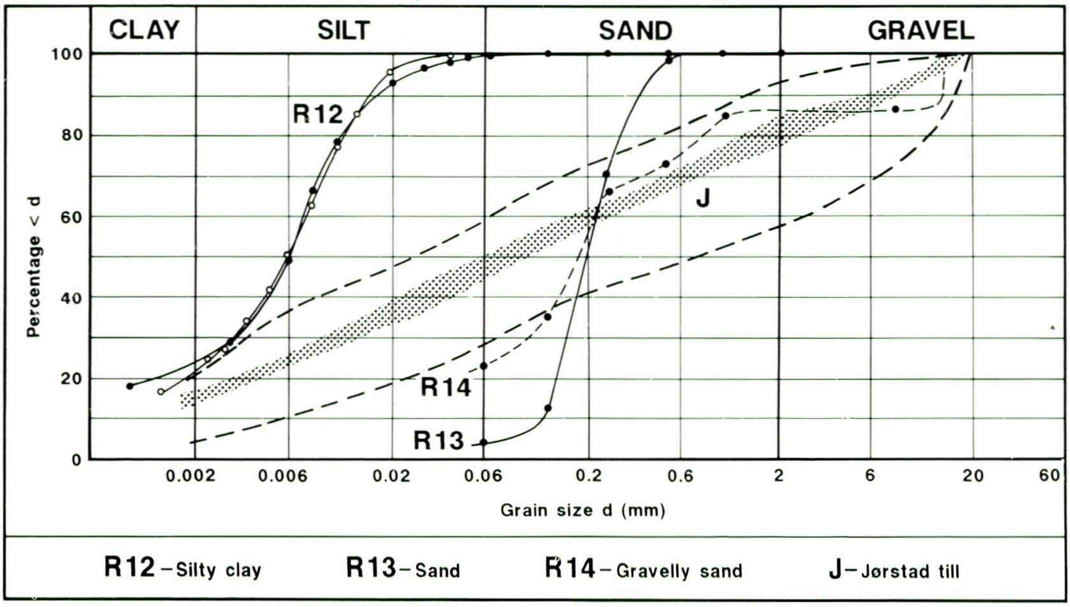

Fig. 4. Grain-size distribution for selected samples from the Rokoberget section. For location of samples, see Fig. 3. The other curves show grain-size distribution for 33 samples of the fine-grained basal Jørstad Till from the Lillehammer area. About 50% of the curves are situated in the shaded area (after Olsen 1985a).

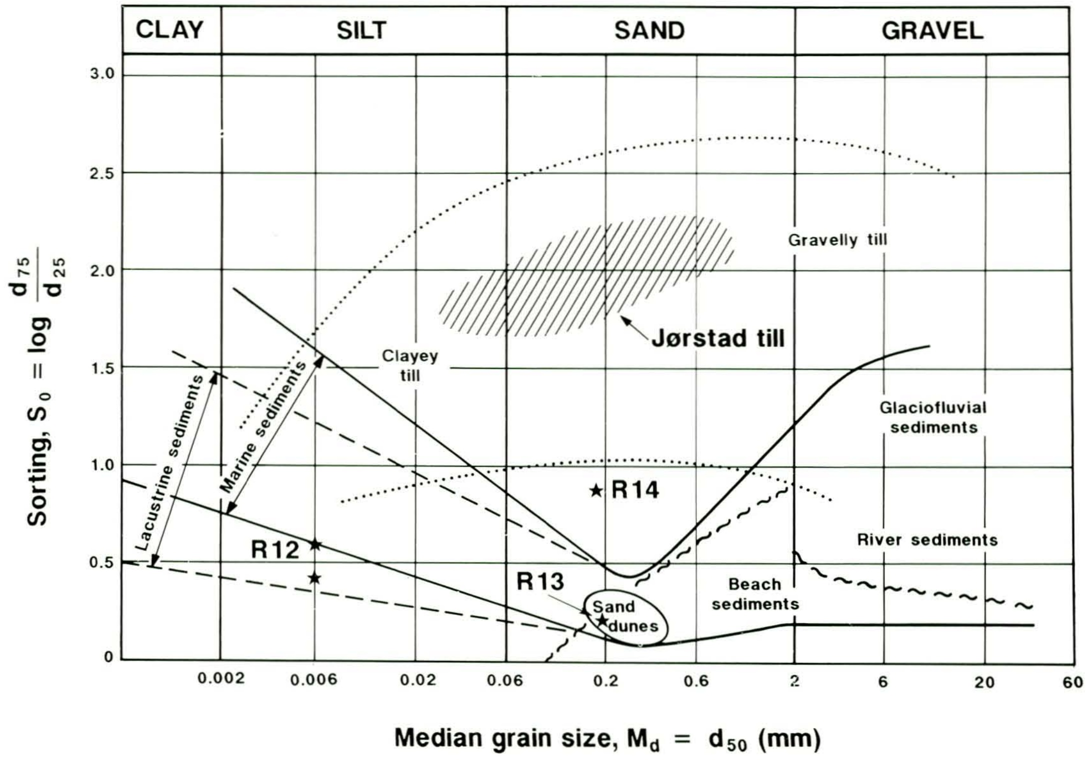

Fig. 5. Grain-size data from samples in the Rokoberget section and the fine-grained basal Jørstad Till in the Lillehammer area, compared with sediments of known origin (after Selmer-Olsen 1954).

Pollen

Pollen analysis was carried out on five different samples (Table 1), four (9 - 12) from various depths in the sub-till sediments and one (8) from the bottom part of the lodgement till overlying the waterlain sediments (Fig. 3). The samples were treated with HF and acetolysis as described in Fægri & Iversen (1989). *Lycopodium* tablets were added to allow absolute pollen analysis (Stockmarr 1972).

The pollen concentration was high ($9x10^3$ - $2x10^4$ pollen grains/cm^3) in the waterlain sediments, but clearly lower ($5x10^2$ pollen grains/cm^3) in the overlying till. Due to relatively poor preservation, the frequency of unidentified pollen grains is high in all samples. Although only a small number of pollen grains were analysed ($\Sigma P=106$ at most), the results are interesting enough to warrant some comments. A difference in composition of the pollen flora can be observed from the till sample (8) to the waterlain sediments (9 - 12), but the sparse nature of the pollen in the till sample does not allow an ecological interpretation. The composition of the pollen flora is very similar in the samples from the waterlain sediments (9 - 12). Herb pollen predominates, with grasses (Poaceae) and sedges (Cyperaceae) being the most frequently occurring pollen types, and wormwood *(Artemisia)* present in the four samples (Table 1).

The predominance of herb pollen types is so clear that the pollen flora is interpreted as reflecting a grass-dominated, treeless vegetation. The composition of the herb pollen flora may indicate an arctic-alpine, tundra-like vegetation, but the possible existence of seashore conditions must also be considered.

Macroscopic plant remains

The contents of macroscopic plant remains were examined in samples taken from three different depths within the silty clay, and from the bottom part of the overlying till. The samples, each c. 50 cm^3 in volume, correspond to four of the pollen samples indicated in Fig. 3 (8-11). The material was washed with water and sieved through metal sieves with mesh widths from 2 mm to 0.125 mm, and examined in a low-power microscope.

Small amounts of unidentified plant remains up to 4 mm in length were present, and in one sample from the silty clay there were fragments of at least five, different, but not identified, moss species.

Table 1. Pollen data.

Rokoberget interstadial sediments																							
			AP						NAP									TOTAL			SPORES		
SAMPLE NO.	Σ Pollen	Pollen concentration (grains/cm³)	Alnus	Betula	Corylus	Pinus	Juniperus	Salix	Poaceae	Cyperaceae	Artemisia	Asteraceae	Caryophyllaceae	Polygnum bistorta type	Ranunculaceae	Thalictrum	Unidentified	% AP	% NAP	% Unidentified	Pteridophyta	Sphagnum	Pediastrum
8	14	$5\cdot10^2$	6		1	1									1		5	57	7	36	2		X
9	87	$9\cdot10^3$		1	3			1	9	2	2						69	6	15	79	1		
10	106	$2\cdot10^4$	1	4	3			1	43	18	1	1			1		33	8.5	60	31.5	5	1	
11	83	$2\cdot10^4$		1	3		5	1	14	6	4			1			48	12	30	58	1		
12	70	$1\cdot10^4$		7	2				31	12	1	1	1			1	14	13	67	20	4	4	

Analyst - S.F. Selvik, 1992

Dating with ^{14}C-AMS

Two organic-bearing silty clay samples from the interstadial sediments at Rokoberget have been radiocarbon - AMS dated in Utrecht, the Netherlands, with the following results:

No.	$\delta^{13}C$‰	Age in ^{14}C-years B.P.
UtC 1963	-29.6	33,800 +800/-700
UtC 1962	-30.4	47,000 +4000/-3000

The first sample (UtC 1963) is from the uppermost part of the sub-till sediments (sample 9 in Fig. 3), and the second from the lowermost part of the sediments more than 1 metre below the first (sample 12). The $\delta^{13}C$-values, at c. -30 ‰, are suggestive of a terrestrial origin, and indicate that any possible contamination of older or younger carbon with biased isotopic fractionation should be fairly low. From the fieldwork carried out on the existing section it is not possible to say for sure if there are any unconformities in the sediments between the sites of the dated samples.

Discussion

Extent and genesis of the sub-till sediments

Blue-grey sub-till sediments or blue-grey till are present below the sandy cover-till (generally ablation till) in several localities at Rokoberget. 'Blue clay' was observed by the first author during well excavation in 1950. Earlier, such clay had also been encountered during excavation for a farm building, where digging proved to be very difficult. The highest of these localities at Rokoengen (Fig. 2) lies at about 275 m a.s.l.

Other similar localities have also been recorded (Fig. 2). Blue-grey sub-till sediments with the local name 'blåkvabb' is reported from a small river near Veideborg. According to local tradition, 'blåkvabb' was also excavated at Prestløkken and used as construction material for the old church on the top of Rokoberget. The relative ages of the sediments from the different sites are unknown at the present time.

The blue-grey clay, or a till with a similar matrix, may thus be present below the younger till over an area of at least 1 km^2 at Rokoberget. The lower boundary, towards the north and northeast, is partly marked as a fairly steep slope (Fig. 2). The change in sediment thickness is striking, from a thick cover in the higher areas to sparse and very coarse-grained sediments in the lower areas around the lake Rokosjøen. This is also reflected in the vegetation which shows a change from a mixed spruce and deciduous forest in the higher areas to pine forest in the lower areas.

The sediment distribution may be explained by a stoss-side accumulation or stacking effect due to the south-southeastward moving ice which subsequently reworked or deformed, compacted and thereby preserved the older sediments on the upper southern side of the Rokosjøen depression. Later ice movements towards the east-southeast and meltwater erosion and transport may have removed the old fine-grained sediments in the lower part of the E-W trending Rokosjøen depression.

The distribution of the blue-grey deposits towards the south and west is more difficult to evaluate, but they may be present below ablation till in areas with a thick sediment cover.

The situation at Rokoberget shows a strong resemblance to the Lillehammer area which has been investigated in more detail (Olsen 1985a, b), and where clay-rich blue-grey till (the Jørstad Till) is found to dominate below a depth of about 2 m over most of the area. It seems evident that the matrix in this blue-grey till must have its origin in deposits resembling the Rokoberget sub-till sediments.

Our interpretation is that the silty clay in the Rokoberget section was deposited in a Middle Weichselian interstadial period where the local water-level in the Rokosjøen basin was raised by at least 25 m compared with the present lake-level (Fig. 2). One possible depositional environment could therefore be that of a lake dammed between ice-lobes in the Mjøsa basin in the west and the Glomma valley in the east (Fig. 1).

If the rise in water-level occurred without ice-damming and with no connection to the sea, then the thresholds both in the west and in the east would have had to have been much higher than today. The lowland both to the west and to the east of Rokosjøen implies, in this case, that a post-Rokoberget interstadial erosion to a depth of at least 15-20 m below the ground surface must have occured over a wide area.

Although some east- or west-directed meltwater erosion is a probable explanation for the rather abrupt lower limit of the thick sediment cover along the southern side of the Rokosjøen basin area (Fig. 2), we find it more likely that the thresholds were not much higher during the Rokoberget interstadial period than today. Therefore, we suggest that the silty clay sediments in the lower part of the Rokoberget section were deposited in a shallow fjord embayment, even though a marine origin is still to be proven.

The silt, sand and gravelly sand in the Rokoberget section (Fig. 3) could be of glaciofluvial origin, deposited in a fjord or lake environment. Aeolian transport should, however, also be considered for the sand and silt fraction, while the gravel component could have been ice rafted.

Regional correlations and age

Following the 1980 conference on the Weichselian in the Nordic countries before 15,000 years B.P., Mangerud (1981a) stated that the two most striking points were, firstly, the large number of Early and Middle Weichselian sites that had been discovered and studied in detail during the last decades; and, secondly, the problems associated with dating and correlating these sequences with each other or with sequences outside Norden. During the decade after the conference, several more sites were discovered (Mangerud 1991), especially in North Sweden and North Norway (Lagerbäck & Robertsson 1988, Olsen 1988, 1989a,b) and several attempts at dating have been carried out. The problems with dating and correlations are, however, still present.

The dates obtained from the Rokoberget interstadial sediments clearly exclude the possibility of a Late Weichselian age. If the sediments described in this paper are from an uninterrupted ice-free period, then they would, within plus/minus one standard deviation of the dating results, represent a Middle Weichselian interstadial lasting for at least 10-15,000 years in the Rokoberget area.

The correlations between the sub-till sediments of the Rokoberget section and the sediments in the coastal areas (Andersen et al. 1981, Mangerud 1981b, Sejrup 1987) and in areas outside Norway (Lundqvist 1981, Lagerbäck & Robertsson 1988, Hirvas 1991) are very uncertain at present and will not be discussed here. We will also exclude from the discussion the stratigraphic information from e.g. Hardangervidda (Vorren & Roaldset 1977), Setesdalen (Blystad 1981), Trøndelag (Bergstrøm unpubl., Olsen unpubl.), Nordland (Lauritzen 1991, Olsen unpubl.) and Finnmark (Olsen 1988, 1989a,b), and concentrate on the more nearby localities east and south of the present watershed (Fig. 1).

The strongest lithological resemblance to the clay at Rokoberget is perhaps shown by the overconsolidated clays at about 260 m a.s.l. in Numedal described by Roaldset (1973, 1980). There too, clay sediments were found below a younger till. Despite a close examination of the sediments no fossils were found. Roaldset (1980), however, favoured a marine origin for the clays based on physical parameters.

East of the lake Mjøsa, some 30 km northwest of Rokosjøen and at ca. 395 m a.s.l., Helle et al. (1981) reported a sub-till interstadial deposit (the Brumunddalen interstadial beds) with a peat horizon that was submerged during deposition of an overlying, more than 2m-thick, silt sequence. The sub-till sediments have a full interstadial, cold-warm-cold, pollen signature. It is possible that the upper silt sequence in the interstadial sediments at Brumunddalen was deposited in a small ice-dammed lake. If the Rokoberget interstadial sediments observed so far represent only the upper and last part of an interstadial period, then they may correlate with the Brumunddal interstadial. Otherwise, such a correlation is not likely because the optimal conditions during the Brumunddal interstadial, as indicated by the pollen content, imply a warm Early Weichselian interstadial climate (Helle et al. 1981), much warmer than that indicated by the preliminary results from Rokoberget.

In Åstdalen, some 45 - 50 km northwest of Rokosjøen (Fig. 1), Haldorsen & Rappol (1990) reported a stratigraphy comprising interstadial silty clay overlain by tills and waterlain sediments. The area is situated at more than 700 m a.s.l. The ice movement phases represented above the interstadial sediments in Åstdalen show a one-to-one correlation with the three youngest ice movement phases found in the Lillehammer area (Olsen 1985b). All these phases are younger than the regionally distributed, fine-grained, blue-grey till (the Jørstad Till). This implies that also the interstadial sediments in Åstdalen may be younger than this till. If not, then the situation may have been that the glacier that deposited the blue-grey Jørstad Till did not completely cover the Åstdalen area or, alternatively, that the area may have been situated relatively unaffected between ice-lobes or perhaps between ice-streams within this glacier. Haldorsen & Rappol (1990) suggested that the interstadial sediments in Åstdalen may have been deposited in an ice-dammed lake, probably during a period of deglaciation. This phase may correlate with the newly recorded ice-free period between the Jørstad Till event and the previous stadial represented by the underlying, coarse-grained, blue-grey Mesna till (Olsen 1985b and unpubl.). The sub-till sediments in the Lillehammer area are ^{14}C-AMS dated to 31.5, 32 and 36 ka, which give the Jørstad Till a late Middle to early Late Weichselian age, as suggested by Olsen (1985a,b). The radiocarbon dates from the interstadial sediments in the Lillehammer area suggest a possible correlation with the younger part of the Rokoberget interstadial sediments.

Radiocarbon dates from Brumunddal (Helle et al. 1981) and Åstdalen (S. Haldorsen, pers. comm. 1991) have given infinite ages (>50, >48 and >47 ka), and a preliminary U/Th dating of peat from Brumunddalen yielded c. 60 ka (S.E. Lauritzen & N. Rye, pers. comm. 1991). The U/Th date of the peat may represent the approximate age of the time when the peat became a closed system with regard to exchange of U with the surrounding groundwater. This situation does not necessarily correspond with the age of the peat; it may well be that the closing time corresponds better with the compaction phase during the subsequent glaciation. Thus, the U/Th date could well be indicating an approximate age for this ice advance and, in addition, a minimum age of the peat. Helle et al. (1981) suggested for the Brumunddalen interstadial a correlation with the regional Brørup interstadial (c. 100 ka). This, and even a correlation with the regional Odderade interstadial (c. 80 ka), will therefore possibly be in approximate concordance with the U/Th date. If this is correct, the ^{14}C-AMS dates of the Rokoberget interstadial would indicate that it is younger than the Brumunddalen interstadial.

A correlation between the Rokoberget interstadial sediments and the lower sub-till sediments in Åstdalen is also difficult. Both the interstadial sediments and the younger ice-phase history are closely comparable in these areas. The pollen signature reported from the interstadial sediments in Åstdalen (Haldorsen & Rappol 1990) also resembles that in the Rokoberget interstadial sediments. The Åstdalen locality, however, is located some 470 m higher than the Rokoberget section which makes the correlation more uncertain. The radiocarbon dates from Åstdalen also indicate that this interstadial is older than the Rokoberget interstadial.

In Gudbrandsdalen, extensive studies have been carried out on the waterlain sub-till sediments (Bergersen & Garnes 1971, 1981, Bergersen & Thoresen pers. comm. 1991). Based on some 20 TL - dates, most of them with ages of about 50 to 70 ka but ranging from 35 - 40 ka to 80 - 100 ka and even more, it seems likely that the sediments from the defined Gudbrandsdalen interstadial (Bergersen & Garnes 1971, 1981) belong to more than one ice-free period. Bones of mammoth found in the sub-till sediments have been radiocarbon dated to infinite ages (>40 ka, Bergersen & Garnes 1981); and some preliminary U/Th datings of mammoth bones from Gudbrandsdalen indicate ages of about 60-80 ka (S.E. Lauritzen pers. comm. 1991). This seems to fit well with several, but definitely not all, of the TL-ages from the sediments.

Some of the reported sub-till sediments from the Gudbrandsdalen interstadial may correlate with the Rokoberget sediments. Likely candidates are, for instance, the Fåvang and the Haugalia sub-till sandur sediments (Bergersen & Garnes 1971, 1981). Both these localities require a water-level in Mjøsa at about 220 - 240 m a.s.l., which probably would be the same for the corresponding sea-level at that time. The high sea-level may be explained by glacial isostatic depression, which in that case would have been of a magnitude comparable to but even greater than that during the last glaciation in this area, expressed by the post-glacial marine limit at c. 190 m a.s.l. in the Mjøsa basin. However, the tectonic behaviour of the Earth's crust in this area may have been different during the Gudbrandsdalen interstadial than during the last deglaciation period. It is therefore not particularly easy to estimate the size of the ice-sheet which caused such a huge depression of the crust. A forebulge effect should also be considered if the interstadial sandur sediments were deposited as proglacial sediments during an advancing ice-lobe event, as suggested by Bergersen & Garnes (1981). It seems more likely, however, that these sediments were deposited during ice retreat phases, perhaps with some more or less floating ice-bodies left as melting ice-remnants in the biggest basins in the southern Gudbrandsdalen area.

A sea-level about 220 - 240 m higher than today would have resulted in a direct marine incursion in the Rokosjøen basin area, including the Rokoberget locality (Figs. 1 & 2). If there was a marine influence connected with the Rokoberget interstadial sediments, then the required base-level for deposition of the Gudbrandsdalen interstadial sediments existed during the Rokoberget interstadial (Bergersen & Garnes 1981). This would support a correlation between these interstadials.

The younger, possibly ice-dammed, interstadial sediments at Rokoberget are most likely younger than the sandur deposits at Haugalia and Fåvang, and they may well correlate with the tills deposited during the initial, valley glacier, ice-phase A, and even the first part of ice-phase B, in the established ice-phase model for 'the last ice age' in the Gudbrandsdalen region (e.g. Garnes 1978, Olsen 1985b). The newly recorded interstadial sediments in the Lillehammer area, situated between tills representing ice-phases A and B, respectively, support this correlation. The ice movement that formed the assumed drumlin where the Rokoberget section is located, may therefore belong to the youngest part of ice-phase B, or to the ice-phase C that includes the last glacial maximum event and most of the Late Weichselian period. Both these ice-phases had south-directed ice movements in the Mjøsa region (Olsen 1985b).

The Sorperoa interstadial in Gudbrandsdalen (Fig. 1) is defined and represented by windblown sand that has been TL-dated to about 40 ka (Bergersen et al. 1991). This interstadial may correlate with the younger part of the complex Rokoberget interstadial.

Based on ^{14}C-dates of gyttja remains below the sub-till clay at Gråmobekken in Folldal, these sediments may be younger than 40 ka (Thoresen & Bergersen 1983), and their pollen signature (Selvik unpubl.) resembles that of the Rokoberget sub-till sediments. Another correlation candidate in this northeastern region is that of the sub-till sediments at Fiskvik in Rendalen (Thoresen & Selvik unpubl.). The Fiskvik locality (Fig. 1) lies about 85 km northwest from the Rokoberget section and at c. 325 m a.s.l. However, the pollen signature for parts of these sediments indicates a warm Early Weichselian interstadial climate similar to that for the Brumunddalen interstadial, and these sediments may therefore also be older than the Rokoberget interstadial. One ^{14}C-dating gave an age of about 46 ka (or more) and two TL-dates gave ages of 50 and 61 ka from these sediments (M. Thoresen, pers.comm. 1991).

Conclusions

The sub-till sediments in the described Rokoberget section are disturbed and partly reworked by ice, but still believed to represent an interstadial glaciolacustrine/lacustrine/marine sediment of regional importance. The local water-level during deposition is assumed to have been at least 240-250 m above present sea-level. This should imply a connection to the sea, but in the Rokosjøen area the marine influence would probably have been rather limited.

Two ^{14}C-AMS dates at c. 34 and c. 47 ka suggest a Middle Weichselian age for the Rokoberget sub-till sediments, and the preliminary pollen data for these sediments resemble those from sites further north in southeastern Norway, which are also considered to be of Middle Weichselian interstadial origin. The most probable correlatives of the complex Rokoberget sub-till sediments are the waterlain sub-till sediments at Fåvang and Haugalia in Gudbrandsdalen (Bergersen & Garnes 1971, 1981), at Mesna and Stampesletta in the Lillehammer area (Olsen, unpubl.), and at Gråmobekken in Folldal (Thoresen & Bergersen 1983). Another correlation candidate is the interstadial aeolian sand at Sorperoa in Gudbrandsdalen, although this sand has been convincingly argued to be younger than the Gudbrandsdalen interstadial sediments (Bergersen et al. 1991).

Correlation between all these local interstadials seems to be quite possible if the Rokoberget interstadial represents a long, 'multi-stage', Middle Weichselian, complex ice-free period, as suggested by the dates and the apparently complex depositional history.

Reconstruction of the regional distribution of such glaciolacustrine/lacustrine or marine sediments is important as the subsequent glaciations have reworked and/or overconsolidated the sediments and formed new deposits with special geotechnical and geological properties. This includes very compact silt and clay deposits and clay-rich tills with properties different from those of the younger tills formed during Late Weichselian time in the inland areas far from the coast.

Many questions still remain unanswered regarding the number, time and extent of the different Weichselian interstadials. New dating methods and careful examination of old and new sections will hopefully reveal more about the Weichselian history in the coming decades.

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