SUB-TILL SEDIMENTS IN THE NUMEDAL VALLEY, SOUTHERN NORWAY

Elen Roaldset

Institute of Geology, University of Oslo, Blindern, Oslo 3, Norway

Abstract. The mineralogical and chemical composition of sub-till clay sediments in the Numedal Valley have been studied. The clay contains considerable amounts of tri-octahedral illite (about 80 %), and minor amounts of chlorite, mixed-layer illite-chlorite and amphibole.

The environmental conditions during the sedimentation of the clay have been elucidated by the distribution of the rare-earth elements. Thus, the elemental distribution suggests deposition in a weakly acid milieu rich in oxygen. This work was a contribution to the Numedal Project.

INTRODUCTION

Sub-till and interstadial sediments in southern Norway have previously been described by several authors, for example, Mangerud (1965, 1970) and Bergersen and Garnes (1971). In the summer of 1971, Professor Rosenqvist and I discovered the first true sub-till sediments in the Numedal area, southern Norway (Fig. 1). In a following paper published in this volume, Rosenqvist (1973) has discussed the grain-size data and, on the basis of geotechnical considerations, has calculated the degree of consolidation for the sub-till sediments. These are highly over-consolidated and represent presumably interstadial or interglacial deposits that have been spared by ice erosion.

This paper presents the mineralogy and geochemistry of a clay bed within the sub-till sequence of over-consolidated sediments. The data obtained are discussed in relation to other Numedal sediments investigated and described before (Roaldset, 1970*a*, 1972).

The Fønnebøfjord sediments

The deposit is situated east of Lake Fønnebøfjord in Uvdal, Upper Numedal (Fig. 1). Deposits of bedded sand and clay are found below a 6-8 m thick ground moraine. The sub-till sediments are highly over-consolidated (Rosenqvist, 1973). The exposed section of the Fønnebøfjord sediments is shown in Figs. 2 and 3.

The sub-till sediments consist of alternating beds of

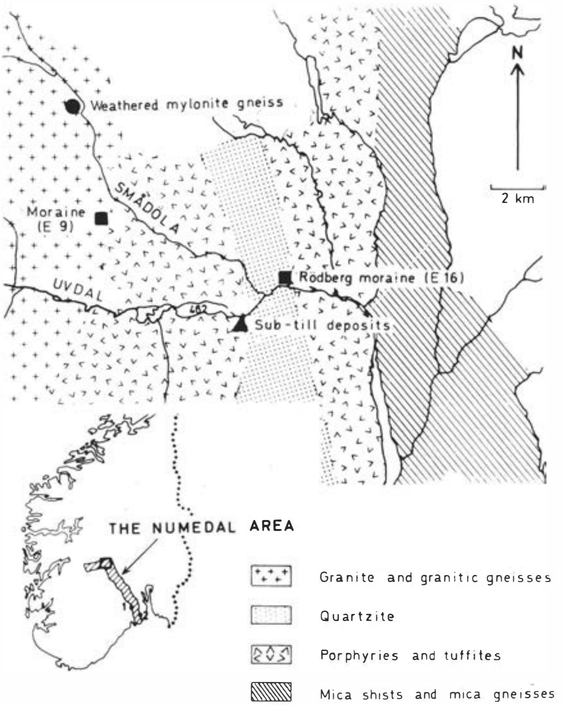

Fig. 1. The geology of the Fønnebøfjord area in Numedal (compiled by B.E. Løberg, 1970, unpublished). Inset map shows location of Numedal in Norway and two localities, (1) Herlandsdalen and (2) Åserum Lake.

gravel, sand, silt and clay (Fig. 3). The lowest part comprises two thick sand layers, separated by an intermediate layer of gravel. There is a gradual transition from the sand to the silt layer above. Over the silt is a 30 cm thick bed of blue clay and then a layer of silty clay. Then follow graded gravel and sand beds, and on top of the sub-till sequence, a thin disturbed clay bed. These sediments are free of any fossils.

Above this sequence of over-consolidated sediments, a coarse ground moraine occurs. The material, which is unsorted and lacks stratification, was presumably

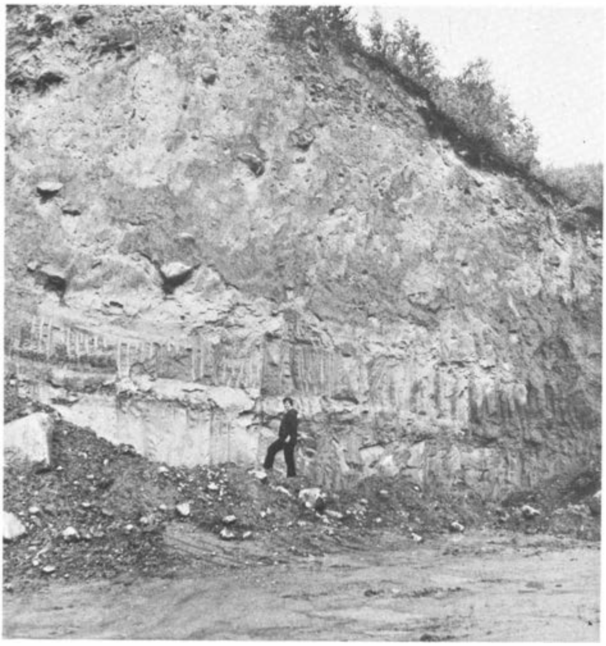

Fig. 2. The section described seen towards the south. The thick clay bed investigated is on a level with the author's head.

deposited by a glacier, which crossed and partly eroded the underlying sediments. The boundary towards the over-consolidated sediments is easily observed. Topmost in the moraine deposits there is a sandy and gravelly ablation moraine.

The bedding plane of the sub-till sediments dips 6—8°

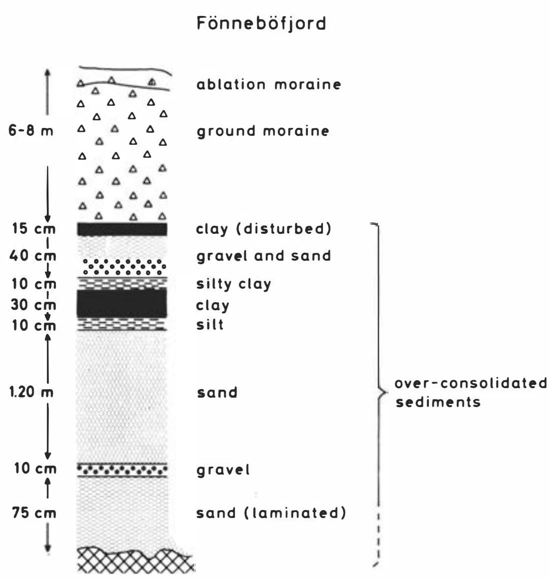

Fig. 3. Sketch of the described section.

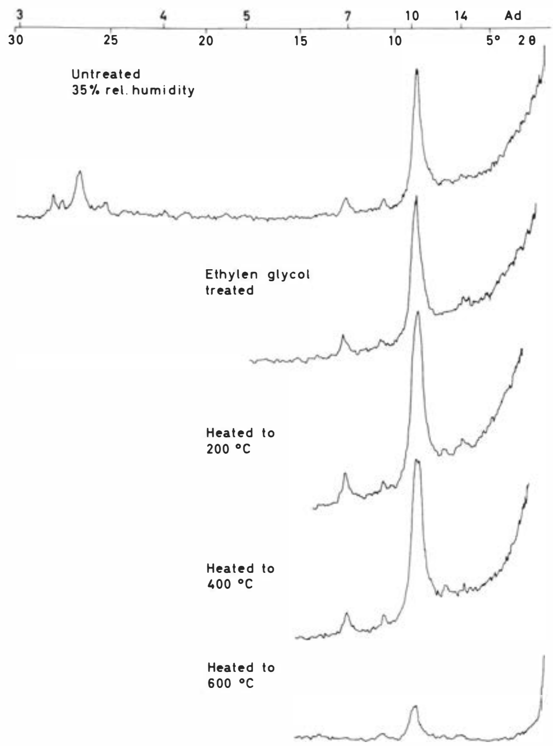

Fig. 4. X-ray diffractogram for oriented sample of the Fønnebøfjord sub-till clay. The material is shown untreated, treated with ethylene glycol and after heating to 200, 400 and 600°C.

towards the ENE and strikes N 165° (recorded in terms of 360°). The sediments were probably transported from the WSW and deposited in an ancient "Lake Fønnebøfjord". Geological considerations suggest that the sub-till sediments were sheltered by a quartzite ridge (Fig. 1) and were thus spared from ice erosion.

The data presented here refer to the $< 2\mu$ fraction of the lower thick bed of over-consolidated clay.

Qualitative and semi-quantitative mineral analyses were performed by X-ray diffractometry along lines suggested by Jørgensen (1965), with additional reference to Graff-Petersen (1961) and Norrish and Taylor (1962). The major elements were determined by X-ray fluorescence spectrography, and the rare-earth elements were determined by spark-source mass spectrometry in accordance with the analytical method proposed by Roaldset (1970*b*).

RESULTS AND DISCUSSION

The X-ray diffraction pattern for the Fønnebøfjord sub-till clay is shown in Fig. 4. The sample contains considerable amounts of illite (about 80 %) and smaller

Table I. Semi-quantitative mineralogical composition of clay fraction ($<2\ \mu$).
— = Small but observable amounts, x = 5–10%, xx = 10–25%, xxx = 25–40%,
xxxx = more than 40%.

	Smådøla moraine (E 9)	Rødberg moraine (E 16)	Fønnebøfjord sub-till clay	Herlandsdalen interglacial (?) clay (E 65)	Åserum lake, recent mud (E 77–79)
Illite	xx	xxxx	xxxx	xxxx	xxx
Chlorite	xx	xx	—	—	x
Vemiculite	x	—	—	xxx	xx
Illite-chlorite	xx	xx	x	—	x
Illite-vermiculite	x			xx	xx
Chlorite	—		—		x
Amphibole	x	x	x	x	—
Quartz	—	x	—	—	—
Microline	xx	xx	—	x	x
Plagioclase	x	x	—	—	—

Table II. Major elemental composition of the clay fraction ($<2\ \mu$) in weight %.

	Smådøla moraine (E 9)	Rødberg moraine (E 16)	Fønnebøfjord sub-till clay	Herlandsdalen interglacial (?) clay (E 65)	Åserum lake, recent mud (E 77–79)
SiO_2	49.8	51.5	53.7	49.6	51.5
TiO_2	1.09	0.79	0.92	1.07	0.92
Al_2O_3	17.5	14.9	17.7	15.7	17.6
Fe_2O_3	15.4	12.8	10.0	14.0	12.2
MnO	0.20	0.19	0.16	0.12	0.26
MgO	4.31	4.00	3.36	5.15	3.22
CaO	1.10	4.45	1.63	2.52	1.75
Na_2O	1.43	2.67	2.69	1.59	1.66
K_2O	5.63	5.30	5.10	3.75	4.07
Loss ignition	5.58	3.75	4.02	5.50	5.35
Total	102.04	100.35	99.28	99.00	98.53

amounts of chlorite, mixed-layer illite-chlorite and amphibole. Traces of vermiculite, mixed-layer chlorite-vermiculite, quartz, microcline and plagioclase are found. The illite intensity ratio $I_{(001)}/I_{(002)} = 26$ and the (060) peak at 1.53 Å are suggestive of a tri-octahedral illite.

The mineralogical and chemical characteristics of the Fønnebøfjord sub-till clay are listed in Tables I and II, together with data for other Numedal samples (Roaldset, 1972). The smådøla and Rødberg moraine clays have illite contents of 16 % and 47 % respectively. The corresponding illite intensity ratios ($I_{(001)}/I_{(002)}$ = 5.5 and 13) show that the Smådøla sample contains both di- and trioctahedral illites, while the Rødberg sample mainly contains trioctahedral illite. The X-ray diffraction curves for the sub-till clay and the Rødberg moraine are nearly identical.

The Herlandsdalen and the Åserum samples incorporated in Table I are from the lower part of the Numedal river system (Fig. 1). On geochemical considerations, Roaldset (1970*a*) assumed that the Herlandsdalen clay had descended from interglacial or interstadial sediments. However, for the time being, no field observations have demonstrated this. The Herlandsdalen clay and the Åserum mud differ from the Fønnebøfjord sub-till clay in containing considerable amounts of vermiculitic minerals and in the presence of di-, and trioctahedral illites.

The major element analyses for all samples are given in Table II. The data refer to material dried at 110°C. The total Fe content is calculated as Fe_2O_3.

The geochemical data for the Fønnebøfjord sub-till clay are in accordance with illite analyses (Deer *et al.*, 1966). The Al_2O_3 content is higher and the Fe_2O_3 + MgO content lower than those normally found for tri-octahedral micas. The contents of TiO_2, Al_2O_3 and CaO correspond to those of recent lacustrine mud (Table II). A high CaO content in Rødberg moraine clay is presumably consistent with the presence of Ca-rich plagioclase.

Concentrations of rare-earth elements in the sub-till clay are listed in Table III, together with other Numedal

Table III. Concentrations (ppm) of rare-earth elements in the clay fraction (<2 μ) of moraine and sub-till clays and recent lacustrine mud. The data for the composite of 40 North American shales are from Haskin and Frey (1966).

Element	Average moraine *a*	Smådøla moraine (E 9)	Rødberg moraine (E 16) Untreated	Rødberg moraine (E 16) EDTA-treated	Fønnebøfjorden sub-till clay	Herlandsdalen interglacial(?) clay (E 65)	Åserum lake, recent mud (E 77–79)	40 North American shales
Y	87.5	275	47	46	27	30	22.9	35
La	77.6	123	93	24	24	18.2	14.9	39
Ce	202.3	378	211	57	34	21	43	76
Pr	19.8	32	26	14.0	6.1	5.8	6.0	10.3
Nd	60.4	67	104	20	27	26	10.5	37
Sm	15.7	24	25	9.8	5.5	11.7	6.9	7.0
En	3.6	6.2	5.9	2.1	1.2	2.8	1.7	2.0
Gd	20.6	19.5	40	8.7	3.5	7.7	4.4	6.1
Tb	1.8	2.5	3.3	0.9	0.55	1.5	0.9	1.30
Dy	14.6	21	21	8.4	4.5	11.1	7.7	
Ho	2.0	3.1	2.6	0.8	0.64	1.7	1.1	1.40
Er	7.4	11.9	11.4	3.4	3.0	6.5	3.4	4.0
Tm	—	—	—	—	—	—	—	0.58
Yb	9.3	15.3	8.6	3.6	3.1	8.3	5.2	3.4
Lu	0.9	1.7	1.1	—	—	—	—	0.60
Total	527	980	600	199	140	152	128	230[b]

[a] Average of 16 moraine, glaciofluvial and fluvial clays. [b] Contains estimates for Dy where analytical values were not available.

samples (Roaldset, 1970*a*) and the composite of 40 North American shales (Haskin and Frey, 1966).

The low total rare-earth content (140 ppm) for the sub-till clay resembles the values obtained for the Herlandsdalen interglacial clay and Åserum mud but differs remarkably from the values for Numedal moraines. The overall rare-earth contents of the Smådøla and Rødberg moraines are 980 and 600 ppm respectively, while an average of 16 samples from the moraine areas in Numedal yielded 527 ppm (Table III). However, these figures do not support a presumed relationship between the sub-till sediments and the clay fraction of the Numedal moraines. However, by treating the Rødberg sample with EDTA, the rare-earth content decreased from 600 to 199 ppm. This value and especially the La, Nd, Er and Yb contents resemble the data for the sub-till clay.

A remarkable feature of the lanthanide elements is the alternation in abundance between adjacent even- and odd-numbered elements ("Oddo Harkins rule"). In order to facilitate the presentation of the distribution of rare-earth elements in geological material, it is usual to normalize the analytical results to other well-analysed material (Coryell *et al.*, 1963). The data of this work are normalized to the composite of 40 North American shales (Haskin and Frey, 1966). Except for a higher Eu content, the shale has the same rare-earth distribution as the average of the Earth's crust. The normalization tends to obliterate the characteristic even-odd effect of the lanthanides, and smooth-looking curves for concentrations as a function of atomic number are obtained. In Fig. 5 the normalized data are plotted on a logarithmic scale versus a linear scale of atomic number.

The distribution pattern for the Fønnebøfjord sub-till clay resembles that for the Herlandsdalen and Åserum samples. In all, Tb and Ho are depleted and Sm, Dy and Yb slightly enriched. In the two first samples, Ce is depleted relative to La. The distribution patterns for the moraines are quite different, and after normalization the data still show an even-odd distribution among the heavier elements. Such variations, which have previously been described for a weathered gneiss and its micas from Smådøla (Fig. 1), are presumably related to the adsorbed ions (Roaldset and Rosenqvist, 1971).

The prevailing chemical conditions when the sub-till clay was deposited are elucidated by the data obtained. According to Garrels and Christ (1965), an extreme content of trioctahedral illite relative to other clay minerals is suggestive of a potassium-saturated, neutral to slightly acid milieu. The low total rare-earth content, with no marked Eu enrichment, corresponds to a slightly acid milieu rich in oxygen (Ronov *et al.*, 1966). Taking into consideration these conditions and the over-consolidation, the sediments seem to have been deposited in an ancient "Fønnebøfjord Lake" in an interstadial/interglacial period. The over-consolidated sediments probably correspond to the Weichselian sub-till sediments in the Gudbrandsdalen Valley (Bergersen and Garnes, 1971).

By erosion and re-deposition, the sub-till sediments have contributed to other Numedal sediments. This is demonstrated with regard to the Rødberg moraine clay. The minerological data suggest a major contribution from sub-till clay material, while the rare-earth content, on the other hand, points to a main supply from weathered Smådøla material. However, considerations based on the mineralogical and geochemical composition show the Rødberg clay to contain mainly re-deposited sub-till material (75 %) mixed with material from the Smådøla area (25 %).

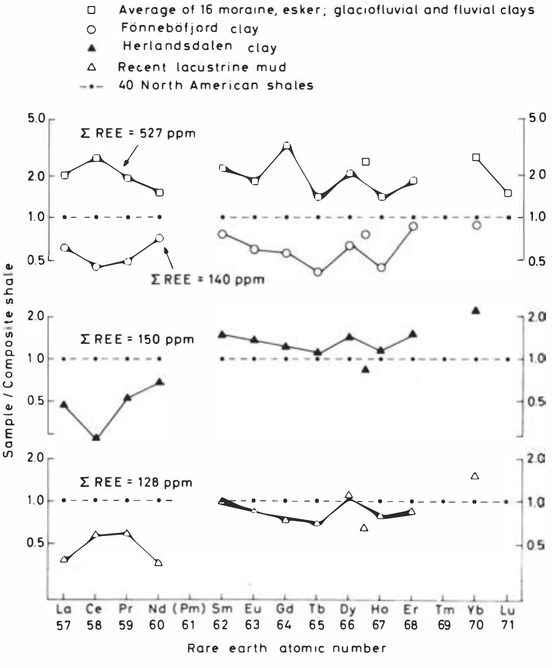

Fig. 5. Comparison plot for the Fønnebøfjord sub-till clay and other Numedal clays.

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