Overconsolidated sub-till clays in Herlandsdalen, lower Numedal, south Norway

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A description is given of overconsolidated sub-till clay sediments situated about 260 m a.s.l., i.e. 90 m above the local marine limit of the last deglaciation. The clay sediments contain neither macro- nor micro-fossils. Textural, mineralogical and geochemical investigations, strongly supported by the Ce deficient lanthanide abundance pattern, indicate marine depositional environment. The clay sediments are assumed to be of Middle-Weichselian age and are thus correlated with the Sandnes Interstadial, described from SW-Norway, and its analogues.

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In the Numedal river basin sub-till sediments have previously been described from the northern parts of the area (Roaldset 1973a, Rosenqvist 1973). This paper presents data on the first sub-till clays in the lower part of the Numedal river basin, where in 1973 in the valley Herlandsdalen, overconsolidated sub-till clays situated 260 m a.s.l. (Fig. 1) were discovered.

Geological setting

A sketch map of the superficial deposits, given in Fig. 2, shows thick till cover in the SW, and thin discontinuous cover of till NE of Herlandsdalen. Dead ice terrain is locally developed, and at Kviberg-Olsli a glaciofluvial delta was deposited and built up to the postglacial marine limit (173±2 m a.s.l.; Korbøl 1972), simultaneously with deposition of marine clays in the ancient ‘Numedalsfjorden’. Accordingly the sub-till clays are found almost 90 metres above the post-glacial marine limit.

The main directions of glacial striae, as observed north and southeast of the Herlandsdalen area, are N 100° and N 160° – 170° respectively (Holtedahl & Andersen 1960, D.E. Nilsen pers. comm. 1978, K. Pederstad, pers. comm. 1978). Like the valley infills of till in valleys tributary to Gudbrandsdalen (Mangerud 1965, Garnes & Bergersen 1977), the preservation of till in SW-areas of Herlandsdalen may be explained by their lee-side position during ice flow obliquely across the valley (Hillefors 1973).

The bedrock consists of Permian monzonite and alkali granite of the Oslo Igneous Province. Precambrian rocks occur about 10 km WNW of Herlandsdalen (Brøgger & Schetelig 1923).

The Herlandsdalen sediments

The sub-till clay was exposed near the head of Herlandsdalen (Fig. 2). The exposed sections are shown in Fig. 3.

The Locality 1 sediments are glacially tectonized and display small fissures and faults. Well rounded pebbles of Precambrian rocks are scattered throughout the clay bed, becoming more abundant upwards. A 30 cm thick bed of silty sand succeeds the clay, with distinct contact to the bluish grey zone above. This zone, being a mixture of clay and till material, gradually changes over to a yellowish brown till. Fragments of rock as well as of consolidated clay occur in the till.

The Locality 2 sediments consist of homogenous fine grained clay in distinct contact with alkali granite below, and till above. The clay shows no sign of glacial tectonism or disturbance, and is presumably preserved in situ. The till is furrowed by small channels (5–20 m wide, 2–10 m deep). The coarser till fragments consist of well rounded cobbles of Precambrian rocks. Fragments of Lower Palaeozoic or of Permian rocks were not identified in the coarsest fractions, but occur in small amounts, below 10 per cent in total, in the gravel fraction.
Fig. 1. Oslofjorden and the location of the Herlandsdalen area. The 300 m contour is indicated. Terminal moraines from the last deglaciation are indicated with broad black lines.

Fig. 2. Superficial deposits in the Herlandsdalen area (Korbvål 1972, unpublished data, Numedalsprosjektet, Institutt for geologi, Universitetet i Oslo).
Sub-till clays in Numedal

Bedrock with small areas covered by till
Thin cover with till
Thick cover with till
Glaciofluvial gravel and sand
Fluvial sand
Bog
Esker
Drainage channel
Glaciofluvial terrace
Contour interval 50 m

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500 m
Neither macro- nor microfossils were detected in clay samples prepared for pollen, foraminifera, and diatom analysis.

Sediment texture and particle size distributions are illustrated by means of electron micrographs in Fig. 4. The Loc. 2 clay shows a great abundance of <2 μm materials with a few scattered coarse fragments, while coarser fragments dominate in the Loc. 1 clay.

Experimental methods

pH measurements were carried out in situ, using a Beckman H5 pH-meter and a combined glass-calomel electrode.

The clay samples were examined without any pretreatment with a JEOL scanning electron microscope.

Geotechnical parameters were determined by conventional methods according to Skempton (1953).

Material coarser than 63 μm was wet sieved employing screens of whole phi unit intervals, while the grain size distribution of the fine fraction was determined by pipette analysis (Krumbein & Pettijohn 1938).

Mineralogical analyses of the clay-sized fraction (finer than 2 μm) were made with oriented samples by X-ray diffractometry (XRD). The methods of mineral identification were essentially based on Brown (1961).

The major elements were determined by X-ray fluorescence spectrography (XRF). Ferrous iron was determined by dissolving the sample powder in cold concentrated HF with subsequent colorimetric titration against K₂Cr₂O₇. The ignition loss was determined as the weight loss of material dried at 110°C after heating for 2 hours at 1050°C.

The relative distributions of lanthanide (Ln) elements were determined by a modified GEC/AEI MS 702 solid source mass spectrometer (Taylor 1965, Nicholls et al. 1967). A description of the analytical procedure is given by Prestvik & Roaldset (1978). Christie (1977) showed that the precision of the method is 8 per cent, the accuracy within sample is 10 per cent and the accuracy of the method, which is a measure of reproducibility of sample preparation, homogeneity and precision combined, is 25 per cent.

Results and comparisons

pH-measurements

In situ the pH value was 7.5 for the sub-till clays, which is of the same order as for Scandinavian postglacial marine clays isostatically lifted above.
Fig. 4. Sub-till clays. Scanning electron micrographs of horizontal sections: Loc 1. A - 300×, B - 3000×; Loc 2. C - 300×, D - 3000×.

sea-level (J. Moum, pers. comm. 1973), and higher than normally found for Numedal tills (unpublished data, Numedalsprosjektet, Institutt for geologi, Universitetet i Oslo).

**Determination of consolidation stress**

The sub-till clays had a considerable hardness and did not crack during drying. They were therefore assumed to be greatly overconsolidated. The clays did not shrink with further drying, which proved that they have been consolidated to beyond the shrinkage limit, which is normally 15–20 relative per cent beyond the plastic limit (Hogentogler 1937). The following considerations and calculations are analogous to those made by Rosenqvist (1973) for the Fønnebøfjord sub-till clay in upper Numedal.
Table 1. Geotechnical parameters for \textit{in situ} sub-till clay (Loc. 2, undisturbed).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content (W)</td>
<td>14.0 %</td>
</tr>
<tr>
<td>Plastic limit (WP)</td>
<td>17.3 %</td>
</tr>
<tr>
<td>Liquid limit (WL)</td>
<td>32.3 %</td>
</tr>
<tr>
<td>Void ratio (e)</td>
<td>0.40</td>
</tr>
<tr>
<td>Plasticity index (PI = WL - WP)</td>
<td>15.0 %</td>
</tr>
<tr>
<td>Content of Clay &lt; 2 μm (c)</td>
<td>55.0 %</td>
</tr>
<tr>
<td>Activity (A = PI/c)</td>
<td>0.27</td>
</tr>
</tbody>
</table>

\(^{1}\) Calculated on the basis of a specific gravity of the particles of 2.7 g/cm\(^3\).

The fundamental geotechnical data for the \textit{in situ} sub-till clay (Loc. 2) are given in Table 1. By using Skempton’s (1953) empirical curves at liquid limit of 50, plasticity index 25, and a void ratio of 0.40, the data correspond to an approximate depth of 2000 ft. in normally consolidated sediments. Similar figures were obtained by extrapolation of data for Horten clay (from Skempton 1953), while such consolidation stresses lie outside Bjerrum & Rosenqvist’s (1958) experimental range for Åsrum clay, lower Numedal. Applying the formula given by Skempton (1953) for the relationship between void ratio and effective overburden pressure, the effective load on the Loc. 2 sub-till clay must have been 10\(^{3.86}\)N per m\(^2\) (or 740 tons/m\(^2\)). This is slightly lower than the estimated load of 1000 tons/m\(^2\) for Fønnebø clays, upper Numedal (Rosenqvist 1973).

Obviously the consolidation stress for the Herlandsdalen sub-till clay was much higher than the weight of the overlying till, and it is unlikely that this material alone consolidated the sediments. Thus the consolidation is due to an overlying glacier with a thickness of at least 7–800 m. This must correspond to a major glacial advance.

**Grain-size characteristics**

The grain size distribution was plotted as weight per cent (log probability scale) versus phi (\(\Phi\)) which is defined as \(-\log_2\) particle diameter in millimetres (Fig. 5). In Fig. 5 the grain size increases from left to right which is the opposite of Folk & Ward’s (1957) proposal. Consequently the equations for particle distribution must be modified (Korbøl 1972). The grain size data in Table 2 gives the following properties of the samples investigated (Folk 1968).

Loc. 1. \textit{Silty clay}, very poorly sorted, strongly fine skewed mesokurtic. 
\textit{Sand}, poorly sorted, coarse skewed very platykurtic. 
\textit{Till}, very poorly sorted, fine skewed leptokurtic.
Table 2. Some standard size and particle distribution parameters (Folk & Ward 1957) for the Herlandsdalen clay and till.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Sub-till Clay</th>
<th>Loc. 1 Sand</th>
<th>Loc. 1 Till</th>
<th>Loc. 2 Sub-till Clay</th>
<th>Loc. 2 Till</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphic mean</td>
<td>7.3</td>
<td>0.16</td>
<td>2.8</td>
<td>10.0</td>
<td>2.3</td>
</tr>
<tr>
<td>Sorting (Inclusive graphic standard deviation)</td>
<td>3.4</td>
<td>1.2</td>
<td>3.0</td>
<td>2.9</td>
<td>2.7</td>
</tr>
<tr>
<td>Skewness (Inclusive graphic skewness)</td>
<td>0.59</td>
<td>-0.18</td>
<td>0.14</td>
<td>-0.08</td>
<td>-0.08</td>
</tr>
<tr>
<td>Graphic kurtosis (Peakedness)</td>
<td>1.00</td>
<td>0.62</td>
<td>1.14</td>
<td>0.96</td>
<td>1.21</td>
</tr>
</tbody>
</table>

1) $M_z = \frac{\phi_{16} + \phi_{50} + \phi_{94}}{3}$
2) $\sigma_1 = \frac{\phi_{16} - \phi_{94} + \phi_{50} - \phi_{95}}{4}$
3) $Sk_I = \frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{2(\phi_{16} - \phi_{84})} + \frac{\phi_{5} + \phi_{95} - 2\phi_{50}}{2(\phi_{5} - \phi_{95})}$
4) $K_G = \frac{\phi_{5} - \phi_{95}}{2.44 (\phi_{25} - \phi_{75})}$

Loc. 2. Clay, very poorly sorted, near symmetrical mesokurtic. 
Till, very poorly sorted, near symmetrical leptokurtic.

The in situ clay is finer than most marine clays around Svarstad (Korbøl 1972), and similar to the most fine-grained marine clays in the Skagerrak (Rønningsland 1976), and sub-till lacustrine clays of central South Norway (Rosenqvist 1973, Vorren & Roaldset 1977). The tills have grain size distributions typical for basal tills of the surrounding area (Korbøl 1972).

By plotting sorting ($\sigma_1$) versus mean grain size ($M_z$) for late- and postglacial sediments of the Svarstad area, a clear distinction appeared between marine clays, tills, fluvial sand, and gravel (Korbøl 1972). The Herlandsdalen samples fit this division. The overconsolidated clays and the sand plot within the areas for marine clays, glacio-fluvial sediments, and fluvial sediments respectively (Fig. 6).

Clay mineralogy

The clay fractions ($< 2 \mu m$) of the tills and the sand bed gave almost identical X-ray diffractograms. The clay beds differed from the coarser sediments but were similar to each other. For this reason only the X-ray diffractograms for the Loc. 2 clay and till are presented (Fig. 7).

The phyllosilicates present in the clay fractions of the tills and the sand bed are illite (10Å), vermiculite, and a mixed layer illite–vermiculite (10–14Å). In addition microcline (3.25Å), plagioclase (3.19Å), amphibole (8.4Å), quartz (4.26Å), and small amounts of smectite were detected. After treatment with HCl the 7Å peak disappears, thus eliminating the presence of kaolinite.

The sub-till clay consists of illite, chlorite (14Å) together with traces of smectite, and mixed layer illite–chlorite minerals. Besides these, amphibole, quartz, microcline, and plagioclase are present. Not in this material either was a 7Å kaolinite peak observed after HCl treatment. The X-ray diffractograms for this clay resemble the diagrams obtained for river mud and some till samples from Numedal (Roaldset 1972) as well as marine Skagerrak clays (Rønningsland 1976).

Treatment of the $< 2 \mu m$ material with sodium-tetraphenyl-boron (NaTBP) revealed in
both cases the illites to be of di- and trioctahedral type (DeMumbrum 1963, Robert 1973, Schmith & Scott 1973, Rueslåtten 1976).

The lack of chlorite in the till and its appearance in the underlying clay samples and the opposite distribution of vermiculite deserves attention. According to Garrels & Christ (1965) chlorite is stable in marine environments, but unstable in weakly acidic ones. The high content of vermiculite minerals in the till can be attri-
buted to formation of vermiculite from biotite and plagioclase (Meunier & Velde 1976, 1977) as well as to transformation of chlorite and trioctahedral illite during subaerial weathering processes.

The mineralogical analyses do not identify the sub-till clay in Herlandsdalen as undisputable marine.

**Chemical composition**

The chemical composition of the < 2μm fraction of the clay and till is given in Table 3. The data are in agreement with chemical data of the clay fractions of Numedal sediments and when recalculated to mol percentages of basic oxides plot within the same area as Numedal clays in a (Fe₂O₃ + FeO + MgO)–Al₂O₃–(K₂O + Na₂O + K₂O) triangle (Roaldset 1972).

Roaldset (1972) found a consistent geochemical variation for mol ratios MgO/Al₂O₃ and K₂O/Al₂O₃ between marine and non-marine clays. The marine clays usually had higher and the non-marine clays lower, mol ratios than MgO/Al₂O₃ = 60 per cent and K₂O/Al₂O₃ = 25 per cent. Using these criteria, the Herlandsdalen sub-till clays (MgO/Al₂O₃ = 64 and 87 per cent, K₂O/Al₂O₃ = 29 and 28 per cent) fall within the marine region, while the tills and sand plot in the non-marine group. Analyses of lacustrine sub-till clay beds and laminae from Hardangervidda and upper Numedalen gave mol ratios MgO/Al₂O₃ = 50–60 per cent, except for one value of 70 per cent. Thus, although the major chemical composition would seem to indicate a marine origin for the clay, a lacustrine depositional environment cannot be completely ruled out.

**Lanthanide (Ln) elements**

The distributions of the Ln elements within the < 2μm fraction, relative to La = 100, are given in Table 4.

To facilitate their presentation it is usual to divide one Ln distribution, element by element, by another distribution, plotting the resulting ratios in a logarithmic scale against a linear scale of atomic number (Masuda 1962, Coryell et al. 1963). The data for the present work were thus normalized to their average compositions and plotted together with a true marine clay from the Skagerrak in Fig. 8.

The lanthanide distribution pattern may be used as an environment indicator within certain limits (cf. Balashov et al. 1964, Ronov et al. 1967, Fleischer & Altschuler 1969, Martin et al. 1976). The pH-dependent oxidation of cerium is well known. At pH 8.2, which corresponds to marine conditions, nearly all cerium exists as Ce⁴⁺, while the prevailing ion at pH 7 is Ce³⁺.

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**Table 3. Major chemical composition (weight per cent) for the clay fraction (<2μm) of the Herlandsdalen sediments.**

<table>
<thead>
<tr>
<th>Elements</th>
<th>Sub-till clay</th>
<th>Sand bed</th>
<th>Till</th>
<th>Sub-till clay</th>
<th>Till</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>49.6</td>
<td>56.2</td>
<td>63.3</td>
<td>53.2</td>
<td>54.9</td>
</tr>
<tr>
<td>TiO₂</td>
<td>1.07</td>
<td>0.95</td>
<td>0.95</td>
<td>1.42</td>
<td>0.86</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>15.7</td>
<td>16.5</td>
<td>15.2</td>
<td>16.7</td>
<td>15.9</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>10.7</td>
<td>7.26</td>
<td>4.93</td>
<td>6.67</td>
<td>4.54</td>
</tr>
<tr>
<td>FeO</td>
<td>3.10</td>
<td>2.80</td>
<td>2.54</td>
<td>3.12</td>
<td>2.50</td>
</tr>
<tr>
<td>MnO</td>
<td>0.12</td>
<td>0.13</td>
<td>0.12</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>5.15</td>
<td>3.08</td>
<td>2.40</td>
<td>4.13</td>
<td>1.98</td>
</tr>
<tr>
<td>CaO</td>
<td>2.52</td>
<td>3.00</td>
<td>3.14</td>
<td>2.68</td>
<td>2.79</td>
</tr>
<tr>
<td>Na₂O</td>
<td>1.59</td>
<td>2.41</td>
<td>2.53</td>
<td>2.04</td>
<td>2.18</td>
</tr>
<tr>
<td>K₂O</td>
<td>3.75</td>
<td>3.66</td>
<td>3.12</td>
<td>4.34</td>
<td>2.49</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.19</td>
<td>0.14</td>
<td>0.23</td>
<td>0.18</td>
<td>0.26</td>
</tr>
<tr>
<td>Loss ignition</td>
<td>5.50</td>
<td>3.96</td>
<td>2.67</td>
<td>5.47</td>
<td>12.3</td>
</tr>
<tr>
<td>Total</td>
<td>99.0</td>
<td>100.1</td>
<td>101.1</td>
<td>100.0</td>
<td>100.8</td>
</tr>
</tbody>
</table>

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Table 4. Relative lanthanide (Ln) distributions (La = 100) for the Herlandsdalen samples.

<table>
<thead>
<tr>
<th>Element</th>
<th>Loc. 1</th>
<th>Loc. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sub-till</td>
<td>Sand bed</td>
</tr>
<tr>
<td>La</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Ce</td>
<td>215</td>
<td>224</td>
</tr>
<tr>
<td>Pr</td>
<td>44</td>
<td>29</td>
</tr>
<tr>
<td>Nd</td>
<td>152</td>
<td>86</td>
</tr>
<tr>
<td>Sm</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>Eu</td>
<td>15.5</td>
<td>2.2</td>
</tr>
<tr>
<td>Gd</td>
<td>98</td>
<td>27</td>
</tr>
<tr>
<td>Tb</td>
<td>10.4</td>
<td>1.8</td>
</tr>
<tr>
<td>Dy</td>
<td>40.5</td>
<td>8.6</td>
</tr>
<tr>
<td>Ho</td>
<td>8.2</td>
<td>1.9</td>
</tr>
<tr>
<td>Er</td>
<td>29</td>
<td>9.6</td>
</tr>
<tr>
<td>Tm</td>
<td>3.3</td>
<td>-</td>
</tr>
<tr>
<td>Yb</td>
<td>17.7</td>
<td>7.7</td>
</tr>
<tr>
<td>Lu</td>
<td>5.5</td>
<td>-</td>
</tr>
</tbody>
</table>

The oxidation of $\text{Ca}^{2+}$ to $\text{Ce}^{4+}$ explains the cerium enrichment in hydrolysate minerals and subaerial weathering products, and the cerium deficiency in ocean water (Goldberg 1961, Carpenter & Grant 1969, Piper 1974 a,b). According to Högdaal (pers. comm. 1967) the North Atlantic deep water has a pronounced cerium deficiency.

Martin et al. (1976) investigated the behaviour of the Ln’s in the river/ocean boundary in the Gironde estuary, France. For soluble river loads they found a gradual decrease in the Ce/La ratio from 1.66 to 0.35 as the salinity increased from 0.1 %o to 35.5 %o.

The Loc. 2 samples (Fig. 8), the clay and the till above, exhibit pronounced positive and negative Ce anomalies respectively, and thus attach

![Fig. 8. Lanthanide comparison diagram relative to the average of the Herlandsdalen samples, together with sample S 32, a true marine clay from Skagerrak (Roaldset & Christie 1975).]
significance when trying to arrive at an understanding of the depositional conditions.

For the overlying till the Ce enrichment produces evidence for a high content of subaerial weathering products.

A Ce depletion occurs rarely in postglacial Numedalen-sediments deposited in brackish and non-marine environments, and has been found only in one sample, which was actually from Herlandsdal (Roaldset 1973b).

The Herlandsdalen clay, due to the Ce deficiency and its resemblance with Skagerrak clay, may have been deposited in a true marine environment. The possibility of a marine origin requires further discussion as the locality lies 90 m above the marine limit of the last glaciation.

Discussion and correlation

The investigations led to the following conclusions:

The pH, grain size, mineralogical and major chemical analyses all suggest a marine depositional environment, though lacustrine conditions cannot be completely ruled out.

The Ce-deficiency exhibited in the distribution pattern points to a marine origin of the sub-till clays.

The degree of overconsolidation of the undisturbed clay indicates a major glacial advance across the Herlandsdal area after the clay deposited. Hence the clay was at least deposited prior to the Weichsel III glacial advance (Lundqvist 1974), which culminated 17,900 ± 1300 years B.P. (Pisias 1976, see also CLIMAP project members 1976, Lawrence Gates 1976, Porter et al. 1977).

As the sub-till clay sediments lie 260 metres above present-day sea-level, i.e. about 90 metres above the postglacial marine limit at this locality, a marine depositional milieu cannot be explained by isostatic/eustatic conditions comparable with those which have prevailed since the last deglaciation.

The lack of organic material, pollen diatoms, and foraminifera unfortunately precludes age datings by means of biostratigraphical and radiocarbon methods.

Age and correlation

The till. – The thin ablation till on top of the basal till (Fig. 3, Loc. 1) was probably deposited during the last deglaciation (Preboreal?) about 10,000 years ago. The basal till may represent either the Weichsel II or III advance (Lundqvist 1974). Extensive studies of distribution and genesis of tills in central south Norway signify that the basal tills were most probably deposited during the onset of a glaciation (Bergersen & Garnes 1977).

The clay. – Since evidence exists that the Eemian shoreline in SW Norway and SW Sweden was only about 10–20 metres above present sea-level (Mangerud 1970, Feyling-Hanssen 1971, Hillefors 1974), and since clays of pre-Eemian age have not been found in Norway, the clays in Herlandsdalen may be assumed to be younger than Eemian. Their stratigraphical position and overconsolidation appear to leave open the possibility that the clay was deposited during a Middle Weichselian interstadial prior to the great Weichsel advance.

Taking into consideration the proposed marine origin, the clay must have been deposited at a time when the sea level was about 100 m above the local postglacial marine limit. The cause of such high sea-level has been generally attributed to glacial isostasy. For the Weichsel glaciation, Assev (1968) considers that the maximum isostatic depression was about 1000 m, and Nansen (1928) and Gutenberg (1941) give minimum values of 550–700 m. As no eustatic rise in sea level above present niveau has occurred within the last 30,000–35,000 years (Milliman & Emery 1968), glacio-isostatic depression alone would explain a marine transgression reaching 250–300 m above present sea level.

Recent investigations present evidence of large postglacial vertical displacements (up to 100 m) within the southern Fennoscandian Border zone and the Baltic Shield (Lagerlund 1977 a,b, Lundqvist & Lagerbäck 1976, Lagerbäck 1977, Mörner 1977 a,b). Worthy of mention is also the observation by Reusch (1901) of vertical displacement across glacial striations at Grytefjellet, near Vøringfossen, west Norway. Thus, referring to these investigations a tectonic uplift of the Herlandsdal area cannot be excluded.

From W and SW Norway marine clays lying far (at Jæren up to 250 m) above the postglacial shoreline has been described by several authors (Grimnes 1910, Kaldhol 1930, 1931, Feyling-Hanssen 1966, 1971, 1974, Garnes 1976). At Foss-Eigeland, near Sandnes, an almost complete Weichselian profile has been recorded.
Here, below a 3–5 m thick basal till, a clay zone occurs with its base 65 m above present day sea level. The clay represents the upper parts of a Middle Weichselian fining upwards sediment sequence corresponding to a marine transgression before the last large glacial advance. This transgression has also been recognized in the Egersund district (Garnes 1976).

The Herlandsdalen clay most probably correlates with the clay unit B) at Foss-Eigeland which according to Feyling-Hanssen (1971, 1974) was deposited during the Sandnes Interstadial (50,000–20,000 years B.P.). This Middle Weichselian interstadial is correlated with the Hirthsals Older Yoldia Clay (Andersen 1971), the Portlandia arctica zone of the Skærumhede I (Jessen et al. 1910), and the zone I of the Skærumhede II sequence (Bahnson et al. 1973), the Swedish analogues the Götäelv and Younger Dösebacka-Ellsesbo interstadials (Brotzen 1961, Hillefors 1969, 1971), and the Cape Broughton Interstadial (Mid-Wisconsin) known from Arctic Canada (Feyling-Hanssen 1976a,b).

Conclusions

The lanthanide abundance pattern may point to a marine origin for the sub-till clay sediments in Herlandsdalen. Their degree of overconsolidation and the fact that they lie about 90 m above the postglacial marine limit support a correlation with the Sandnes Interstadial. Thus in the terms of Mangerud et al. (1974), the clay was deposited during a Middle Weichselian Interstadial. The interstadial conditions were followed by the great Weichsel II (II/III advance(s) (Lundqvist 1974). Glaciers from the NW overrode the clay (Loc. 2), eroding it and transporting part of it as thrust slices and also incorporating some clay in the till (Loc. 1) which was subsequently deposited.

The author wishes to keep open the question whether the high Middle Weichselian sea level in Herlandsdalen was due to glacio-isostatic depression, or to neotectonic movements, or combination of such effects.

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