7. GRAIN-SIZE DISTRIBUTION OF THE CORES – WITH EMPHASIS ON THE SEDIMENTARY PATTERNS AROUND THE PLEISTOCENE/HOLOCENE BOUNDARY

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METHODS

The methods used for grain-size analysis followed standard procedure. Organic matter was first removed with hydrogen peroxide according to Jackson (1965) whereupon the water-soluble salts were washed out with distilled water. In order to avoid the crust on sediment dried at 105°C, the pretreated samples were freeze-dried at a pressure of about 0.02 torr and a temperature of –35°C. The water content in the freeze-dried sediment samples was less than 1 %. The granulometric analyses were performed with the hydrometer method (Gandahl 1952) for particle sizes smaller than 0.062 mm, and by sieving the dried sediment (Knutsson and Ljunggren 1960) for particle sizes coarser than 0.062 mm. The sieves used had square meshes with the widths of the 1922 Wentworth scale (Wentworth 1922).

The nomenclature of the grain-size distribution follows the size limits of the Massachusetts Institute of Technology, M.I.T. Scale, of 1931 (Terzaghi and Peck 1960). For the nomenclature of sand, silt and clay mixtures, the system of Shepard (1954) was used (see Fig. 7:4). The quartile Q_{75} and median Md are the size values used by Pettijohn (1957). In the interpretation of the cumulative curves, no importance was attached to the interruptions at 0.062 mm, caused by the difference between sieving and sedimentation analysis.

RESULTS

Results from each sample are plotted *versus* depth in Figs. 7:1–3 and in triangle diagrams in Fig. 7:4.

Solberga core – The coring at Solberga started below the dry crust – 1.2 m thick – in a silty clay at a depth of 2.1 m and reached down to firm bottom at a depth of 27.3 m below ground surface (situated about 2 m above sea level). From the top of the core there is a gradual increase in the clay

SOLBERGA CORE

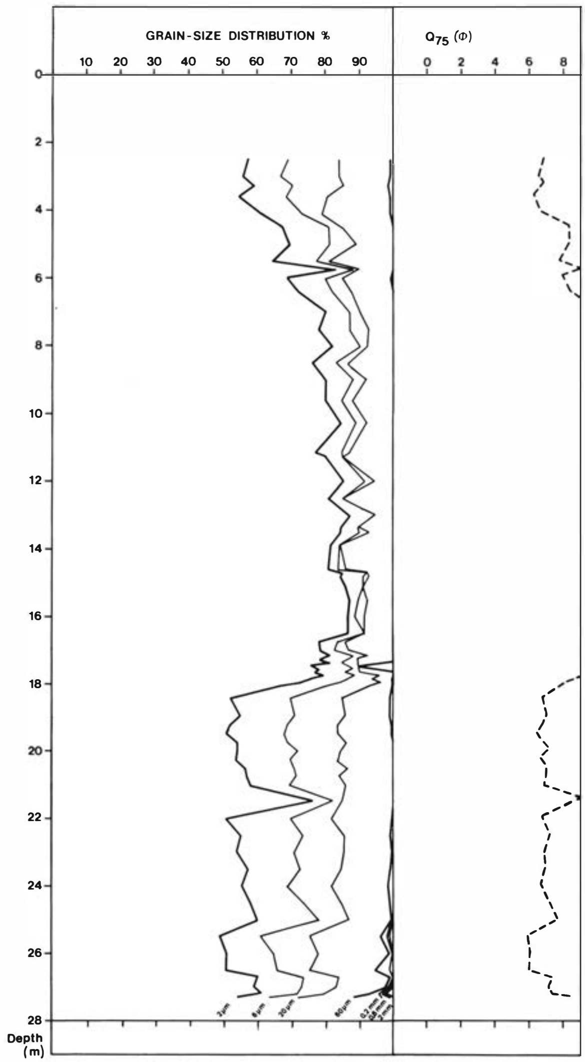

Fig. 7:1. Grain-size distribution and variation of the quartile Q_{75} *versus* depth in the Solberga core.

content from about 55 % to about 75 % at a depth of 6.7 m (Fig. 7:1), where the silty clay yields to a very fine-grained homogeneous clay (75–85 % < 2 μm) reaching down to about 17.5 m depth.

The sand fraction, comprising only a few per cent of the silty clay, disappears in the homogeneous clay. At a depth of 17.5 m the sand fraction appears again with a distinct peak of 10 %, but falls immediately to a few per cent and remains fairly constant to the bottom of the core.

BRASTAD CORE

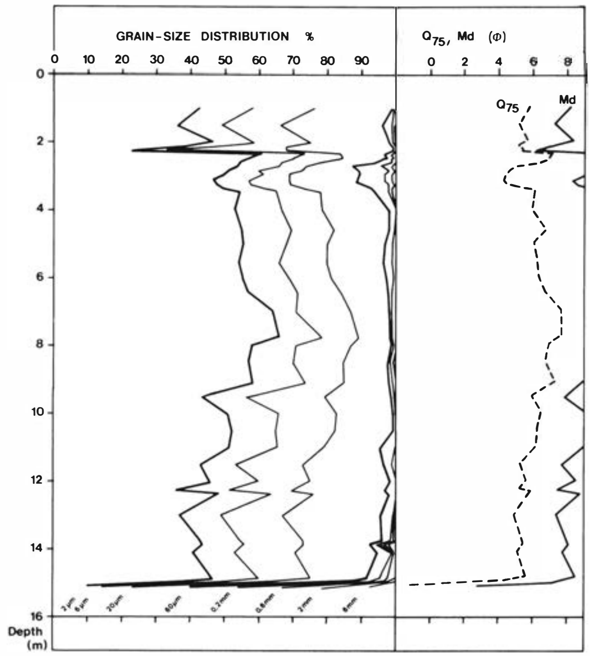

Fig. 7:2. Grain-size distribution, variation of the quartile Q_{75} and the median value *versus* depth in the Brastad core.

From the sand peak and downwards there is a simultaneous sudden drop in the clay content. The clay content decreases from about 80 % to a little more than 50 % in less than 1 m at a depth of 18.4 m. The homogeneous clay becomes a silty clay, which forms the sediment in the lower part of the core above the firm bottom. The distinct peak of the clay fraction at a depth of 21.40–21.45 m is also worthy of note.

Brastad core – The coring at Brastad started below the dry crust – 0.5 m thick – in clayey silt at a depth of 0.8 m and reached down to sand and gravel at 15.1 m below ground surface (situated about 45 m above sea level). The clayey silt at the top of the core abruptly yields to a thin silty layer (75 % silt) at 2.20–2.31 m depth (Fig. 7:2). Below this layer the core consists of silty clay, which has a maximum clay content of 65 % at 7.8 m. From this maximum, the clay content decreases progressively downwards to about 40 % and the sediment becomes a clayey silt from about 11 m down to the bottom of the core.

The sand content is with one exception fairly constant (1–4 %) from the top of the core down to a depth of about 11 m, where there is a slow increase

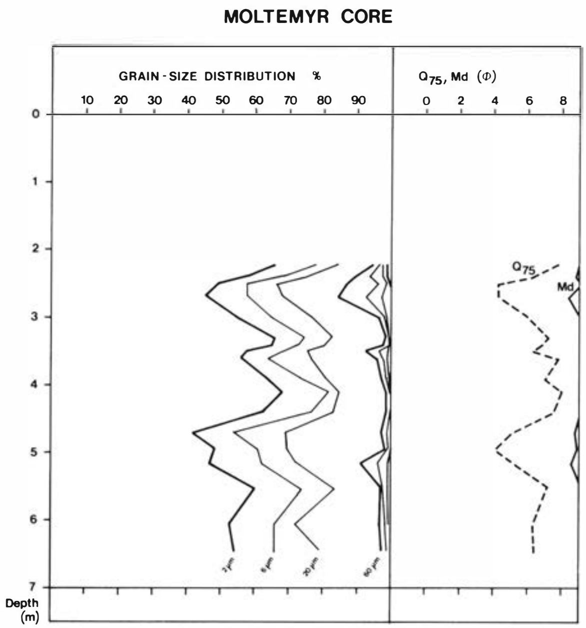

Fig. 7:3. Grain-size distribution, variation of the quartile Q_{75} and the median value *versus* depth in the Moltemyr core.

to 10 % at the bottom of the core. Below the silty layer at a depth of 2.5–3 m, the sand fraction has a peak of about 13 per cent. In the very lowest part of the core, *i.e.* the transition zone to the basal sand and gravel, the grain size increases and the deepest sample is classified as a silty sand. However, this sample was taken from the mouth piece of the Foil Piston Corer so the possibility cannot be excluded that during the coring this sediment was artificially formed by mixture of the basal sand and overlying clayey silt.

Moltemyr core – The coring at Moltemyr started in a fen peat at a depth of 0.5 m below ground surface (situated about 55 m above sea level), continued through a layer of detritus gyttja (1.65–2.12 m) down into silty clay and stopped at 6.5 m depth (clay thickness >27 m; see Chapter 4).

With the exception of a strong minimum at 2.5 m depth the clay content varies between 55 and 70 % in the upper clastic part of the sediment core (Fig. 7:3). A sudden drop in the clay content occurs at a depth of about 4.1 m. Over little more than 0.5 m the clay content decreases from nearly 70 % to about 40 % at a depth of 4.7 m. The silty clay becomes a clayey silt, which passes downwards into silty clay.

The sand fraction varies between 2 and 4 %, but three peaks occur at 2.7, 3.5 and 5.2 m depth. The sand content in the upper peak reaches 15 %, while the others contain little less than 10 % sand.

DISCUSSION OF THE SEDIMENTARY PATTERNS

The three cores Solberga, Brastad and Moltemyr contain sediments ranging from clayey silt through silty clay to clay (Fig. 7:4). The Solberga core is the most fine-grained, with a median diameter (Md) less than 2 μm (9ϕ) throughout, while between 7 and 18 m depth the quartile Q_{75} shows that as many as 75 % of the sediment particles have a diameter less than 2 μm (9ϕ). (See Fig. 7:1.) In general the quartile Q_{75} approaches 16 μm (6ϕ) in the Brastad and Moltemyr cores (Figs. 7:2 and 7:3).

The grain-size composition of the cores clearly shows (with one exception in Brastad, see below) that the three sites represent stable depositional environments in the past. However, variations in the fine-grained texture *versus* depth indicate that the patterns of sedimentation changed with time. The most pronounced changes are as follows.

1, a distinct change in the grain-size distribution between 17.7 and 18.4 m in the Solberga core, resulting in a very homogeneous clay (80 % < 2 μm) sequence between 17.7 and 5 m,
2, a sudden occurrence of a thin silt layer between 2.20 and 2.31 m in the Brastad core and
3, a marked change in the grain-size distribution between the levels 2.5–3 m and 3.3–3.5 m and 4.1–4.7 m in the Moltemyr core, resulting in homogeneous clay sequences.

Focussing at first on the Solberga core, the rapid but gradual decrease in the grain size from below upwards and the occurrence of a sand peak in the above-mentioned zone indicate changes in the supply and type of sediment and in the mechanisms of transportation. The different size fractions were not transported by the same means. Clay, fine and medium silt were transported in suspension while the coarser fractions travelled along the bottom.

As can be seen from the diagram (Fig. 7:1), the change from 18.4 m depth upwards starts from below with a strong increase in the clay content of the sediment, while the other fractions diminish. The first substep in the dramatic change of the grain-size composition indicates an increased supply and sedimentation of the suspended load during the period of deposition. The next substep is the occurrence of a sand peak followed by increased clay and coarse silt fractions with a simultaneous diminution of the fine- and medium-silt fraction upwards. This suggests a suddenly increased bottom transport simultaneously with the suspended load transport, which in turn indicates a sudden occurrence of currents at the time of deposition. The disappearance of the sand fraction, which is replaced upwards by coarse silt, shows that the strength of the currents was strongest at their onset.

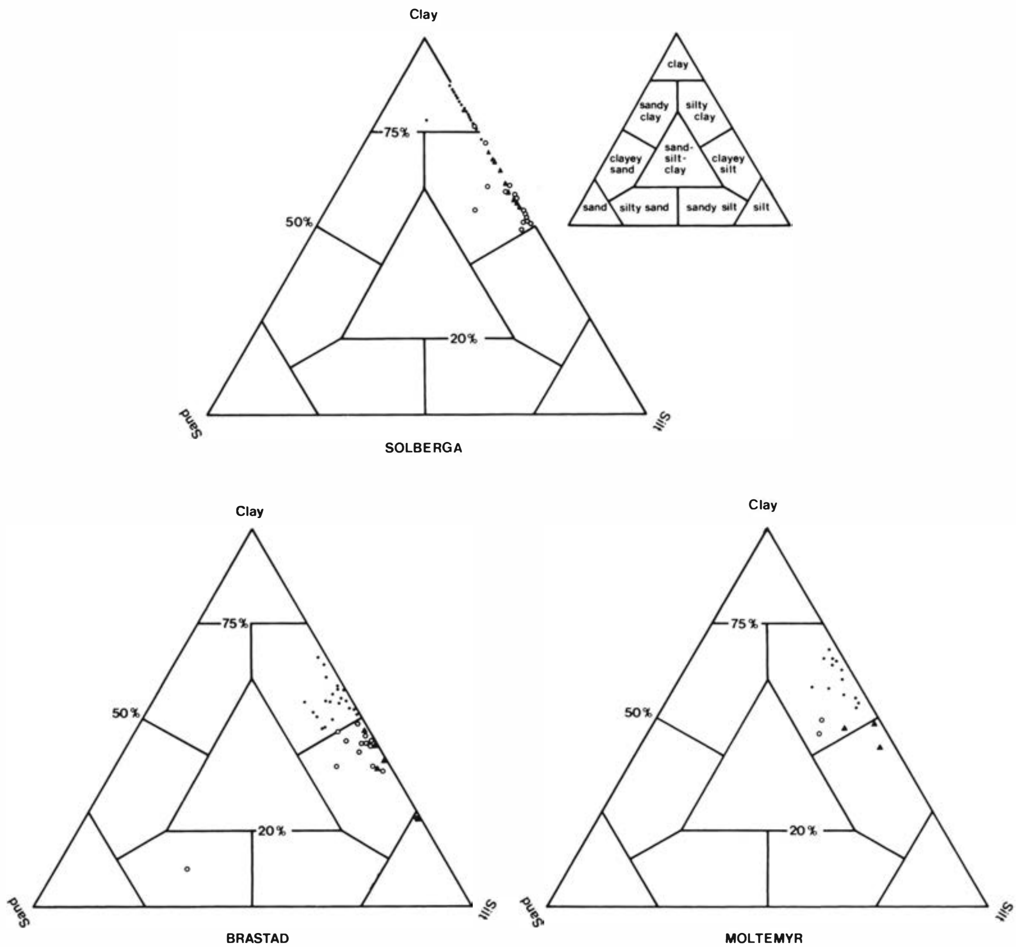

Fig. 7:4. Triangle diagrams of grain size from the Solberga, Moltemyr and Brastad cores.

The question arises, what can have caused the hydrographical conditions, which gave rise to the changed sedimentary pattern in Solberga? There is much evidence of intrusion of a water-mass with a heavy load of clay-size particles, *i.e.* the water-mass must have been transported long enough for the bulk of the coarser particle load to have settled and the current must have slackened so much, as to lose its erosive effect.

This points to the enormous discharge of meltwater, due to the intense retreat of the land ice during the Preboreal times. Approximately 500 000 km^3 meltwater (see Chapter 2) and about 10 000 km^3 freshwater from the Baltic Ice Lake (Strömberg 1977) were discharged into Skagerrak.

This huge quantity of water must have had a strong erosive capacity, particularly on the first part of the approximately 250 km long drainage route. As the gradient of the mainland declined towards the coast the flow velocity of the discharged water decelerated, which caused deposition of the bottom load and the coarser material in the suspended load, followed by more fine-grained material as the velocity of the flow decreased. Only the most fine-grained material reached the coast and settled as the stream slackened and ceased.

The freshwater outflow into the marine environment causes the hydrographically mixed region thus formed (cf. *inter alios* Pritchard 1967, Bowden 1980) to act as a trap for fine-grained sedimentary material of freshwater origin. The clay-size particles flocculate in contact with salt water (Postma 1967) and settle more rapidly than when in peptized form. Clay-size particles may therefore predominate within, or in the bottom region adjoining a freshwater outflow into the marine environment, where particles measuring about 20 μm (ф 5.5) mainly settle (cf. Sundström 1970, Cato 1977, p. 67). This can also be seen in the Solberga core (Fig. 7:1) where the clay fraction predominates together with the coarse silt fraction (20–60 μm) above the zone discussed.

The peak in the sand fraction at Solberga probably represents the initial phase of drainage, but since the bottom transport is a much slower mode of transportation than the transport in suspension (cf. Haldorsen 1974, p. 30), the increase of the clay content occurs before the sand peak at this (during the time of deposition) further more offshore site. Higher up in the Solberga core the fine- and medium-silt fractions increase upwards when the clay content decreases and the grain-size distribution gradually returns to a more "normal", for this region, marine distribution at about 5 m depth. The lowest part of the core contains irregularities in the grain-size distribution which are typical of more or less varved glacial sediments (cf. the Tuve cores in Häger 1981).

The melt- and freshwater discharge followed two main courses; the Göta River Valley and the presumably most important one over the Uddevalla strait. The cores taken from Solberga and southwards (see below) represent the former and Moltemyr and Brastad in varying degrees the latter course.

Examination of the Brastad core revealed no clay-rich sequence as in the Solberga core. Instead there is a silt layer at 2.20–2.31 m depth, which separates clay sediments of a very different character above and below (see Chapter 6). This may indicate either a break in the sedimentation or exogenous disturbances such as slides, local erosion *etc.*

The interpretation of the Moltemyr core is far more difficult. The coarsening of the sediment from about 3 m upwards, followed by a decreased grain size at the top of the clastic part of the core is probably related to the shallowing due to the isostatic uplift and the isolation of the site from the sea, respectively. Deeper down in the core the grain size decreases upwards at two levels, *i.e.* between 3.3 and 3.5 m and between 4.1 and 4.7 m. One of these variations may reflect the said discharge of meltwater during the Preboreal times or merely hydrographical changes of more local origin. Judging by the afore-mentioned decrease of the finer fractions, due to the shallowing of the site, it seems as though this change starts already at about 4 m depth. However, this change is interrupted by the occurrence of a peak in the sand fraction at 3.5 m depth which is directly followed by a 10% increase of the clay-, fine- and medium-silt fractions. The progress of this change resembles that found in the Solberga core rather than the change in the grain-size distribution at 4.1–4.7 m depth, which would imply that the change to a clay-rich sequence between 3.3 and 3.5 m more probably reflects the meltwater discharge in question. The very moderate increase of the finer fractions at this level in Moltemyr compared with e.g. Solberga may occur because Moltemyr is well protected by bedrock hills, which consequently may have diminished the effect of the meltwater discharge.

CORRELATION WITH ADJACENT AREAS

The grain-size distribution of the described Solberga core is essentially the same as those observed in other deep corings in the Göteborg area (Fig. 7:5).

At Tuve, cores were obtained in connection with the geotechnical and geological investigations carried out after the landslide in 1977. The complete stratigraphy of the locality was clarified (Cato *et al.* 1981) from an undisturbed 26.5 m long core, taken outside the slide area. At a depth of about 8 m the silty clay sequence was interrupted by a 1 m thick zone containing several thin layers of silt (Häger 1981). This stratum is overlain by a 3 m thick layer characterized by a high clay content (75–80 %), a very low calcite content (Cato 1981a and b) and an extremely high incidence of planktonic freshwater diatoms (Miller 1981). The two zones were assumed by Cato *et al.* (1981) to have been formed as a consequence of the increased meltwater discharge due to the rapid ice retreat and the drainage of the Baltic Ice Lake during the Preboreal times. The initial phase of this discharge was represented by the silt layers. These zones seem to correspond to the zone 5–18.4 m at Solberga.

At Bäckebol (Sällfors 1975) the clay content in a 10 m long core from about 6.5 m downwards is about 30 % higher than in the upper part of the core. The depth of penetration of this zone of increased clay content into the 40 m thick sediments is not known. However, there are many indications

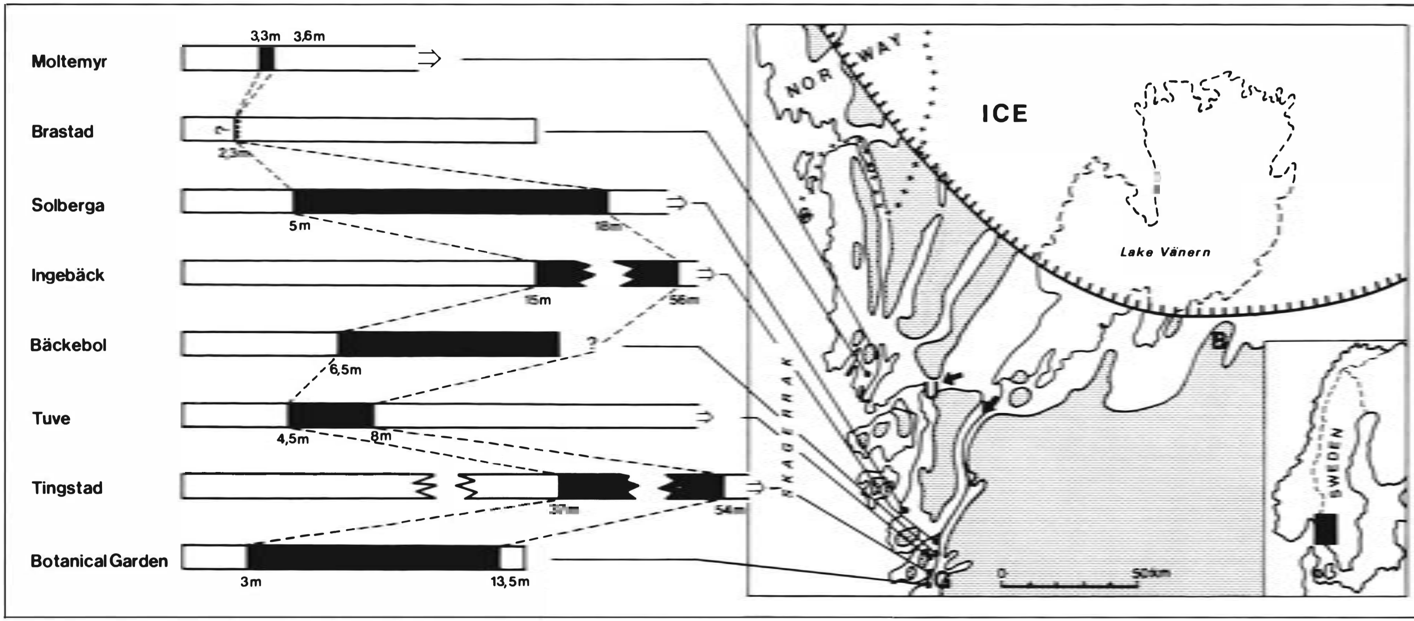

Fig. 7:5. The preliminary outlines of the extent of land (hatched areas) and ice during the opening of the Närke Strait and the presumtive main courses of the meltwater discharge to Skagerrak (black arrows). The cores show the extent, variation and position of the clay-bed originating from this drainage during the Preboreal times. B, L, U, and G denote Billingen, Lysekil, Uddevalla, and Göteborg.

that this clay-rich zone corresponds to the upper part of the Solberga zone 5–18.4 m, since the Pleistocene/Holocene boundary was found to be located at about 16 m depth (Klingberg 1977) or even deeper (see Chapter 14) in another core from Bäckebol.

The same increase of the clay content can also be seen between 54 and 56 m depth in a 70 m long core from Ingebäck (Tullström 1961) and between 51 and 54 m in a 93 m long core from Hisingen (Brotzen 1960, unpubl.).

In core B 873 from the Botanical Garden, Göteborg, (Mörner 1976) grain-size analysis was only performed on the upper 5 m. However, this part shows strong similarities with the upper part of the Solberga core. From about 3 m and down to the deepest analysis at 5 m depth in core B 873 the clay content is about 75–80 %. The water content of core B 873 is fairly constant from 3 m down to about 13 m, where it decreases by 50 %. It is likely that this change depends on a change in the grain-size distribution. If this assumption is correct the transition to the very fine clay sediment, documented in the upper part of the core, starts already at this level. Thus, the level of about 13 m depth in core B 873 corresponds to the 18.4 m level at Solberga.

In general no correlation between cores from different sites, based solely on the grain-size distribution, is possible, since the sedimentary conditions vary from place to place. However, similarities in the cores as above may be obtained. Whether or not these can be correlated, depends on whether an overall change in the sedimentary patterns due to the same hydrographical conditions occurred, and whether these patterns were strong enough to be reflected in the sediment, and bridge other processes causing changes of the sedimentary conditions at the different sites. Here these requirements seem to be fulfilled due to the enormous discharge of meltwater, which must have dramatically changed the hydrographical conditions along the former Skagerrak coast. But one can never be absolutely sure without studying other parameters.

SUMMARY AND CONCLUSION

It is thereby likely that the very fine-grained clay sequence seen in the Solberga core between 5 and 18.4 m depth also – as far as we know at present – appears with some variations in cores from the Göteborg region in the south up to the Lysekil area in the north (Fig. 7:5). Furthermore these considerable amounts of fine-grained sediments were transported to, and rapidly deposited in the Skagerrak as a consequence of the enormous discharge of meltwater from the rapidly retreating land ice during the Preboreal times. The rapid melting and retreat of the land ice was due to a milder climate during this period. The transition into the upwards very clay-rich sequence (5–18.4 m) in Solberga at 18.4 m depth, and in other cores mentioned, may therefore indicate the improvement in the climate, and from a sedimentological point of view consequently corresponds to the transition from Pleistocene to Holocene. In Moltemyr this typical change in the grain-size composition may be seen at 3.5 m depth, while in Brastad it is lacking, probably because of a break or other exogenous disturbances in the sedimentation at 2.3 m depth.

With the exception of the uppermost 2.3 m in the Brastad core, these sites were found to represent stable depositional environments in the past.

According to Mörner (1976, p. 199) marine sediments of the Kattegatt Sea seem generally to record the change from the Younger Dryas to the Preboreal by a coarsening of the sediment; in his view the "Younger Dryas clay" is characterized by a very high clay content. It must be stressed that no such process was observed in this study; instead the opposite trend (cf. above) occurs along the Skagerrak coast.

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