11. MAGNETOSTRATIGRAPHY

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INTRODUCTION

Virtually all sediments carry a remanent magnetization (RM), the direction and intensity of which is a function of the geological history of the sediment in question. The magnetic properties are complex functions of mineralogy, grain size, biological activities, diagenesis, lithological disturbances and variations of the geomagnetic field during and after deposition.

The purpose of the present work is to present the magnetic signals stored in three continuous sediment cores from Solberga, Brastad and Moltemyr, north of Gothenburg, and to deduce some palaeomagnetic and magnetostratigraphical results from these records.

SAMPLING TECHNIQUES

SOLBERGA AND BRASTAD

Azimuthally oriented vertical cores were obtained in the field with the help of a 66 mm Piston Foil Corer (see Chapter 4), the north direction being carefully indicated by means of small plastic plugs (±2°) in each core section. In the laboratory radiographs were made, and the declination and horizontal intensity preliminarily measured on the core sections mounted in plastic liners on a Digico vertical spinner magnetometer (Molyneux 1971).

The palaeomagnetic subsampling was performed together with the lithological description and joint sampling of the whole core for the stratigraphical, lithological and palaeontological studies. Cylindrical 1″ x 1″ polystyrene beakers were pressed into the cleaned, undisturbed sediment orthogonal to the core axis, and with common azimuthal orientation. The magnetic sampling interval was usually 10 cm, except around the suspected Pleistocene/Holocene transition, and around declination anomalies in the preliminary magnetic record, where the sampling interval was condensed to 3–5 cm.

The palaeomagnetic specimens were sealed with a lid and weighed immediately afterwards to give the bulk density (wet), the volume being constant. This bulk density proved to be a rapid and easily determined, useful indicator of lithological changes, which in combination with the preliminary magnetic intensity record served to focus the attention on the suspected Pleistocene/Holocene boundary, enabling a denser sampling around this depth for various other purposes already at this early stage of the joint investigations.

MOLTEMYR

At Moltemyr a somewhat different procedure was followed, as a magnetic pilot study was first made on a 1 m long piston core section (2.5 to 3.5 m depth), and later on a 14 m long by 37 mm thick piston foil core (Moltemyr 1981) was sampled and palaeomagnetically investigated in detail.

MAGNETIC TECHNIQUES

Besides the whole core vertical spinner measurements of the natural remanent magnetization (NRM) which were essentially used as a guide for the magnetic subsampling, the subsequent measurements of the remanent magnetizations (RM) of the oriented specimens were also made on the Digico spinner magnetometer. The spin time was adjusted to allow an accuracy in direction of ±2° for intensities >1μG ($\cdot 10^{-3}$ A/m).

After measurement of the NRM intensity J_o, the stability of the remanent magnetization was tested by alternating field demagnetizations in zeroed earth field (±10γ). Most specimens were subjected to stepwise demagnetizations with peak alternating fields of 100 and 300 Oe, and every fifth specimen was further demagnetized in fields of 500, 900, and 1500 Oe peak.

Finally, the reversible bulk susceptibility k of all specimens was measured in a 1 Oe (1 kHz) susceptibility bridge with a noise level of $3 \cdot 10^{-7}$ G/Oe ($4\pi \cdot 3 \cdot 10^{-7}$ SI), and the modified Koenigsberger ratio $Q = J_o/k$ computed.

MAGNETIC MEASUREMENTS ON SOLBERGA CORE

INTENSITY

The intensity J_o of the NRM is shown in Figs. 11:1b and 11:2a, the general range being between 0.8 and 10 μG ($\cdot 10^{-3}$ A/m). On the whole the intensity varies broadly from a maximum at 26 m to a minimum at 12 m and a maximum again at 6 m.

Through most of the core the intensity varies fairly smoothly, apart from the depth intervals 17 m to 13.2 m and 7 m to 5 m, where the scatter is notably higher. This probably reflects a higher variability in the grain size or

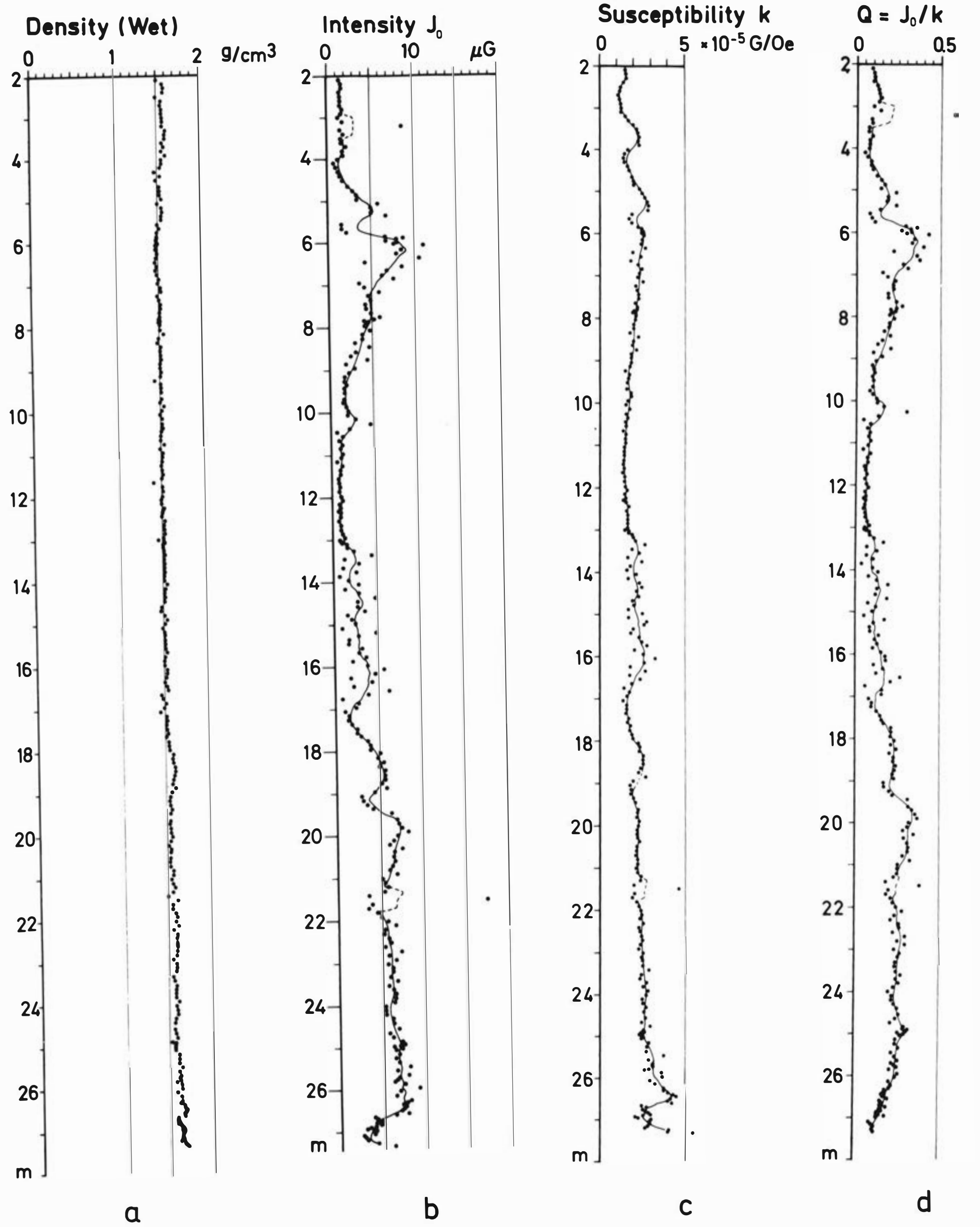


Fig. 11:1. Density, NRM intensity J_o, susceptibility k and modified Koenigsberger ratio Q = J_o/k of the Solberga core. Continuous curves are 5-point moving averages; depth in metres.

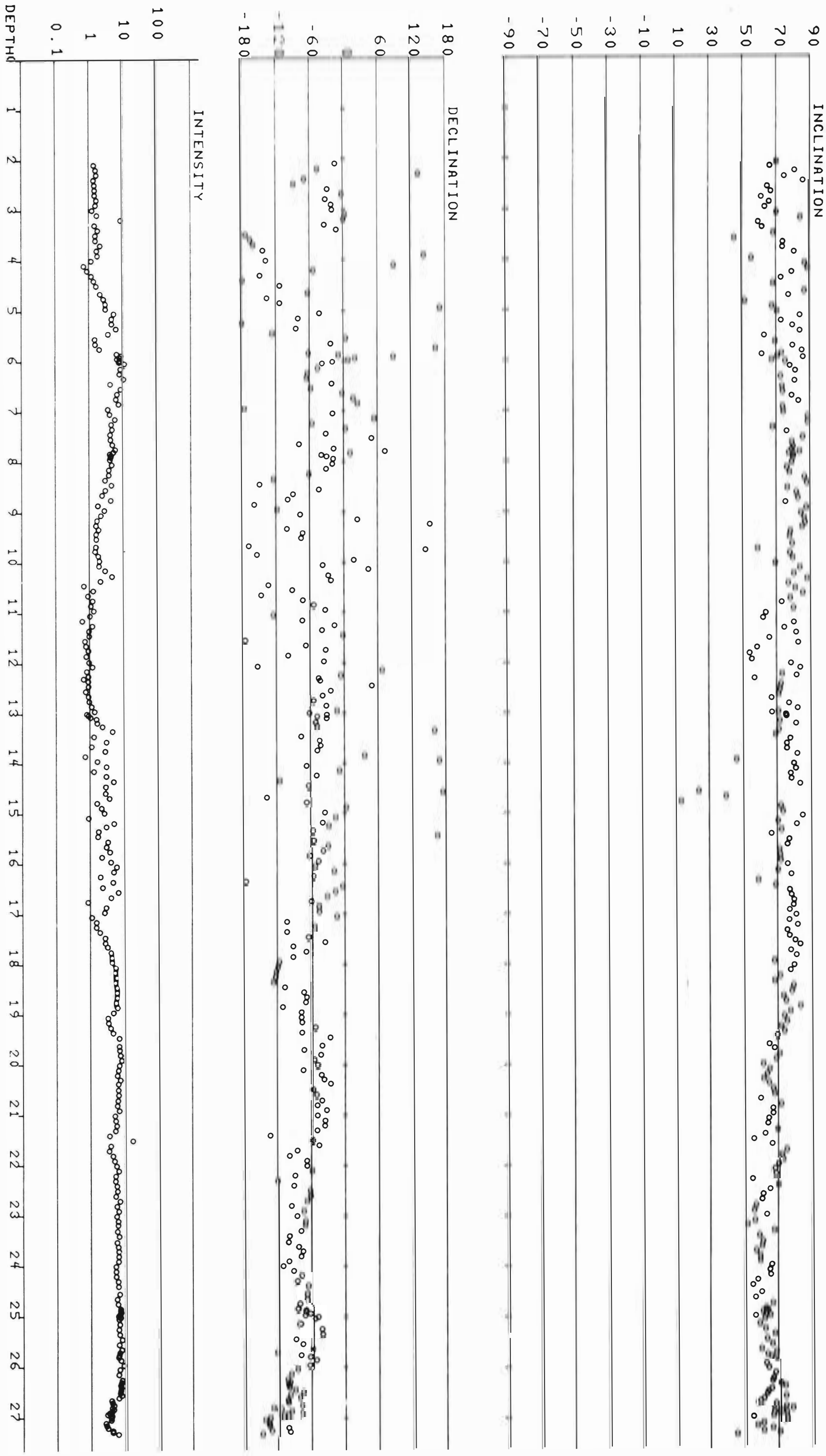


Fig. 11:2a–c. Intensity (log scale), declination and inclination of the Solberga core. Individual measurements; curves are 5-point moving averages. Swings in the declination and inclination are labelled D1 through D8 and I1 through I13, respectively. a. Solberga, NRM.

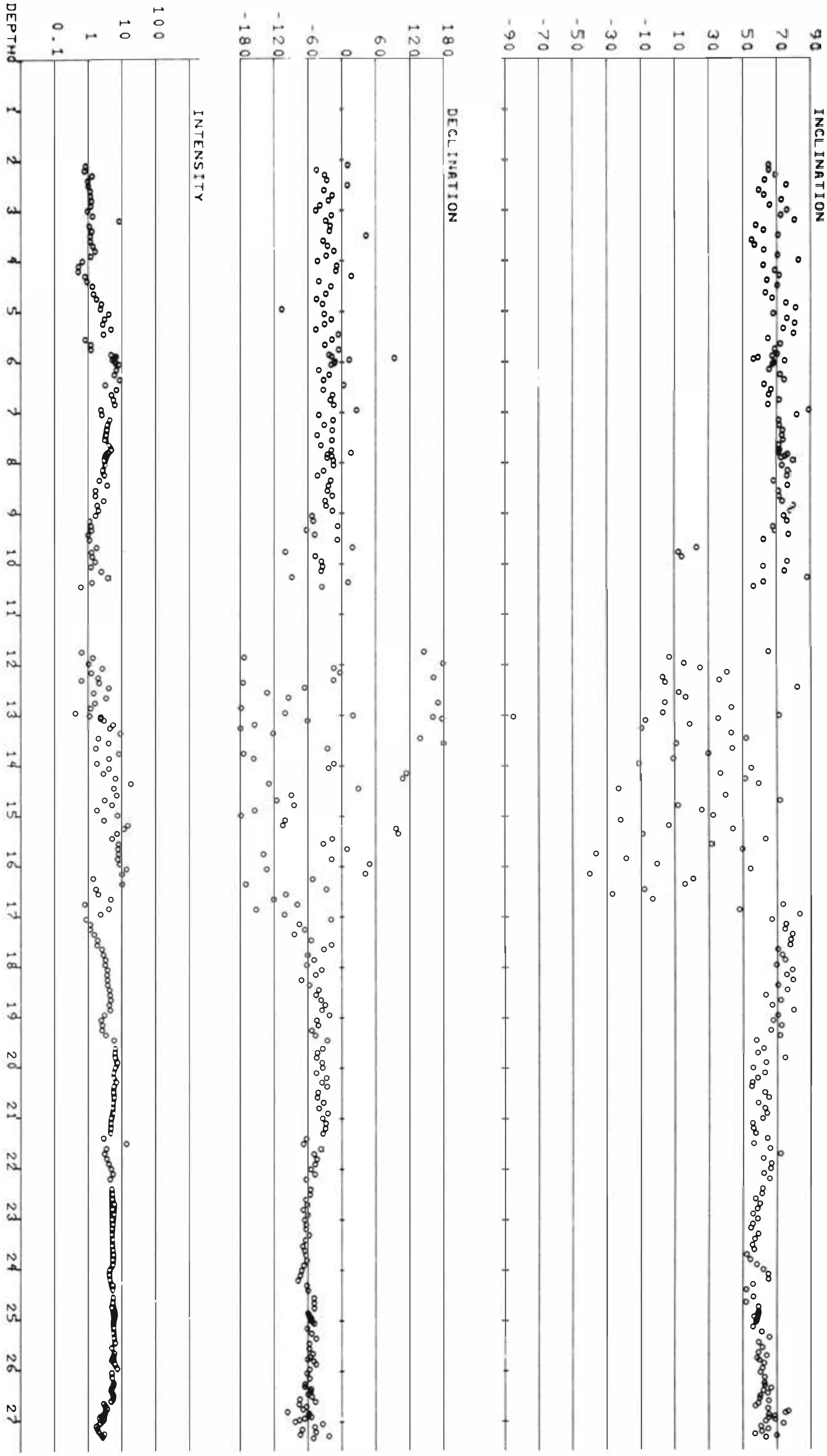


Fig. 11:2b. Solberga, F = 100 Oe.

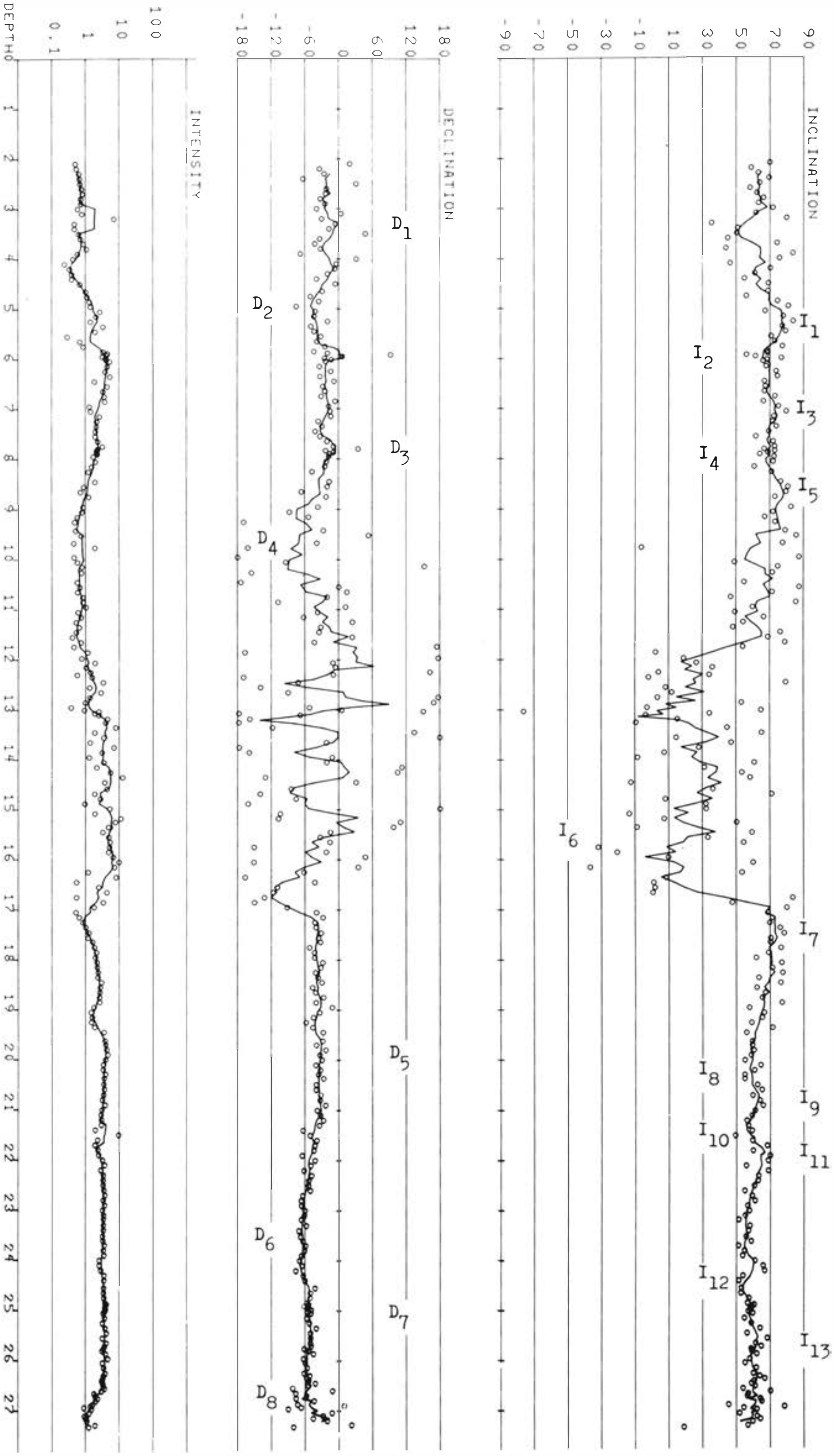


Fig. 11:2c. Solberga, F = 300 Oe.

content of the ferromagnetic minerals, and hence indicates a variation in depositional and environmental conditions, such as e.g. grain-size distribution, bioturbation, slumping, water depth, turbulence, salinity, and/or temperature. This is further discussed below.

The low intensity values <5 μG at the bottom up to 26.6 m are probably caused by the higher sand content in the clay. Between 26.6 m and 19.45 m the intensity is relatively smooth and constant (between 5 and 8 μG), except for a local minimum at 21.4–21.7 m with one isolated high value. At 19.4–19.0 m the intensity drops significantly, and above another well defined offset at 18.95 m a very smooth decrease until 17.0 m is found, probably indicative of some systematic change in lithology and/or environment.

Between about 17 and 9 m the intensity is systematically low, at first rather scattered with a mean level about 3 μG, but above 13.2 m with constant values around 1 μG up to 10.4 m. Above a local peak at 10.2 m the values gradually increase up to a (somewhat scattered) peak of 8 μG at 6 m depth. Above a local minimum between 5.8 and 5.5 m the intensity finally decreases and stabilizes around 1–2 μG at the top.

SUSCEPTIBILITY

The reversible susceptibility k varies between 10 and 50 μG/Oe ($\cdot 4\pi$SI), and is obviously strongly correlated with the intensity, as the susceptibility record (Fig. 11:1c) is in many respects a mirror image of the intensity record. This is the case too with regard to the scatter between 17.0 and 13.2 m and to the position of peaks and gradually broad changes. However, the susceptibility variation is smoother, the range of variation relatively smaller, and the peaks generally less pronounced, apart from those at 26.5 m and 3.8 m, which are barely noticeable on the intensity record.

It thus appears that on the whole we may assume that the integrated contribution of the individual ferromagnetic particles to the NRM intensity and the reversible low field susceptibility are approximately proportional; hence the compositional variations should tend to be cancelled when forming the Q-ratio, the magneto-sedimentary properties being roughly constant (except for the 'diluted' interval, as discussed below).

Q-RATIO

The modified Koenigsberger ratio $Q = J_o/k$ shown in Fig. 11:1d varies in general between 0.05 and 0.4. Between 27 m and 6 m about 3/4 of a fairly regular sinusoidal cycle appears to be present, followed by a sharp decrease in the Q-ratio above 6 m. Taking the broad sinusoidal minimum around 13 m as 0.06, and the broad maximum around 22 as 0.30, this corresponds to a variation between 33% and 167% of the broad mean value of $Q = 0.18$.

Provided that the suggestion concerning the individual ferromagnetic particles above is correct, this wide variation in the Q-ratio is likely to mirror the geomagnetic field intensity variations at the site during the deposition of the sediment, the NRM intensity being proportional to the inducing field. Correlations with sequences of equal ages and non-variant lithology may thus be possible. The relative variation is slightly higher than the average global intensity variations of the geomagnetic field (between about 50% and 150%) for the last *c.* 9 000 years inferred from palaeointensity studies on archaeomagnetic materials (Bucha 1970, Kovacheva 1980, Shaw 1979).

DIRECTIONS OF REMANENT MAGNETIZATION

The intensity of the NRM has already been commented upon in relation to the susceptibility and Q-values of Fig. 11:1 (linear scales). In Fig. 11:2a the NRM intensity is replotted on a logarithmic scale together with the (true) declination and inclination, while Figs. 11:2b and 11:2c show the intensity, declination and inclination after partial demagnetizations in zeroed earth field with alternating peak fields of 100 and 300 Oe, respectively.

The NRM declination (Fig. 11:2a) is fairly well defined with moderate scatter between 27 m and 17 m depth, whereas above this level the declinations are more discrete, although a systematic pattern is still visible. The local mean of the declination is systematically westerly, with an overall mean around 60° west.

The NRM inclination generally varies between 50 and 90° with a few low values around 15 m, the overall mean value being close to the central axial dipole inclination of 71° at the site. A broad sinusoidal variation is apparently present, with maximum at 27 m, minimum at 23–25 m, and generally high values above 19 m.

Turning to the partially demagnetized values, at 100 and 300 Oe in Figs. 11:2b and 11:2c, the importance of magnetic cleaning is clearly demonstrated, as both records have significantly changed: The cleaned declination records generally show less scatter than the uncleaned NRM values, and hence are likely to give a better estimate of the geomagnetic declination pattern. We still observe a higher scatter in declination between 17 and 9 m (as well as in intensity between 17 and 13 m).

Between 27 and 17 m two cycles in the declination are seen (D_8, D_7, D_6, D_5 in Fig. 11:2c) with amplitudes of 10 to 15°, and between 12 and 3 m another double cycle (D_4, D_3, D_2, D_1) with amplitudes between 15 and 20° may be present. These amplitudes are of the same magnitude as that of present day secular variation as known from historical and archaeomagnetic records, as well as from post-glacial lake sediments in England (Creer *et al.*

1972) and Poland (Creer *et al.* 1979) and late-glacial sediments in Denmark (Abrahamsen and Knudsen 1979, Abrahamsen and Readman 1980).

The cleaned inclination records with F = 100 Oe (Fig. 11:2b) and F = 300 Oe (Fig. 11:2c) show a systematic secular variation pattern between 27 and 17 m (I_{13}–I_7), and between 9 and 2 m (I_5–I_1) with amplitudes of between 4 and 7°. Between 17 and 12 m, however, the inclination values have been significantly lowered by the cleaning process (I_6), the majority of values now falling between –30 and +50°, although the scatter has increased. The increased scatter may be due to some kind of disturbance, followed by a postdepositional partial remagnetization in the present steeply inclined field direction as caused by the increasing freshwater flux discussed below.

At the same level, the declination is very scattered too, variations up to ±180°, and the intensity and the Q-ratio are low. The age of this scattered low-inclination interval is somewhat younger than 10 000 years B.P. See further discussion below.

MAGNETIC MEASUREMENTS ON BRASTAD CORE

INTENSITY

The NRM intensity J_o is shown in Fig. 11:3b on a linear and in Fig. 11:4a on a logarithmic scale. Between 15 and 8 m the intensity reaches a relatively high level, between 20 and 40 μG, with a sharp drop at 8 m to a level around 5 μG between 8 and 3 m. From 3 to 2.3 m the intensity decreases to around 1 to 2 μG and remains low except for a sharp peak at 2.3 m, which coincides with a lithological hiatus also present in the density record (Fig. 11:3a).

SUSCEPTIBILITY

The susceptibility (Fig. 11:3c) varies more smoothly from high values at the bottom about 100 μG/Oe to a level of 30 to 40 μG/Oe between 8 and 3 m. Above 3 m the susceptibility approaches 15 μG/Oe, except for a peak at the hiatus at 2.3 m. Both major trends and minor anomalies in the susceptibility record are clearly discernible in the density record of Fig. 11:3a, too.

Q-RATIO

The Q-ratio increases fairly smoothly from 0.2–0.3 at the bottom to about 0.6 at 8.5 m, with a sudden drop above 8 m to a level of between 0.1 and 0.2. Moreover in Q there is a peak at the hiatus at 2.3 m.

Both the intensity and the Q-ratio records suggest rather significant lithological (and hence environmental) changes at 8 m, 3 m, and 2 m, whence any conclusions about the palaeointensity would be problematic. The density and susceptibility records show a smoother variation around 8 m. All parameters clearly indicate the hiatus at 2.3 m.

DIRECTIONS OF REMANENT MAGNETIZATION

The directions (declination and inclination) of the NRM are shown in Fig. 11:4a, while Figs. 11:4b and 11:4c illustrate the same parameters after partial demagnetizations in zeroed earth field with alternating peak fields of 100 and 300 Oe, respectively; in Fig. 11:4c a 5-point moving average has been superposed on the data.

The declination of the primary data is rather scattered, whereas in the cleaned data the scatter has diminished considerably. In Fig. 11:4c about half a cycle of a broad-scale, secular variation is seen, the declination being around 60°E at the bottom (d_7), decreasing to about 60°W at 5 m depth (d_2), and increasing to around O° at the hiatus at 2.3 m. At the top of the core, the declination again varies rapidly to about 60°E (d_1). The latter trend towards the east above the hiatus (*i.e.* of postglacial age) may be correlated with an equivalent eastward change, recorded in some Ancylus-Yoldia sedimentary cores from the Baltic Sea east of Bornholm (Abrahamsen, in prep.).

The NRM inclination data mostly vary between 60° and 80°, while the cleaned data are lowered slightly to between 60° and 70° in most cases, the overall mean being 5° to 10° below the axial dipole inclination of 71°. In the cleaned data about 5–6 short period cycles with amplitudes of 4° to 8° appear (i_{11}–i_1) superposed on a broad cycle with maximum at 14 m, minimum around 10 m, maximum around 6 m and minimum at 3 m.

MAGNETIC MEASUREMENTS ON MOLTEMYR CORE

INTENSITY

The NRM intensity J_o is shown in Fig. 11:5b on a linear, and in Fig. 11:6a on a logarithmic scale. Below 15 m depth the intensity is relatively high (13 to 22 μG). Between 15.0 and 14.7 m the intensity decreases to about 5 μG. Between 14.7 and 7.1 m it remains fairly stable with values typically between 5 and 8 μG (depths between 14.7 and 9.7 m), the mean level gradually increasing to around 10 μG (9.7 to 7.1 m) and with local peaks around 11, 9.6, 9.2, 8.6, and 7.9 m. After a sharp drop at 7.1 m to 4 μG, the intensity gradually decreases to about 2 μG at 5.1 m. Between 5.1 and 4.3 m a rapid oscillation (0.3 to 12 μG) is seen, and above 4.3 m the level finally stabilizes around 1 to 2 μG.

SUSCEPTIBILITY

The susceptibility k (Fig. 11:5c) shows essentially the same trends as the intensity. Three levels with high (~50 μG/Oe), intermediate (~30 μG/Oe) and low (~10 μG/Oe) average values are found below 15 m, between 15 and

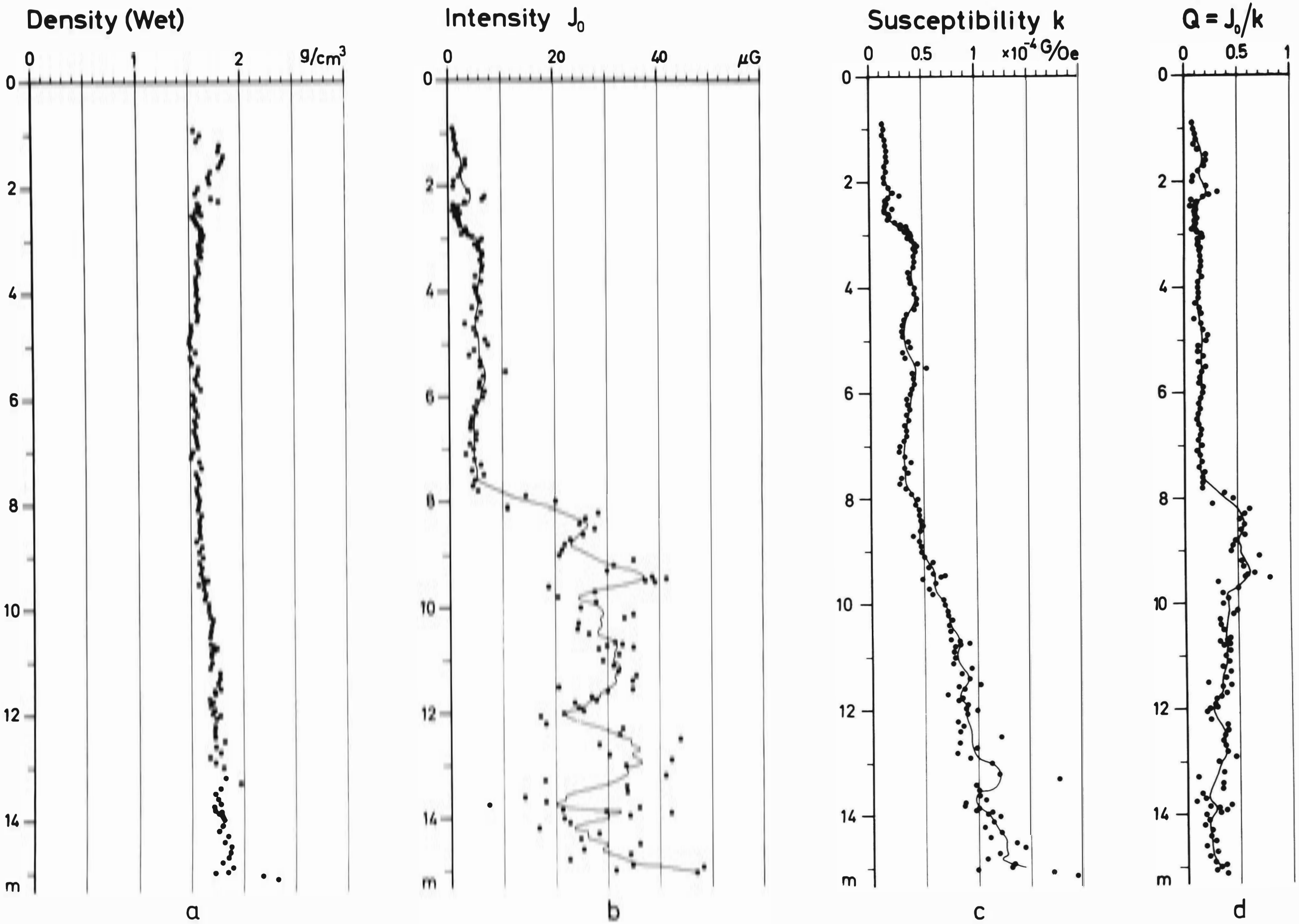


Fig. 11:3. Density, NRM intensity J_o, susceptibility k and modified Koenigsberger ratio Q = J_o/k of the Brastad core. Continuous curves are 5-point moving averages; depth in metres.

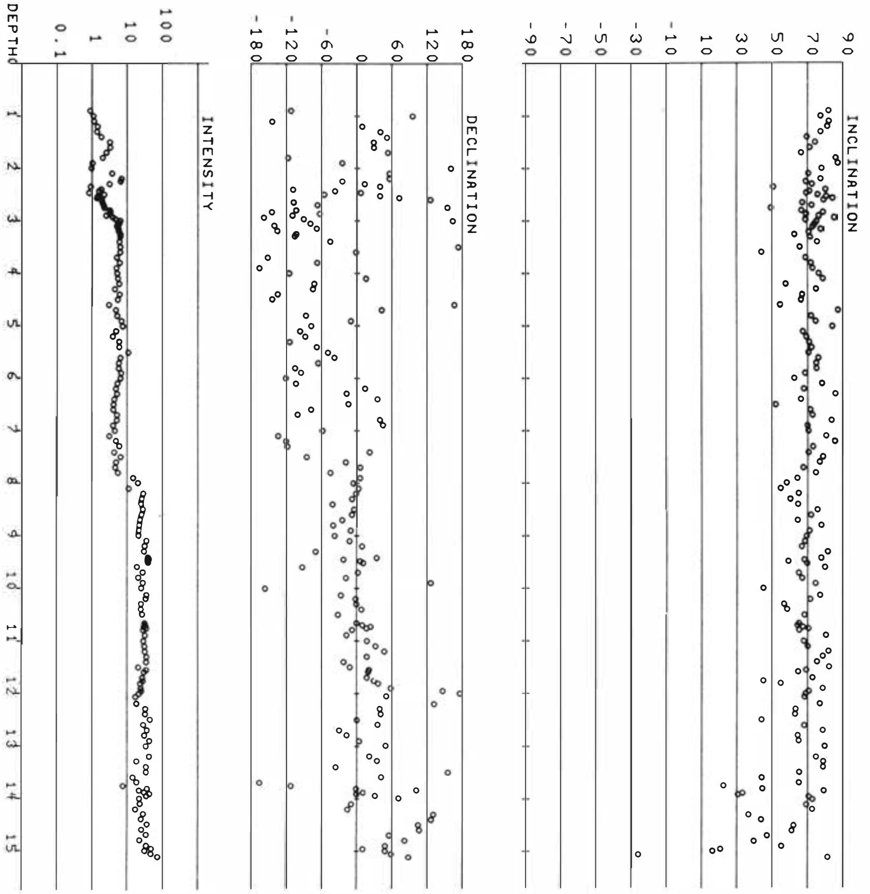


Fig. 11:4a–c. Intensity (log scale), declination and inclination of the Brastad core. Individual measurements; curves are 5-point moving averages. Swings in the declination and inclination are labelled d1 through d7 and i1 through i11, respectively. a. Brastad, NRM.

6.3 and above 4.3 m, respectively, while more or less pronounced local peaks are seen at 15.2, 13.7, 10.8, 9.7, 9.2, 8.0 to 7.2, 5.5, and 5.0 to 4.3 m, respectively. The three levels and most of the local peaks are easily recognizable and closely correlated with the density record, as described elsewhere (Chapter 8). Hence at least part of the density variations are likely to be caused by variations in the dominating magnetic minerals.

Q-RATIO

The record of the Q-ratio (Fig. 11:5d) shows a smooth variation with values around 0.3 at the bottom, a level around 0.17 between 14.7 and 9.7 m, a higher level around 0.25 between 9.7 and 7.8 m and a low level around 0.1 between 7.0 and 3.2 m. Very pronounced peaks are found at 9.2 (Q=0.7)

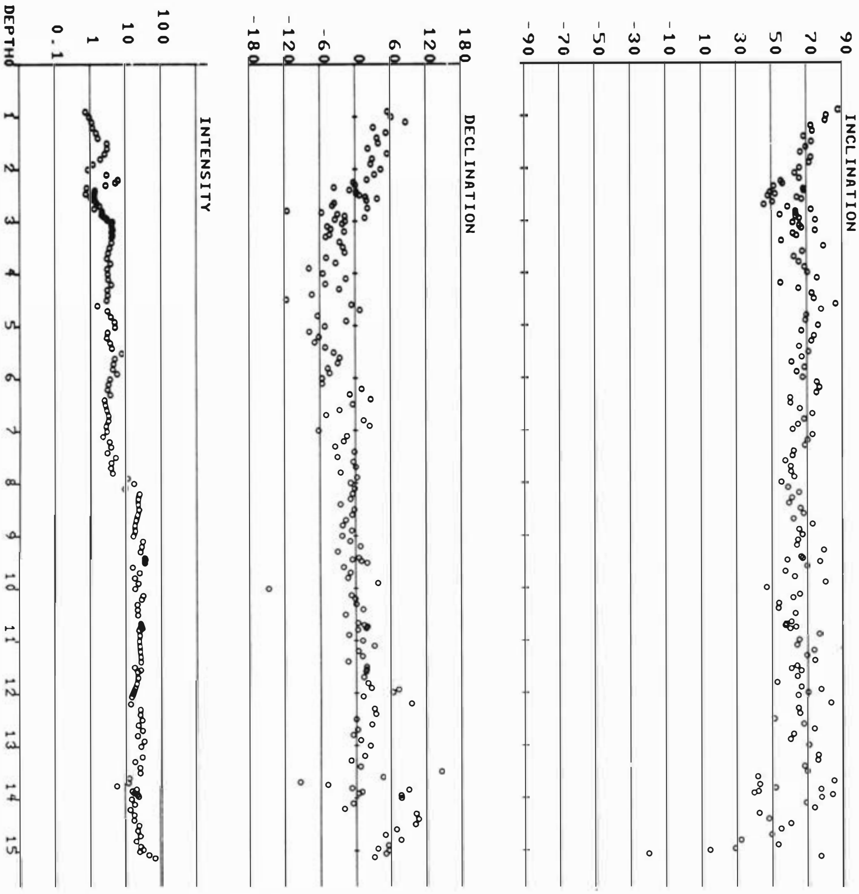


Fig. 11:4b. Brastad, F = 100 Oe.

and 2.2 m, and minor peaks are seen at 11, 8.6, 8.0, 7.1, and 4.65 m (Q=0.23), the latter being a rapid oscillation with a minimum of .026 at 4.40 m. At this level the grain-size distribution indicates a shift in lithology from clayey silt to silty clay (see Chapter 7).

DIRECTIONS OF REMANENT MAGNETIZATION

The NRM intensity (logarithmic scale), declination and inclination records are illustrated in Fig. 11:6a, while Figs. 11:6b and 11:6c show the same parameters after partial demagnetizations in alternating peak fields of 100 and 300 Oe respectively. In Fig. 11:6c the curve is a 5-point moving average. Pilot demagnetizations indicate median destructive fields typically between

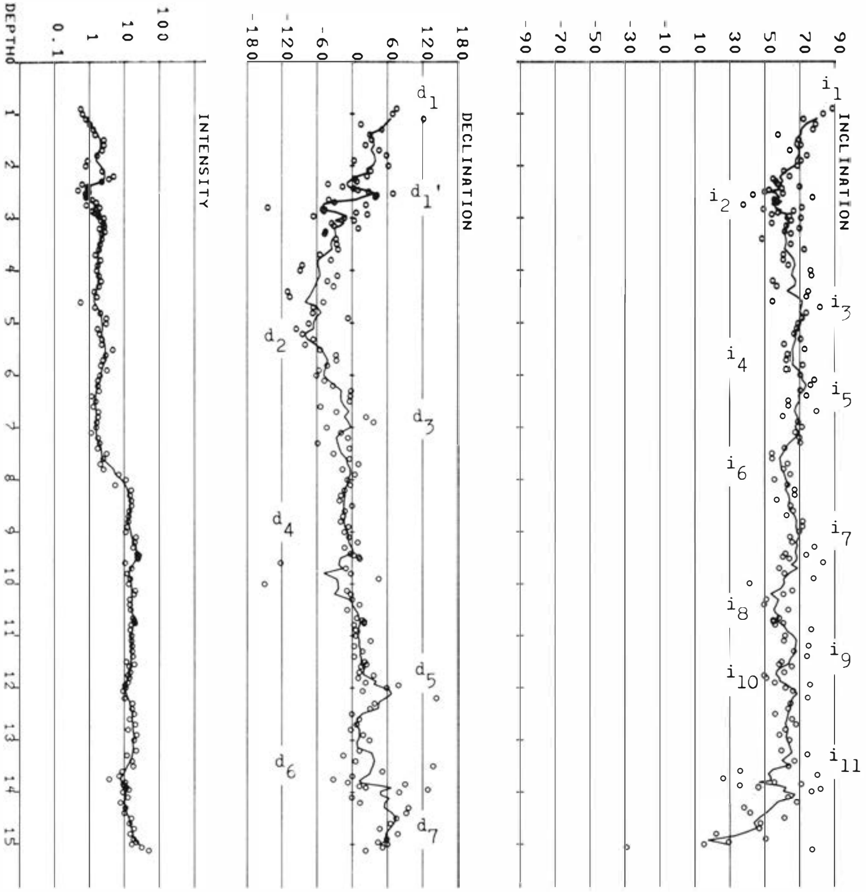


Fig. 11:4c. Brastad, F = 300 Oe.

200 and 300 Oe. The declination records show only minor changes during the magnetic cleaning in contrast to the Solberga and Brastad cores.

The declination record of the Moltemyr core appears to be somewhat dubious below 8.2 m, as systematic offsets between 90 and 180° seem to be present at 8.2, 9.5 and 12 m. These levels coincide with some of the sections, into which the core was cut before transportation and subsampling in the laboratory, as indicated in Fig. 11:6a. Furthermore as the inclinations do not change sign the shifts in declination cannot be due to reversals, and errors in the azimuthal orientation are the most likely explanations of the offsets. In the declination record, the original measurements are given by circles, while crosses indicate a 180° correction in search of better continuity.

The inclination records show a systematic increase from about 70° at 15 m to 85° at 10 m, with minor short wave oscillations superposed. Above 10 m the mean inclination is 50 to 60°, except at the top. Because of the higher scatter, the interval between 10 and 3 m of the inclination record appears to be less reliable. It may be recalled, that highly scattered and low inclination values were found also in the cleaned records of the Solberga core between 17 and 12 m.

DISCUSSION

SOLBERGA

Most of the lithological, stratigraphical and palaeontological parameters studied by the working group suggest the existence of a boundary around the 19 m level in the Solberga core.

Focussing especially on the 19 m level in the Solberga core, a change is indicated in the wet density at 18.95 m, a jump occurs in the NRM intensity at 18.95 and 19.35 m, a smooth increase in susceptibility begins at 19.0 m (and a jump at 18.85 m), and there is a jump in Q at 18.95 and 19.35 m, with a significant change in level above 19.35 m. A directional change is seen in the NRM declination record at 17.95 and 18.50 m but not in the cleaned records. The inclination shows a smooth variation below 17 m with a gradual increase between 20 and 17 m, indicating that at least up to this level, a postdepositional disturbance of the sediment is unlikely to have occurred.

The combined magnetic information thus supports the idea that a significant transition, presumably induced by climatic variations causing a change in environment, lithology and hence magnetic properties, may be present around the 19 m level.

The directionally very scattered interval between 17 and 12 m is interesting from a geomagnetic point of view, as it may indicate an excursion of the geomagnetic field. However, no well documented excursions of the geomagnetic field in Holocene time are yet known, and the directional scatter could most simply be explained as due to some kind of postdepositional disturbance such as sliding, slumping, bioturbation, or compaction.

As described elsewhere in this volume (Chapters 3, 7, 10, and 16), there are several signs in the Solberga core around 18–19 m depth of a change in the environment from saline to more brackish water conditions. This may be related to the climatic amelioration at the Pleistocene/Holocene transition, with an increase in the meltwater flux and with the drainage of the Baltic Ice Lake.

The increased flux of sediment-carrying freshwater into the marine waters is likely to increase the deposition rates, as the accompanying clay particles flocculate in the saline waters. Indeed, the clay percentage increases at 18 m depth from 50–55% to 80–85% while the silt persentage is reduced (Chapter

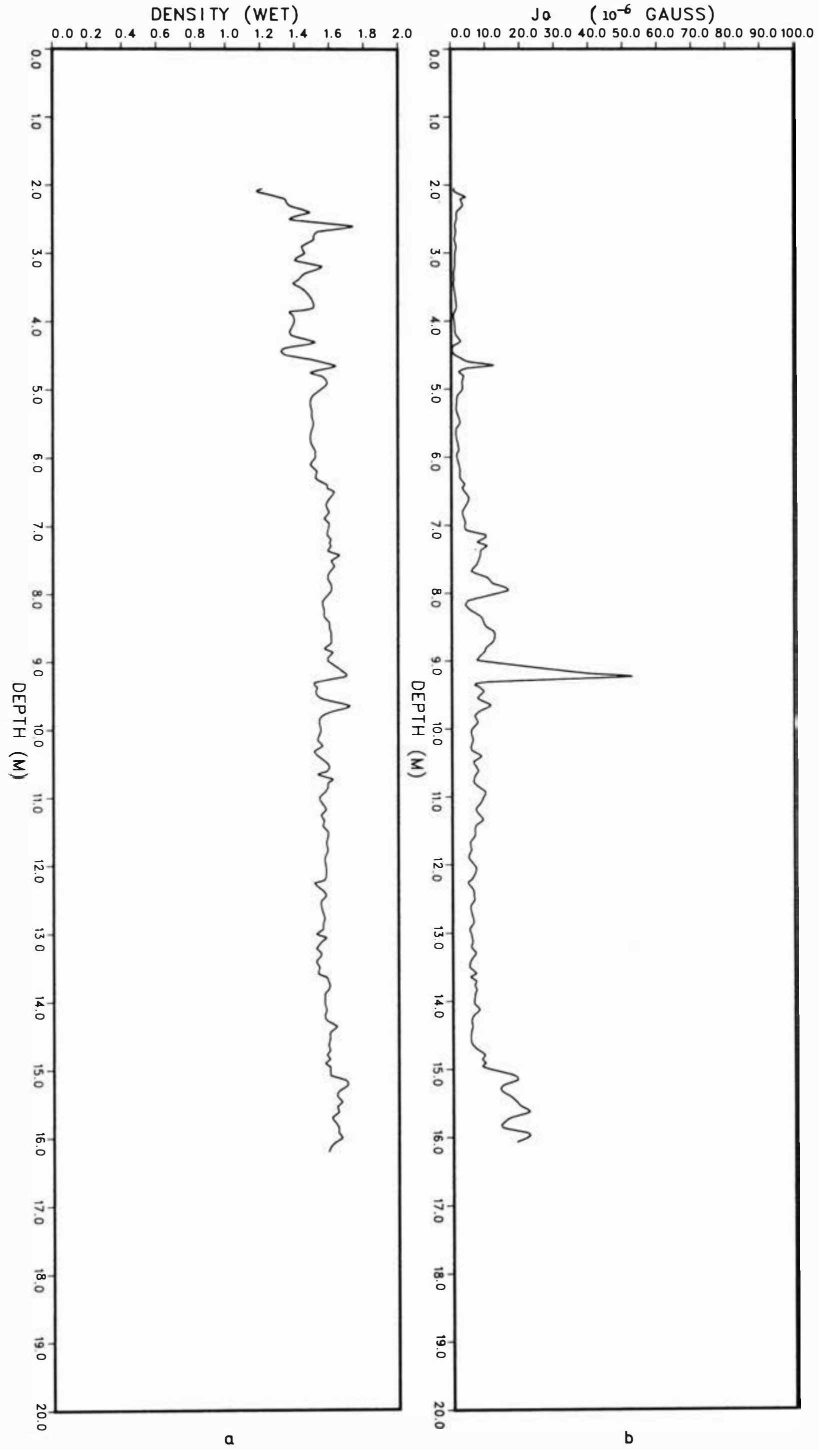
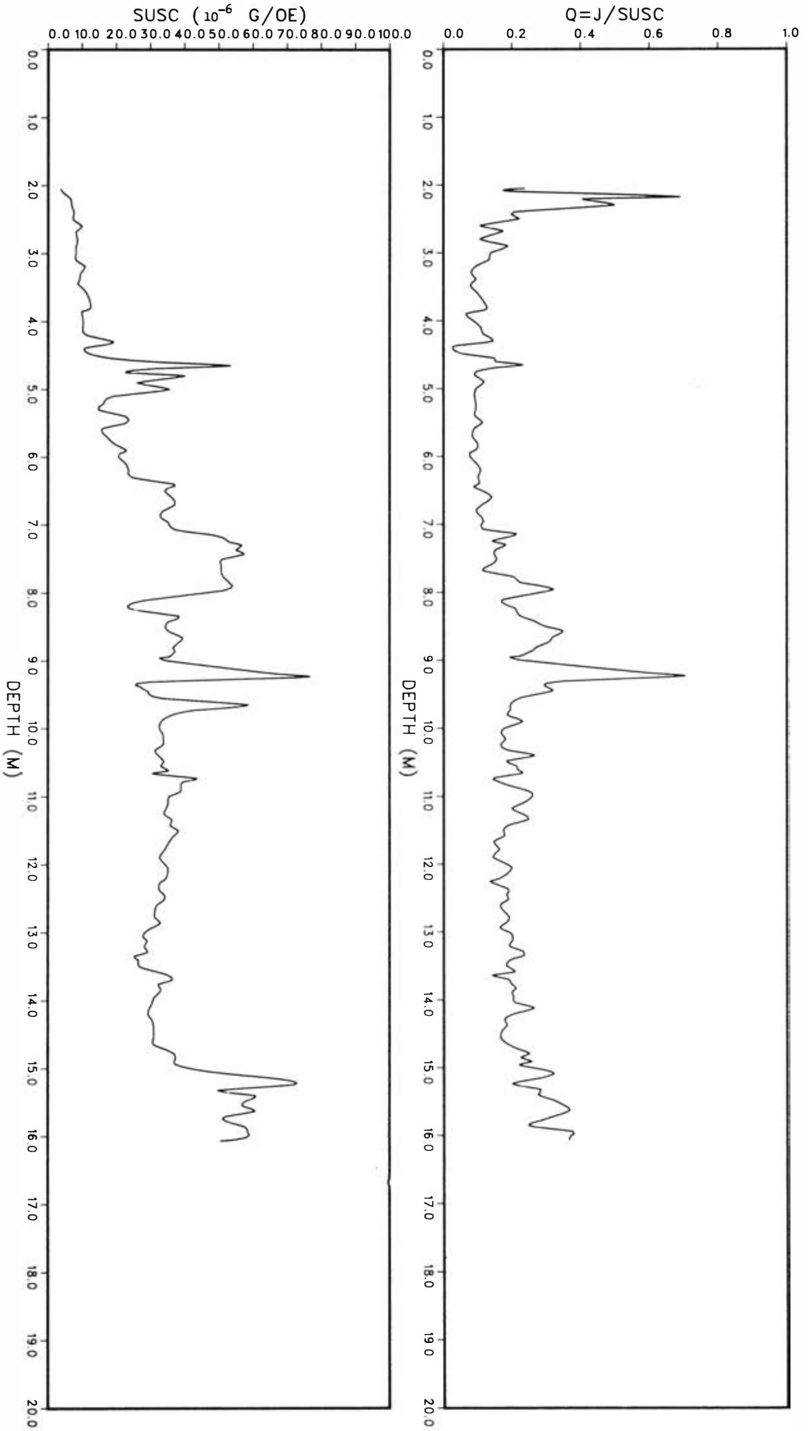


Fig. 11:5a–d. Density, NRM intensity J_o, susceptibility k and modified Koenigsberger ratio



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$Q = J_o/k$ of the Moltemyr core. Depth in metres.

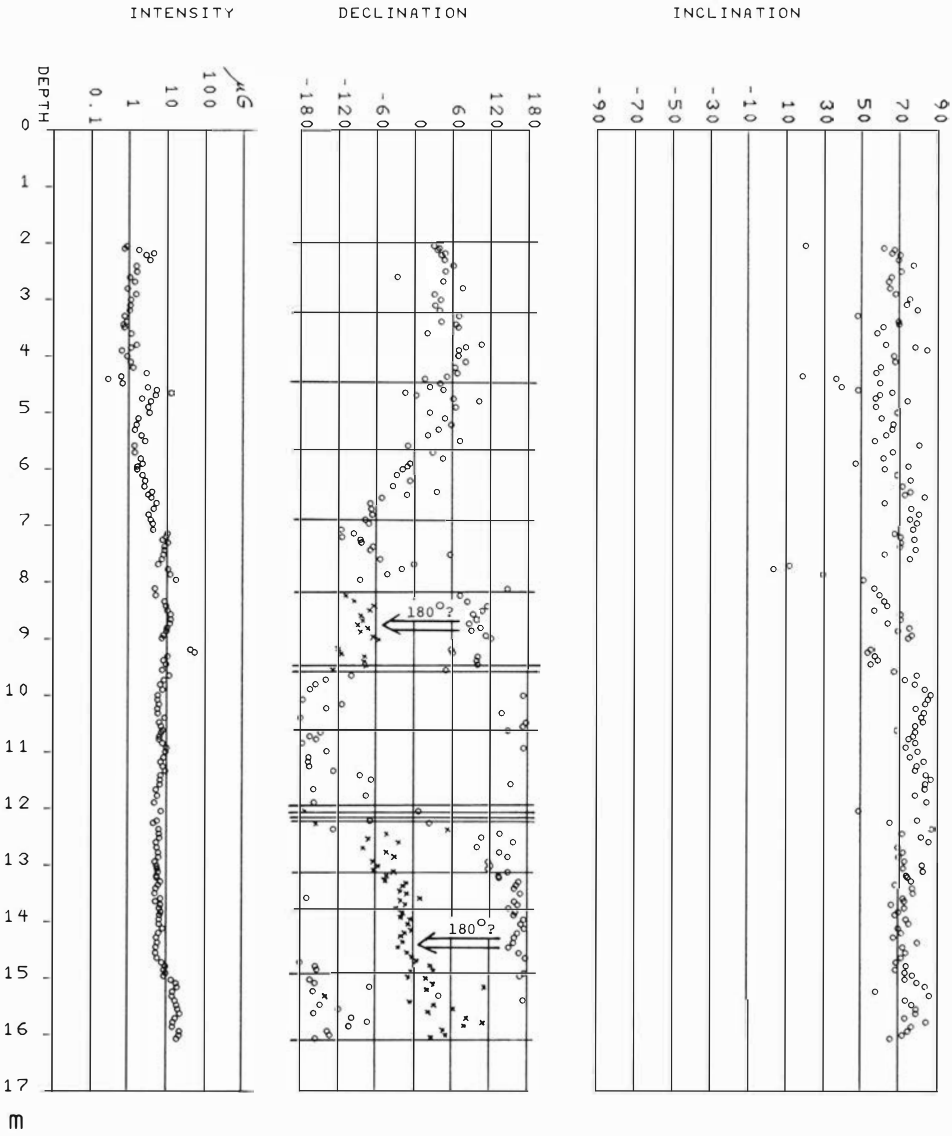

Fig. 11:6a–c. Intensity (log scale), declination and inclination of the Moltemyr core. Horizontal lines in the declination record indicate the core sections. Original data are indicated by small circles, while crosses indicate a possible (hypothetical) shift in azimuth of 180°. The curves are 5-point moving averages. a. Moltemyr, NRM.

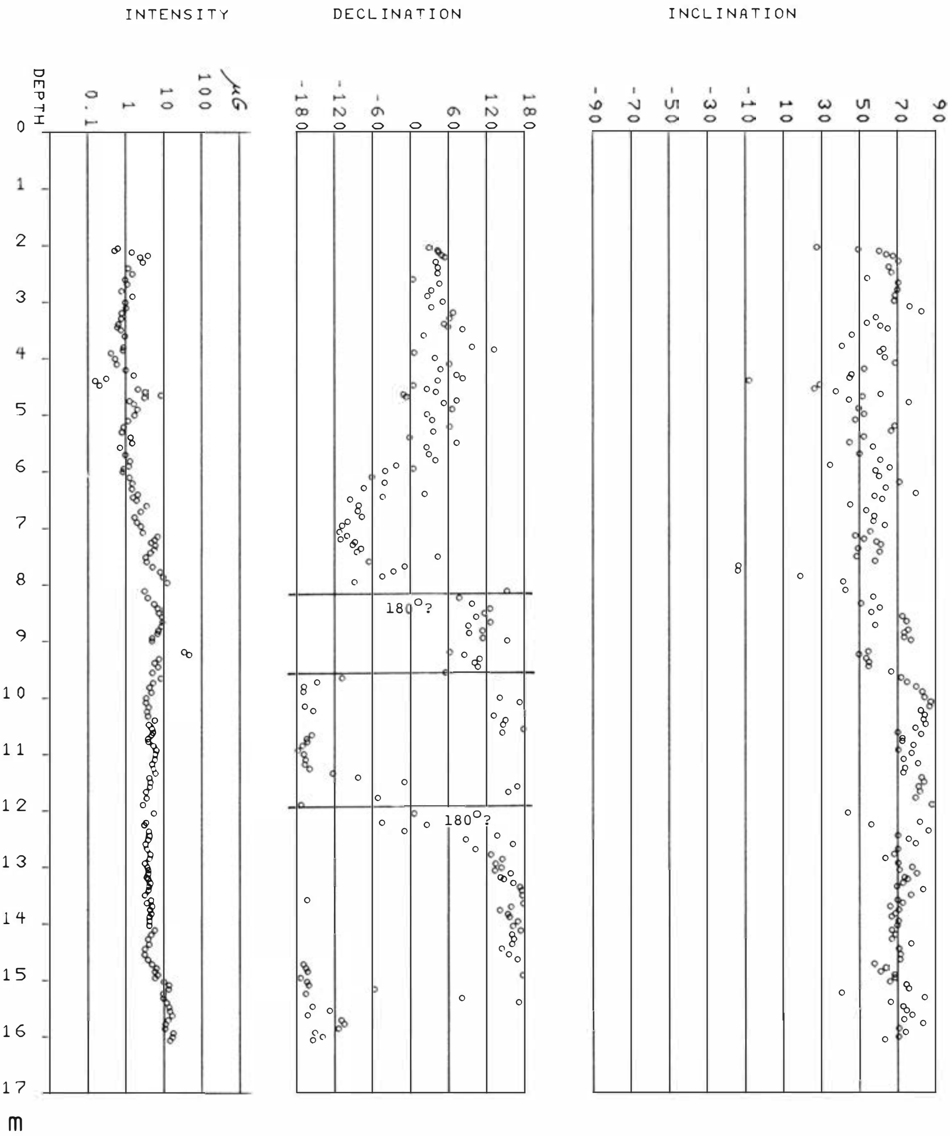

Fig. 11:6b. Moltemyr, F = 100 Oe.

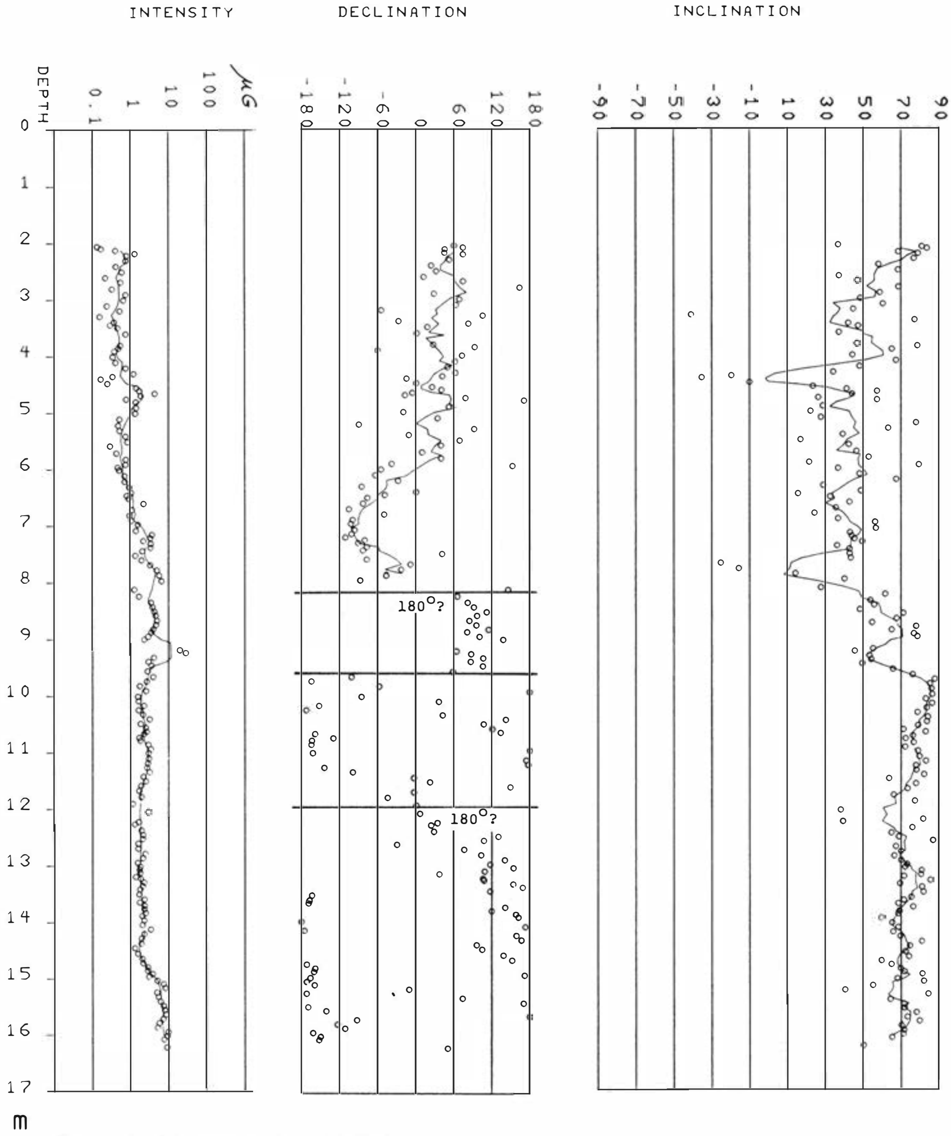

Fig. 11:6c. Moltemyr, F = 300 Oe.

7) and the numbers of fossils (Chapters 13, 14, 16, and 17) decrease, indicating a "dilution effect" of the clay by the increased rate of deposition.

Suppose that the majority of the carriers of remanence are detrital magnetites of silt fraction size (2–60 μm). The "dilution effect" of the increase in the clay percentage would then cause a reduction of the NRM intensity. The average intensity between 26.6 and 18 m depth is 6.2±.1 μG, and between 17 and 12 m (the scattered interval of inclination) 2.3±.2 μG, the ratio of mean intensities thus suggesting a "dilution factor" of 2½–3. The reason why this dilution is less perceptible in the susceptibility record must be that a significant contribution to the susceptibility stems from the paramagnetic minerals in the clay fraction <2 μm.

Thus the rate of deposition is presumably far from constant in the Solberga core, the time scale probably being enlarged by a factor of 2–3 between 17 and 12 m depth as compared with the lower parts of the core. Between 12 and 6 m the intensity gradually increases, the clay percentage decreases, and the diatoms are still dominated by freshwater species (Chapter 16). This interval may represent a recovery phase with more tranquil sedimentological conditions compared with the increased rate of deposition from the meltwater discharge due to the Preboreal rapid ice retreat.

The unusually high directional scatter between 17 and 12 m is likely to be related to a change in the grain-size distribution. Low inclination values could thus be caused by postdepositional compaction of the flocculated clay particles after acquirement of the depositional NRM. A still younger postcompactional viscous magnetization would give the ordinary inclination values of the NRM found, in which case partial magnetic cleaning would reveal the more scattered low inclinations. The intensity of the remanent magnetizations is usually reduced by partial demagnetizations, as is also generally found in the Solberga core, except in the interval 12–17 m, where the intensity in most cases increases at F = 100 Oe and then decreases at F = 300 Oe. This indicates that a significant part of the NRM in this interval is indeed of viscous origin in accordance with the mechanism suggested above.

Thus, on comparison of the cleaned and uncleaned records, a directionally dominant viscous magnetization is found, as the cleaned directions scatter and deviate drastically from the ordinary geomagnetic field direction at the site (D = O°, I = +71°), whereas the NRM direction is close to it.

The possibility of disturbance (slumping and bioturbation) is contradicted by the discovery of only minor signs of possible disturbances in the radiographs, and in the carefully described, photographed and sampled cores. Furthermore compaction, bioturbation and slumping are unlikely to cause a systematic change in declination, since the ambient field tends to induce the ordinary direction during any disturbance in the sediment.

Nevertheless, the cleaned records as summarized in the histograms of Fig. 11:7 demonstrate a significant bias in both D and I away from the axial dipole direction, which is difficult to explain. The cleaned records may therefore depict a diffuse signal of geomagnetic origin. The apparent distance of the corresponding virtual geomagnetic pole would be about 90 degrees from the site, and the virtual colatitude about 60 degrees.

Pending an independent proof of the reality of such an "excursion" shortly after 10 000 years B.P., however, we prefer to ascribe it to an unexplained disturbance of the sediment, rather than due to a (local?) excursion of the geomagnetic field.

BRASTAD

In the Brastad core, a hiatus is obviously present at 2.31 m. Furthermore, the very pronounced change in remanent intensity, susceptibility, and Q-ratio at 7.8 m in the Brastad core, which is not found in the Solberga core (although deposited in about the same Lateglacial environment) suggests that the lower half of the former is older than the bottom of the latter, which after subtraction of the reservoir age was radiocarbon dated (Chapter 19) to 11 020±340 years B.P. (26 to 26.5 m level) and 11 520$\pm^{440}_{380}$ years B.P. (26.5 to 27 m level), respectively. The two cores may tentatively be correlated by the swings in declination d2 to d1′ at 5 m and *c.* 3 m in the Brastad core, and D8 (or D6) and D5 at 26–27 m (or 23–24 m) and 19–21 m in the Solberga core.

The "Gothenburg Excursion" of the geomagnetic field, which is suggested to end at 12 350±50 years B.P. (Mörner 1976) is too early to appear in the Solberga core with an age at the bottom of 11 200±400 years B.P.

The Brastad core, however, is likely to reach further back in time as discussed above. Below 13.5 m the declinations and the inclinations are very scattered, and at the very bottom of the core, four specimens with low inclinations and ordinary declinations are indeed found (Figs. 11:4a–d). Above 14.8 m the core is dominated by clay (36–66%) and silt (32–76%), but at the base the grain size is very much coarser, with 10% sand and 2% gravel at 14.90–14.95 m level and 38% sand and 21% gravel at 15.03–15.09 m (Chapter 7). A significant inclination error (Griffiths *et al.* 1960, McElhinny 1973) may then be expected here, and the low inclinations found may be ascribed to the coarse grain size rather than the geomagnetic field. During magnetic cleaning the scatter is not significantly altered in the bottom metre, indicating that viscous components do not influence the scattered directions. The directional scatter must therefore be due to orientational scatter in the sediment rather than a differential response to viscous overprints in the ambient field. This prompts the conclusion that a

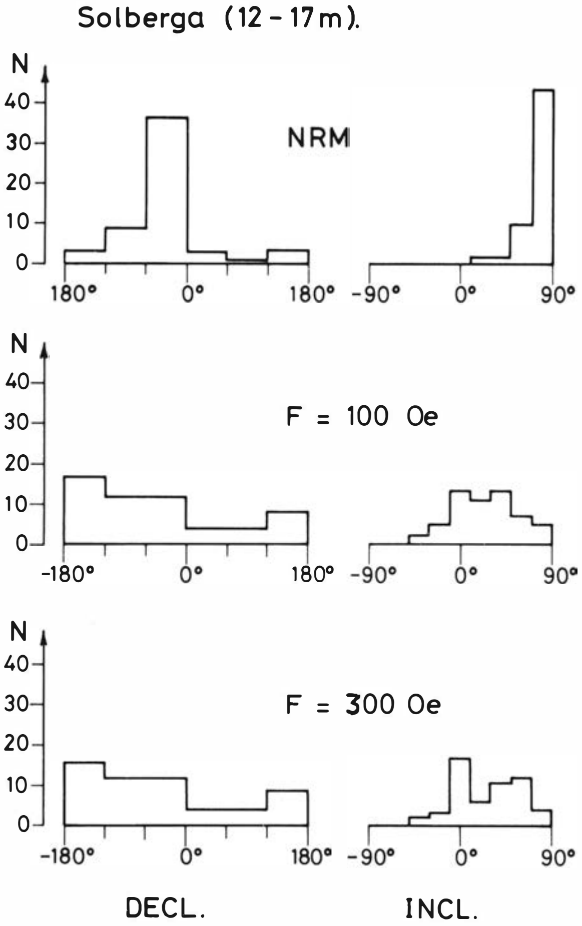

Fig. 11:7. Histograms of declination and inclination of 57 specimens of the scattered interval 12 to 17 m of the Solberga core. During demagnetization, the mean declination changes from *c.* 30° W to *c.* 150° W, and the inclination values are split into a bimodal distribution with peaks at *c.* +50° and 0°. The cleaned directions may indicate either a geomagnetic excursion or a postdepositional disturbance. See text for further discussion.

geomagnetic excursion is probably *not* seen at the bottom of the Brastad core.

An equal shift in intensity, susceptibility and Q-ratio, as seen at 7.8 m in the Brastad core, was found at 11 m in the Lateglacial cliffs of Younger Yoldia Clay at Nörre Lyngby in North Jutland (Abrahamsen and Readman 1980, Fig. 6). At Nörre Lyngby this level was deposited at about 14 000 years B.P. The two levels are unlikely to be of exactly the same age, as the ice recession and the isostatic adjustments at Brastad were out of phase and probably somewhat younger than those of Nörre Lyngby. This is supported by the lack of correlation between the secular variation pattern at Brastad and the well developed pattern in the top part of the Nörre Lyngby profile. Although somewhat different in age, the magnetically equivalent shifts at both localities may suggest that sedimentological/environmental changes were equivalent. Lithostratigraphically the Nörre Lyngby profile may, therefore, be considered to be an "open section equivalent" of the Brastad core, more easily accessible to further studies.

MOLTEMYR

The directional variations in the Moltemyr core (Fig. 11:6c) were not labeled, as the declination and inclination records are considered less reliable. Based on similarities in the Moltemyr records of J, k and Q as compared with those of the nearby Brastad core (about 5 km away), it may however be suggested, that the 4.5 m level in Moltemyr is lithologically correlated with the 2.4 m level in Brastad, and 15 m in Moltemyr corresponds to 8 m in Brastad. Because of the greater distance to Solberga and the probable variance in environment, no magneto-lithological correlations with this site were attempted.

CORRELATIONS

A possible correlation with magnetic secular variation patterns in European lake sediments of Lateglacial age may be found in Lac de Joux near Lake Geneva, about 1 400 km SSW of the present sites. The magnetic record of a 5 m core from Lac de Joux (Creer *et al.* 1980) shows a distinct pattern of inclination maxima and minima, with interpolated "magnetic" ages as follows: ϱ (minimum ~ 14 000 years B.P.), π (maximum ~ 13 400 years B.P.), ξ (min. ~ 12 800 years B.P.), ν (max. ~ 9 800 years B.P.), μ (min. ~ 8 300 years B.P.), and λ (max. ~ 7 200 years B.P.), while the declination record shows easterly and westerly extremes marked P (westerly ~ 14 000 years B.P.), N (easterly ~ 13 400 years B.P.), M (W ~ 12 900 years B.P.), L (E ~ 12 400 years B.P.), K (W ~ 12 000 years B.P.), J (E ~ 10 800 years B.P.?), I (W ~ 10 200 years B.P.), H (E ~ 9 000 years B.P.), and G (W ~ 8 200 years B.P.).

The rate of deposition at Solberga and Brastad was an order of magnitude higher than that at Lac de Joux, so we may expect to see details in Solberga and Brastad which are not present in the cores of Lac de Joux. Bearing this in mind, as well as the geographical distance, and also the scatter in the absolute ages, it may cautiously be suggested that I_5 to I_7 at Solberga may correlate with ν (~ 9 800 years B.P.) at Lac de Joux, D_2 or D_4 with G (~ 8 200 years B.P.), D_3 to D_5 with H (~ 9 000 years B.P.), D_6 with I (~ 10 200 years B.P.), D_7 with J (~ 10 800 years B.P.), and D_8 with K (~ 12 000 years B.P.).

The general westward change in declination of the Brastad core between d_7 (15 m), or d_5 (12 m), and d_2 (5 m) with intervening minor deflections at d_3 and d_4, or d_3, d_4, d_5 and d_6 may correlate with the equivalent trend at Lac de Joux between N (~ 13 400 years B.P.) and K (~ 12 000 years B.P.) or I (~ 10 200 years B.P.) with the intervening minor deflections of M and L, or M, L, K, and J, respectively. In contrast to the declination, the simple Lateglacial inclination pattern of Lac de Joux apparently has no simple equivalents in the Lateglacial part of the Brastad core with 4 short-term inclination cycles.

Indeed, short-term secular variations with periods of a few hundred years duration are known from both historical and archaeomagnetic records, and recently, short periods between 522 and 670 years in inclination and between 290 and 372 years in declination have been suggested to be present in highly scattered palaeomagnetic records of Holocene lake sediments in northern Poland (Tucholka 1980). In Peary Land (northern Greenland) too, rapid variations in the inclination were found in marine sediments *c.* 8 000 years B.P. (Abrahamsen 1980). The rapid minor variations in the Solberga and Brastad cores may demonstrate that such short periods were present in Lateglacial time also.

SUMMARY

Three azimuthally oriented piston-foil cores of clay and silty clay from Solberga, Brastad and Moltemyr in south-western Sweden have been palaeomagnetically investigated with the purpose of investigating the transition from Pleistocene to Holocene time as part of a joint project (IGCP 128) in search for a holotype for this boundary or transition.

Susceptibility, density, Q-ratios and natural remanent magnetizations were measured on 666 specimens, as well as cleaned values after partial demagnetizations in peak fields of 100, 300, 500, 800 and 1500 Oe. Characteristic levels of k, Q and J were found, which indicate lithological variations, and local magneto-lithological correlations between the Brastad and Moltemyr cores are suggested.

The remanent directions are generally stable, and a detailed directional record was obtained, suggesting rather short-periodic geomagnetic secular variations in Lateglacial time. Parts of the Solberga core variations are tentatively correlated with those from Lac de Joux in Switzerland. During the progressive alternating field demagnetizations, an interval of the Holocene part of the Solberga and Moltemyr cores show decreasing

inclinations probably due to viscous magnetic overprints, which may indicate *either* unusual magneto-sedimentological properties related to an increase in deposition rate because of flocculation of clay particles caused by the increased freshwater flux of the amelioration period into the marine environment, *or* a hitherto unrecognized Postglacial (local?) geomagnetic low-inclination excursion, occurring shortly after 10 000 years B.P. The geomagnetic Gothenburg excursion, dated to end around 12 350 years B.P., is not seen in these records, although the Brastad and Moltemyr cores probably reach further back.

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