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Abstract. The altitudes of some Late Weichselian and Flandrian shore-lines were determined in a 1090 km long profile across Fennoscandia from Estonia in the south-east to the Atlantic coast of Norway in the north-west. The shape of the shore-lines suggest that the land uplift during the last 10000 years was dome-like, with the summit of the dome in the eastern part of the Scandinavian mountains. There was possibly a marginal hinge-line or hinge zone in the Gulf of Finland, which bent the shore-lines. No other irregularities in the land uplift could be demonstrated.

INTRODUCTION

The aim of the present study was to determine the altitudes of some Late-glacial and Post-glacial, or, using the division and terminology suggested by West (1968) and adopted here, Late Weichselian and Flandrian shore-line surfaces in a narrow belt across the Fennoscandian area of land uplift. In this way a distance diagram of the shore-lines could be constructed, in which the abscissa shows the distance between the sites and the areas studied within the belt, and the ordinate the altitude of the shore-lines above the present sea-level. The area covered by the study and shown in Fig. 1, was comprised of Estonia, south-western Finland, a part of Västerbotten in Sweden and also a part of Nordland in Norway. The total length, including the gaps consisting of the Gulf of Finland, the Gulf of Bothnia and the Scandinavian mountains is 1090 km. The width of the areas from which the observations were included and projected perpendicularly onto the base-line, was in Finland and Sweden 90 km, in Estonia 130 km and in Norway 125 km. When, as here, a straight line is used as a base-line (= abscissa) for the shore-line diagram, it is part of a great circle on the earth's surface. In the map projection used in Fig. 1 it would appear as a slightly curved line, but the curving is negligible in a distance of 1090 km and a straight line was therefore drawn on the map. The angle at which the line crosses the meridians changes, however, from one area to another. The direction

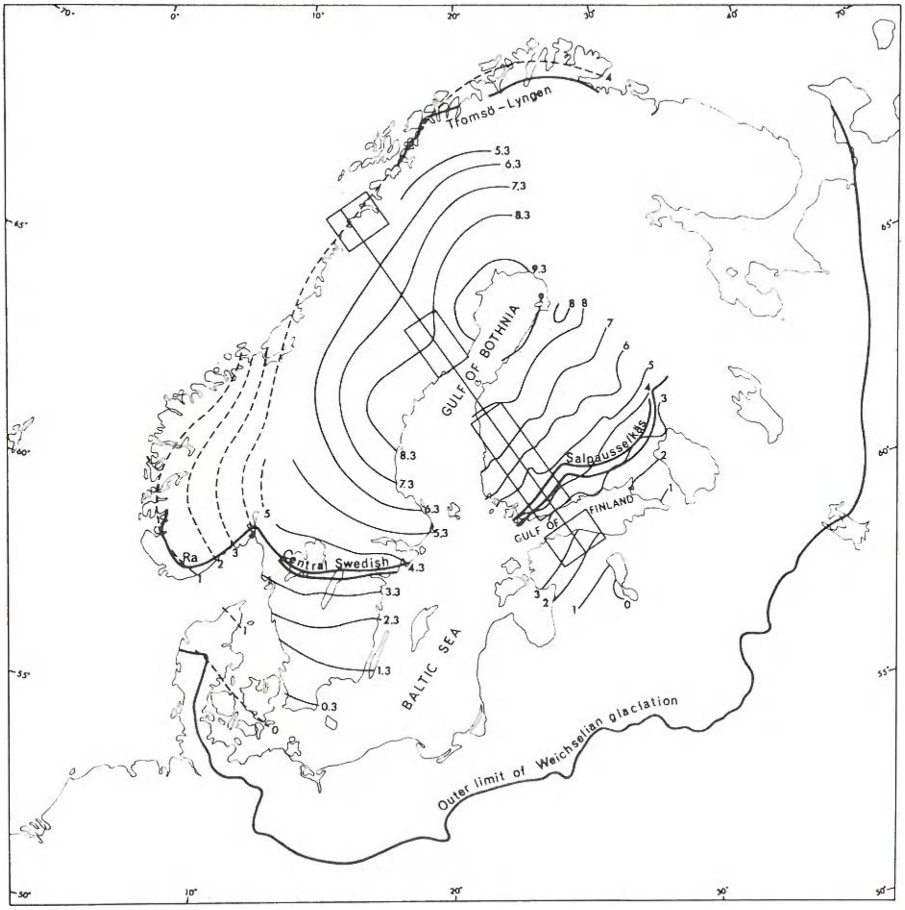

Fig. 1. Map showing areas studied in Estonia, south-western Finland, Västerbotten in Sweden and Nordland in Norway, and base-line used for shore-line diagrams. Map also gives the outer limit of Weichselian glaciation and the position of the Fennoscandian moraines, where determined, as well as isobases for the recent uplift in mm per year, as compiled by Kukkamäki (1968).

of the base-line for the shore-line diagram should, ideally, be at right angles to the isobases of the land uplift. The only isobases which are sufficiently well determined in the whole area covered by the present study are those for the recent uplift, as determined by repeated precise levellings or by sea-level recordings. The isobases in Fig. 1 for the recent uplift in mm per year were drawn on the basis of the map compiled by Kukkamäki (1968) on the basis of available data from Fennoscandia, the most detailed isobases being those constructed for Finland by Kääriäinen (1966), but in Fig. 1 only given for every mm. From Fig. 1 it can be seen that the base-line for the shore-line diagram is not everywhere perpendicular to the isobases. If also the isobases for older shore-line surfaces were at an angle to the base-line, some inaccuracies can be expected in the determination of the altitudes of the Late Weichselian or Flandrian shore-lines. The effect of the inaccuracies is lessened by using a narrow belt from which the sites are chosen, but even then some areas, such as the Norwegian coast, show that the area must be divided into even more narrow strips before the position of the shore-lines can be determined. Apart from showing the position of the base-line for the shore-line diagram and the isobases for the recent uplift, Fig. 1 also shows the outer limit of the Weichselian glaciation (after WOLDSTEDT 1958 and SEREBRYANNY 1965), within which the area studied clearly lies, as well as the Fennoscandian moraines, represented by Salpausselkä I and Salpausselkä II in Finland, the Central Swedish moraines, the Ra moraines in southern Norway and the Tromsö-Lyngen moraines in northern Norway (see ANDERSEN 1968).

The present paper is a direct continuation of some earlier papers in which the shore-lines were determined in more restricted areas. Combined with an evaluation of the various methods which can be used in the determination of the altitude of the Late Weichselian and Flandrian shore-lines, these shore-lines were first determined in the area in south-western Finland shown in Fig. 1 (DONNER 1964, Fig. 11). Later the shore-line diagram thus constructed was extended south-eastwards across the Gulf of Finland to Estonia, and a shore-line diagram covering a distance of 450 km could be drawn (DONNER 1966, Fig. 3). South-western Finland and Estonia are therefore only treated in the present paper as far as corrections and additions to the former results are concerned. One addition is the more accurately determined shore-lines determined in the Salpausselkä belt in south-western Finland with the help of the altitudes of delta plains and their relationship to the retreat of the ice margin dated with the help of the varve chronology. Thus, these results (DONNER 1969) could be added to the shore-line diagram constructed earlier for south-western Finland and taken into account in the construction of the diagram in Fig. 4. The material used in the determination of the shore-lines in Sweden and Norway was collected from published papers, but the areas in Sweden and Norway treated in the present investigation were visited in the summer of 1966 so that the field evidence on which the conclusions in these papers were based could be assessed. In the description of the areas they are treated separately beginning from the south-east.

ESTONIA

The determination of the shore-lines for the Baltic Ice Lake, before its final drainage, the transgression of the Ancylus Lake, and for the second transgression of the Litorina Sea, L II, as earlier presented in a shore-line diagram (DONNER 1966) on the basis of available data, is in agreement with more recent detailed stratigraphical investigations in Estonia, particularly by KESSEL and RAUKAS (1967). Using their results some additions could be made to the shore-line diagram as well as some corrections in the datings, as new radiocarbon determinations have now been obtained from some sites in Estonia. The additions and changes were all taken into account in constructing the diagram in Fig. 4. The L II (= L II^b) transgression of about 1.5—2 m, which forms the highest Litorina limit in most parts of Estonia dealt with and which reached its peak in 3500 B.C., was preceded by the first transgression of the Litorina Sea, L I, of about 3 m in north-western Estonia (KESSEL and RAUKAS 1967). The position of this shore-line can stratigraphically be determined and, as seen in Fig. 4, it intersects L II in the Tallinn area in north-western Estonia. L I is not, however, traceable with the help of raised beaches (see DONNER 1966) and its altitude is not equally well determined as the shore-line for the upper limit of the Litorina transgression, which is here L II. The age of the earlier transgression L I is in Estonia 5000—4500 B.C. A radiocarbon determination of mud, which is synchronous with a peat lens 3 m below the shore-line of L I at Keila-Joa (Site 5, DONNER 1966) gave an age of 7180±270 B.P., 5230 B.C., and is placed at the beginning of the Atlantic period (Mo-223, VINOGRADOV et al. 1968). The determinations of the pollen stratigraphy at Endla (TA-85 to TA-98, PUNNING, ILVES and LIIVA 1968), however, indicate that some of the zone boundaries in Estonia are somewhat younger than calculated when drawing the earlier shore-line diagram (DONNER 1966). At Endla the zone boundary V/VI, in the division by T. NILSSON (1935) adopted in Estonia, just older than L I, was determined to 6480±70 B.P., 4530 B.C., a date in agreement with the results presented by KESSEL and RAUKAS (1967) in a stratigraphical table also including radiocarbon dates. The two Litorina transgressions in Estonia were correlated with the corresponding transgressions in Finland and south Sweden by KESSEL and RAUKAS (1967), but the radiocarbon determinations seem to indicate that L I, formed at 5000—4500 B.C. in Estonia, may here be somewhat younger than further north or west in the Baltic area. The dating of L II to 3500 B.C. agrees with the dating of this transgression elsewhere. The transgression of the Ancylus Lake, which exceeded 10 m in northern Estonia reached its maximum between 6500 B.C. and 6000 B.C., as seen from the results presented by KESSEL and RAUKAS (1967) and also confirmed by the radiocarbon determinations from the Endla series of the zone VIII period, corresponding in age with the Ancylus transgression, which gave an age of 8495±85 B.P., 6545 B.C., and of the zone boundary VII/VIII, following the time of the maximum of the transgression, which gave an age of 7865±

75 B.P., 5915 B.C. (TA-98, TA-96; PUNNING, ILVES and LIIVA 1968). The date of 6500—6000 B.C. for the maximum of the transgression of the Ancylus Lake, A, and thus for its shore-line, is younger than the age earlier calculated for it by the author (DONNER 1966), *i.e.* 7000—6800 B.C. The age determinations or calculations of the duration of the Ancylus Lake, as well as for the time at which it reached its highest position in those areas of the Baltic in which it was transgressive, still vary and only permit a dating with the accuracy given above, as shown by the review of the study of the Ancylus Lake by FREDÉN (1967). The uppermost shore-line for Estonia in Fig. 4 is that for the level of the Baltic Ice Lake before the drainage at Billingen in Sweden. Earlier the date of 8300 B.C. was given for this shore-line (DONNER 1966), but after the dating of the drainage of the Baltic Ice Lake to 8213 B.C. in Sweden (E. NILSSON 1968) the shore-line in Estonia and the corresponding shore-line, B III, in Finland (see DONNER 1969) can be dated broadly to 8300—8200 B.C.

Of the four shore-lines for Estonia presented in Fig. 4 only two, those for the Litorina Sea, L I and L II, show the former position of the sea-level, whereas the shore-line for the transgression of the Ancylus Lake and the shore-line for the Baltic Ice Lake give the former position of the water-level at times when it was dammed and stood above sea-level. In Fig. 4 the vertical lines under the shore-lines for the Baltic Ice Lake and the Ancylus Lake show approximately how much above sea-level the water-level of these lakes stood. The areas in which there is stratigraphical evidence for a transgression (see KESSEL and RAUKAS 1967) before the water-level reached the position of a shore-line marked in the diagram, are shown by arrows pointing upwards, as in the diagram constructed earlier (DONNER 1966). The arrows, however, do not give the total amount of the transgression, as this is often not possible to determine.

SOUTH-WESTERN FINLAND

In the determination of the shore-lines in south-western Finland the Clypeus limit, at 5500 B.C., was separated from the first transgression of the Litorina Sea, at 5000 B.C., mainly on the basis of a site near the coast where the transgression could be demonstrated (Site S 17, DONNER 1967). Further, the first stage of brackish water in the Baltic after the drainage of the Ancylus Lake, the Mastogloia Sea, was separated from the Litorina Sea on the basis of the diatom flora containing *Campylodiscus clypeus* in the sediments. As these differences in the diatom flora, especially the occurrence of *Campylodiscus clypeus*, foremost reflect the conditions, such as water depth and the presence of lagoons, just before the emergence of the coast where the basins studied became independent lakes, the limit at which there was a change from fresh water to brackish water, regardless of diatom flora, was here taken to represent the beginning of the Litorina Sea period (see DONNER 1964, Fig. 7). This limit is somewhat older at higher isobases, about 5500 B.C., with a continuous regression at this time, than near the coast in southern Finland, where the first Litorina transgression, L I at about 5000 B.C., occurred. On the basis of the material used the shore-line, however, is a straight line. If the line is extended towards Estonia it joins the L I shore-line in Estonia, with a slight bend as the younger Litorina shore-line, L II, which it intersects near Tallinn in Estonia. The L I appears to be somewhat younger in Estonia than in southern Finland. Its age decreases towards the marginal parts of uplift and the shore-line is metachronous in the way typical for a shore-line formed during a transgression. The dating of the first transgression, is, however, still tentative and, as it is not the uppermost Litorina transgression in Estonia, its dating there is not stratigraphically as clear as in southern Finland where L I is clearly above L II. In the earlier shore-line diagram, in which the shore-lines in Estonia were compared with those in south-western Finland (DONNER 1966, Fig. 3), the Litorina shore-line L I could not be connected across the Gulf of Finland. This is not any more the case when the upper limit for the Litorina Sea was drawn as one single shore-line, as in Fig. 4.

The shore-line corresponding to the zone boundary V/VI, which was earlier dated to 6300 B.C. (DONNER 1964), can now, when the new radiocarbon dates in south-western Finland are taken into account (ALHONEN 1968, DONNER 1969), be placed at 6000 B.C. At the time corresponding to this shore-line the level of the Ancylus Lake had already dropped to the level of the sea (see DONNER 1964, 1969). As the marked change in the salinity of the coastal waters took place later, at about 5500 B.C., which is the beginning of the Litorina Sea period, there is a transitional period between 6000 B.C. and 5500 B.C. during which salt water had not yet penetrated to the shallow waters of the coast. As it is probable, however, that the Baltic was already connected with the ocean, and that the level of the Ancylus Lake therefore had already dropped, this period of 500 years has in Finland been separated as the Mastogloia Sea period. It is, however, not well defined nor dated in south-western Finland. In those areas where there were rapid land/sea level changes, as in the coastal areas in western Finland with a quick relative uplift of land, the difference between the position of the shore-line for 6000 B.C. and for 5500 B.C., or possibly 5000 B.C., is considerable.

The two positions of the shore-line determined for 7000 B.C. and 6000 B.C. are sea-level positions above and below the shore-line for the Ancylus Lake determined in Estonia. On the basis of some sites in southern Finland (DONNER 1964) it could be extended to this area, and it lies immediately below the shore-line determined for 7000 B.C. Its position in Fig. 4 was drawn on the basis of the sites in which the Ancylus transgression in the zone V period was stratigraphically determined (Sites S 38 and S 43, DONNER 1964). Of the shore-lines earlier determined with the help of the pollen stratigraphy that for the zone boundary III/IV was omitted in Fig. 4, because the vegetational change on which this zone boundary was based, is not, in view of radiocarbon determinations, considered to be a synchronous pollen stratigraphical boundary in areas close to the retreating ice margin (DONNER 1967). The oldest shore-lines in Fig. 4 for south-western Finland are those determined in the Salpausselkä belt (DONNER 1969), B I and B III representing levels of the Baltic Ice Lake, the latter the same as the level determined in Estonia, and g and Y I representing positions of the sea-level. g was formed before B I and Y I immediately after the drainage of the Baltic Ice Lake at Billingen, for which the date 8213 B.C. (E. NILSSON 1968) was used here, as also when these shore-lines were determined (DONNER 1969). As 8305 B.C. (see FROMM 1963) was earlier used for the drainage at Billingen, those dates earlier based on the varve chronology become about 100 years younger than before (DONNER 1964). Thus, the new date for the shore-line below Y I is now 7600—7500 B.C., and the positions of the ice margin dated with varve chronology are 8200 B.C., just inside Salpausselkä II, 7900 B.C. and 7500 B.C. The area in which the two Salpausselkä moraines occur are also shown in Fig. 4, their closer relationship to the B levels having been discussed elsewhere (DONNER 1969).

The altitude and tilt of shore-lines B III and g in Fig. 4 is almost exactly the same as for the two highest shore-lines determined earlier (DONNER 1964). There are many raised beaches below B III but above the Y I level. and some inside the position of the ice margin at 8200 B.C. (DONNER 1964, Fig. 2). They may, therefore, represent one or two intermediate levels formed during the drainage of the Baltic Ice Lake from B III to Y I. The marginal delta plains at the levels of B III and Y I are, however, very close to each other (DONNER 1969), which shows that if there were intermediate levels formed during the drainage of the Baltic Ice Lake, they represent a relatively short period of time.

VÄSTERBOTTEN, SWEDEN

When the line for the shore-line diagram in Fig. 4 is continued from Estonia and south-western Finland across the Gulf of Bothnia towards the northwest, it crosses Västerbotten (Fig. 1). The sites used for the determination of the shore-lines are from an area 90 km broad, as in Finland, and 150 km long, in the coastal area. The areas further inland were not affected by land/sea level changes following deglaciation. In Västerbotten the land uplift was still relatively rapid during the time of the Litorina Sea in the Baltic. Therefore, there was no transgression in this area during this time, nor were any clear beaches formed which could be used in determining the Litorina shore-line. The position of the shore-line in the beginning of the Litorina Sea period was in Västerbotten determined with the help of the highest sites in which sediments containing salt-water diatoms occur (GRANLUND 1943). The sites studied by GRANLUND show that below some sites containing only fresh-water diatoms, there is a transitional zone of about 4 m with sediments containing *Mastogloia*-species and below this zone sediments containing *Campylodiscus clypeus*. As the period represented by the *Mastogloia*-species was very short, GRANLUND did not separate it as a Mastogloia Sea period, but used the term *salt-water limit* for the highest limit to which the influence of salt-water reached at the beginning of the Litorina Sea period (see also J. LUNDQVIST 1965). The salt-water limit thus defined in Västerbotten corresponds to the upper limit of the Litorina Sea in the north-western part of the area studied in Finland. The Mastogloia Sea period as dated and defined in Finland has not been separated in Västerbotten from the Ancylus

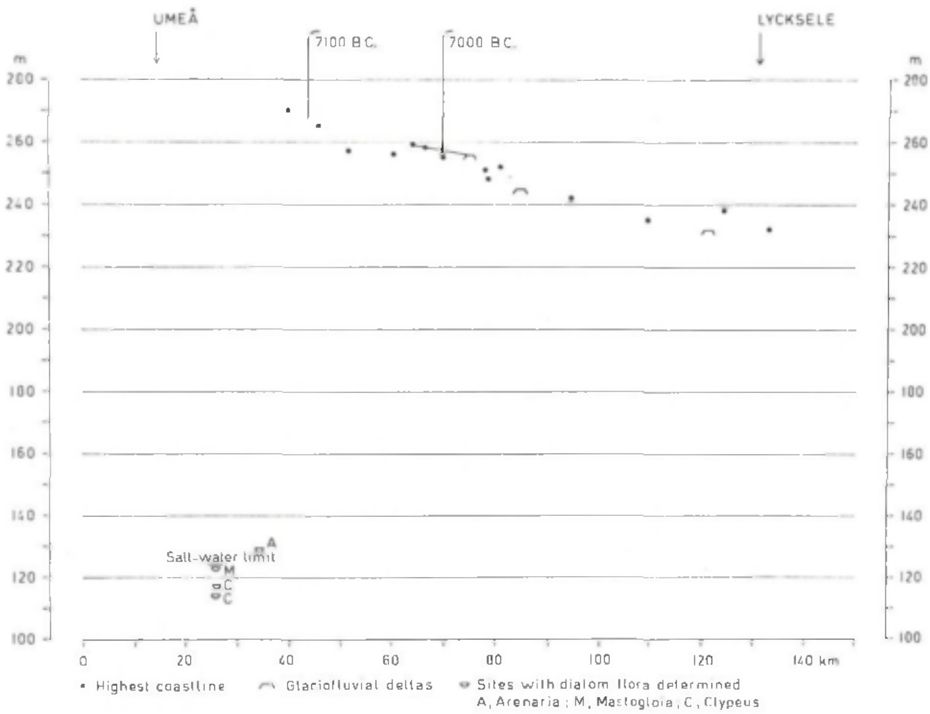

Fig. 2. Diagram of determined positions of the salt-water limit and the highest coastline in Västerbotten, Sweden. The position of the ice margin in 7100 B.C. and 7000 B.C. is also shown.

Lake period, which here continued until the beginning of the Litorina Sea period (GRANLUND 1943). As the first penetration of salt-water, marking the beginning of the Litorina period, was determined with the help of pollen analysis of varved clays in Ångermanland to have occurred not earlier than 5400 B.C., and probably at 5100—5000 B.C. (FROMM 1938), the date 5400—5000 B.C. can also be used in the area of Västerbotten dealt with here, lying immediately north-east of Ångermanland. The date of 5500 B.C. used for the salt-water limit in Finland was not dated in the area in which it was used but taken from the earlier determinations in Sweden in general (FLORIN 1963, FROMM 1963), which may be a few hundred years too old. As the salt-water limit on each side of the Gulf of Bothnia is similar in character, it must be considered to represent an almost synchronous shore-line. Taking into consideration also some younger radiocarbon dates of *c.* 5000 B.C. (see FROMM 1963) the age of 5500—5000 B.C. can, therefore, be used for this limit on both sides of the Gulf of Bothnia. A more exact date can not be given on the basis of the present material.

The altitude of the salt-water limit in the coastal area of Västerbotten falls from about 126 m in the south-west to just under 120 m in the north-east, as shown in a diagram by GRANLUND (1934, Fig. 90). Of the sites on which GRANLUND based his determination of the salt-water limit only four are in the area dealt with here, sites 4 and 5 near Djupsjö, site 6 near Hörnsjö and site 8, earlier studied by HALDEN, north-west of Umeå (GRANLUND 1943, p. 107—108). These sites were included in the shore-line diagram in Fig. 2. The sediments of the uppermost site have an *Arenaria*-flora, which shows that it is above the salt-water limit, whereas the others are below it. Site 5 at 123 m is just below it and has *Mastogloia*-forms, whereas the two other sites at lower altitudes also have *Campylodiscus clypeus.* On the basis of these sites the salt-water limit is at about 124 m in the area west of Umeå. As the salt-water limit could only be determined in a small area a line for the limit could not be drawn in the diagram in Fig. 2. The tilt of the salt-water limit along the coast of Västerbotten towards the north-east does not help in determining the position of this limit in the direction of the base-line used in the diagram in Fig. 2 and Fig. 4. In connecting the salt-water limit in the area near Umeå in Västerbotten with the corresponding shore-line on the Finnish side of the Gulf of Bothnia (Fig. 4), it was assumed, without any direct evidence, that the area in which the uplift has been greatest since the time of the formation of the salt-water limit, lies north-west or south-west of the Umeå area, in spite of the isobases for the recent uplift, which rather suggest a centre of uplift in the northern part of the Gulf of Bothnia (Fig. 1). Further away from the coast in Västerbotten, north-west of the area studied, ice-dammed lakes were formed at the time of deglaciation, and in narrow valleys lakes were dammed by endmoraines or eskers (in Swedish called »selsjöar», GRANLUND 1943, p. 82—85). The tilting of the shore-lines of these lakes suggest, according to GRANLUND (1943, p. 85—86), that the area in which the uplift has been greatest is situated north-west of the lakes Malgomaj, Storuman and Storvindeln, near the Norwegian border. The determination of the former shore-line surfaces in northern Sweden is, however, made difficult by the possibility that the centre of uplift has shifted from one area to another during and after the time of deglaciation and, further, that there may even have existed two centres of land uplift (J. LUNDQVIST 1965, p. 174).

The profiles from mires, in which the pollen stratigraphy can be compared with the land/sea level changes by determining the time of the isolation of the basins from the Baltic, are all below the salt-water limit in Västerbotten (GRANLUND 1943) and the older land/sea level changes could not, therefore, be dated in this way. The only level which can be determined in addition to the salt-water limit is the highest coastline, *i.e.* the uppermost limit to which the Baltic Sea reached after the last glaciation. A number of measurements (GRANLUND 1943, Fig. 57) of the altitude of glaciofluvial deltas and of the upper limit of wave action, as shown in Fig. 2, show the position of the highest coastline, falling from an altitude of 270 m near the coast to nearly 230 m further inland. The highest coastline is, however, a metachronous shore-line formed during the relatively rapid regression of the water-level at a time during which the margin of the ice sheet retreated into the Scandinavian mountains. Only by comparing the highest coastline with dated positions of the retreating ice margin, as done in south-western Finland, can the altitude of this line be compared with shore-lines determined in other areas. The recession of the ice margin has not been dated in Västerbotten, but the detailed investigations in Ångermanland (HÖRNSTEN 1964), bordering the area studied in Västerbotten, can be used for this purpose. Using measurements of varved clays HÖRNSTEN dated the retreat of the ice margin in the valleys of Ångermanälven and Moälven and drew recession lines for every 50 years of ice retreat, covering a period of 400 years, the zero year being the youngest (HÖRNSTEN 1964, Fig. 6). The zero year is the same as in the varve counts by BORELL and OFFERBERG (1955), dated to 6923 B.C. (HÖRNSTEN 1964, E. NILSSON 1960, 1968). A radiocarbon measurement of the humus fraction from the varves +56 to +82 in a varve series from Lugnvik, Ångermanland, gave an age of 9000^{+1400}_{-1200} B.P. (U-215, HÖRNSTEN and OLSSON 1964), the expected age beign 8800 B.P. The determined age may, however, not be the real age, as pointed out by HÖRNSTEN and OLSSON, and the unsoluble portions gave considerably older dates, 30000 years and more. In those varve series where pollen counts have been made, the change-over from a pollen flora dominated by *Betula* to a flora with mainly *Pinus* takes place at about the zero year. The diatoms analyzed show that the water of the Baltic in the year 6823 was fresh in the Ångermanland area but in 7323 B.C. still mesohalobous (HÖRNSTEN 1964). Using the detailed results from Ångermanland the recession lines for 7000 B.C. and 7100 B.C., interpolated from the lines drawn by HÖRNSTEN, were drawn for the bordering area in Västerbotten. The lines were drawn parallel to the tentative lines for the latter area as presented by G. LUNDQVIST (1961), who used the direction of endmoraines in determining the direction of the retreating ice margin. In the shore-line diagram in Fig. 2 the innermost position of the ice margin at 7100 B.C. and 7000 B.C. was drawn on the basis of the recession lines, as earlier done in south-western Finland (DONNER 1964, Fig. 2). The uppermost glaciofluvial deltas and the upper limits of wave action formed at about 7000 B.C. were connected with a line in Fig. 2 and its altitude at the point where the ice margin stood 7000 B.C. is 257 m. About 7100 B.C. the water-level stood at about 265—270 m, when the ice margin was nearer the coast. No shore-lines from the time around 7000 B.C. can, however, be determined in the area.

A connection of the altitude of 257 m for 7000 B.C. in Västerbotten with the shore-line for this period in south-western Finland is possible with a curved line, similar to that for the salt-water limit, assuming the greatest land uplift to have been further inland in Västerbotten also at this time. The shore-line surface for 7000 B.C. was dated in south-western Finland on the basis of the zone boundary IV/V in that area and the corresponding level in the pollen stratigraphy of Ångermanland is also at about 7000 B.C., possibly somewhat younger, as mentioned above. Further, the results from Ångermanland, also applicable in Västerbotten, showed that the Baltic was probably still connected with the ocean at 7000 B.C., thus excluding the possibility that the altitude for the water-level at this time should represent the level of the Ancylus Lake in Västerbotten. The results in south-western Finland agree with this conclusion. There the change-over to the Ancylus Lake period is in the beginning of zone V in the pollen stratigraphy (DONNER 1964).

NORDLAND, NORWAY

The Norwegian sites included in the present study, were all from an area in Nordland. It is 100 km long in the direction of the base-line in Fig. 1 and 125 km broad, stretching from Mo in the south to Fauske and Bodö in the north, the main valley being Saltdalen, with Saltdalsfjorden and Skjerstafjorden outside it. From this area there are a number of levelled altitudes of raised beaches, which were used in the shore-line diagram in Fig. 3. Most of the sites were studied by GRÖNLIE, who after a preliminary paper on the shore-lines of northern Norway (GRÖNLIE 1940) produced a

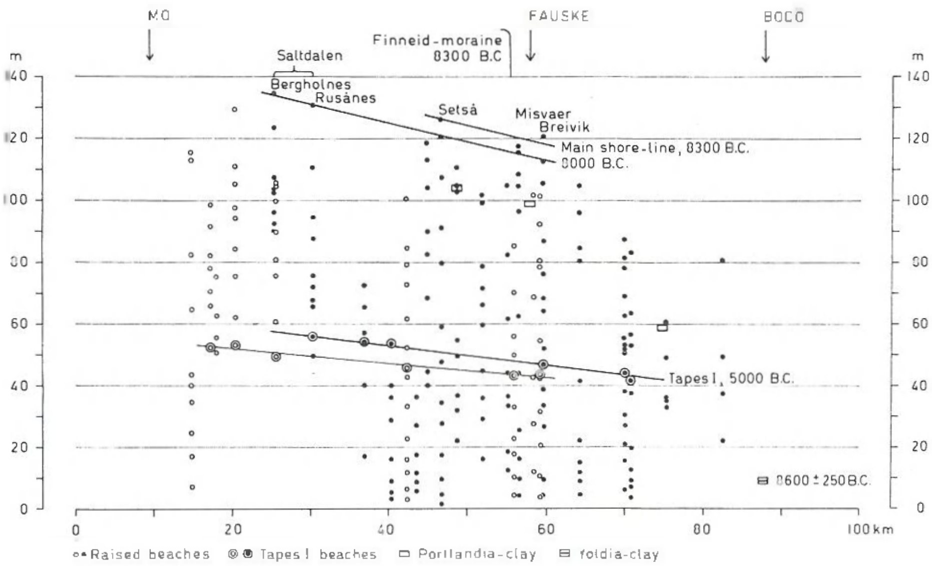

Fig. 3. Shore-line diagram for Nordland, Norway, with raised beaches and sites with marine clays. Open circles are observations from the south-western half of area studied in Nordland and black dots from the north-eastern half.

more complete list of sites with additions and corrections to the earlier list (GRÖNLIE 1951). Two sites, in which the terraces were levelled by REKSTAD (1910) but not included in the lists published by GRÖNLIE, were included in the diagram. The total number of determined raised beaches included in Fig. 3 was 235. Some sites with marine clays containing shells were also included in Fig. 3 if they were of direct use in dating the shore-lines (the sites used in Fig. 3 are listed in the Appendix).

In representing the shore-lines GRÖNLIE (1940, 1951) used relation diagrams, or epeirogenetic spectra, similar to those introduced by TANNER (1930) for the shore-lines in northern Fennoscandia. GRÖNLIE used, as TANNER had done before, the Tapes line or b-line as a reference level, in relation to which all other altitudes of raised beaches were plotted (the construction of shore-line diagrams has been discussed elsewhere, DONNER 1965). As the uppermost Tapes shore-line is one of the few shore-lines which in northern Norway, especially at lower isobases, can be singled out among the number of raised beaches observed at different altitudes, it was separated in Fig. 3. It was determined with the help of all those sites, listed by GRÖNLIE (1951), in which a particular raised beach, among a number of raised beaches at different altitudes, falls on the b-line. When all these beaches of the b-line were marked in Fig. 3, it became clear that they represent two separate tilted lines, not one. When the geographical distribution of the sites used is taken into account, this difference can be explained. Those sites which represent the lower, less tilted line, are all in the south-western half of the area, whereas those which represent the higher, slightly more tilted line, are all in the north-eastern half. As the raised beaches representing the b-line are likely to be correctly grouped, the difference must be caused by the direction of the base-line used in the shore-line diagram in Fig. 3. It is probably not perpendicular to the isobases at the Norwegian coast, as suggested by the isobases of the recent uplift of land (Fig. 1) and further supported by the suggested direction for the isobases for the b-line, as presented by GRÖNLIE (1940). Thus, the area 125 km broad along the coast is obviously too broad for an accurate determination of the former shore-lines, as far as they can be separated on observations of raised beaches alone. The area was therefore divided into two halves, the south-western and the north-eastern, and the altitudes of the raised beaches marked differently for each half in the diagram in Fig. 3. Therefore, there is a separate b-line for each area. The determination of the Tapes shore-line to 40—60 m is supported by the occurrence of shell-bearing sediments with a fauna characteristic for Tapes beds. Of the sites described by REKSTAD (1910) the highest is at Moldjord in Beiarn, where a clay with shells is found undernearth terrace sands at 43 m. The Tapes line in Fig. 3 is here at about 47 m.

Assuming that the position of the Tapes shore-line, as drawn in Fig. 3, was correctly determined on the basis of the studies by REKSTAD (1910) and GRÖNLIE (1940, 1951; see also HOLTEDAHL 1953, Pl. 18), it can be correlated with the Tapes I shore-line elsewhere in Norway. At an altitude of 40—60 m, at which it occurs in the area dealt with, it is the highest Tapes shore-line, as seen, for instance, in the diagram for West-Finnmark constructed by MARTHINUSSEN (in HOLTEDAHL 1960). At lower isobases, where the Tapes I shore-line was transgressive, radiocarbon dates have been obtained for peats overlain by beach gravels and sands. At Vadsö in Finnmark a date of 7750±150 B.P. was obtained and another sample from Andöy in Nordland gave a date of 7400±150 B.P. (T-182, T-270, MARTHINUSSEN 1962). MARTHINUSSEN gave an age of *c.* 6600—6500 B.P. for the Tapes shore-line in this area, but, as seen from the dates above, it may be 7000 years old or more, which would be closer to the date obtained elsewhere. In the Oslo area, where the shore-line displacement was studied in great detail by various authors, there were no transgressions at the time during which the Tapes shore-lines were formed in Atlantic time (HAFSTEN 1956, 1959). In a general correlation of the land/sea level changes in the Oslo area with those in other parts of Norway, also with the above-mentioned results by MARTHINUSSEN, the Tapes I shore-line was dated to about 5000 B.C. (FEYLING-HANSSEN 1964, see also ANDERSEN 1965). As the first Tapes transgression can be considered to be synchronous with the first Litorina transgression in the Baltic, this date is supported by those obtained in Sweden and Finland. The date for the Tapes I shore-line at higher isobases, where it was not transgressive, may, however, be somewhat older, as was the case in the Baltic.

According to the above-mentioned datings the Tapes I shore-line in the coastal area of Nordland in Norway is of approximately the same age, about 5000 B.C. or slightly more, than the salt-water limit in Västerbotten in Sweden, and therefore these two shore-lines could be joined across the Scandinavian mountains as shown in Fig. 4. The Tapes I shore-line used for Norway was the upper one from Fig. 3, because it represents the north-eastern half of the area dealt with, as do the shore-lines for the highest coastline in the same area. The continuation of the salt-water limit joins the Tapes I limit in Nordland, which slopes down towards the Atlantic, if the curving of the shore-line, already suggested by the results from Västerbotten and south-western Finland, continues across Scandinavia.

The shore-lines above the Tapes line in the area dealt with in Nordland can not be separated on the basis of the altitudes of raised beaches alone, even when the observations were divided into two groups. As seen in Fig. 3, the raised beaches, formed during the relative regression of the sea-level from its highest position, occur irregularly and no grouping along certain tilted shore-lines can be traced. The diagram is similar to the diagram for raised beaches in south-western Finland (Donner 1964, Fig. 2). The only shore-lines which could be determined above the b-line were those representing the highest coastline. In the coastal areas of Västerbotten and particularly in Finland, where the topographical differences are comparatively small, the ice margin retreated as a uniform ice front for which recession lines can be drawn. In Norway the withdrawal of the ice was more varied because of the broken topography with fjords and deep valleys between high mountains, some of which are still glaciated. Each fjord and valley had its own retreating glacier during the final stages of deglaciation, and in following the position of the highest coastline they have to be treated separately. The north-eastern half of the area dealt with is the only part in which the shore-line for the highest coastline could be reconstructed (Fig. 3). In the inner part of Saltdalen the highest raised beaches at Bergholnes and Rusånes lie on a tilted line, and when the line is extended three observations of raised beaches, *i.e.* at Setså, Saltdalsfjorden, at Breivik, Skjerstafjorden, and at Misvaer, fall on the same line. At these sites, however, the highest raised beaches are about 5 m above this line, as seen in Fig. 3. The two lines drawn for the highest coastline probably give the approximate altitudes for two shore-lines from the time of the ice recession, the higher shore-line being formed when a glacier was still occupying the lower reaches of Saltdalen, but the fjord was ice-free, and the lower shore-line formed when the glacier had already withdrawn higher up into Saltdalen and the valley was a continuation of the present fjord. Both shore-lines for the highest coastline are more tilted than the Tapes shore-line.

In the north-eastern half of the area dealt with in Nordland, in the area in which the two above-mentioned shore-lines for the highest coastline were determined, there is an assumed position of the ice margin during its retreat at Saltstraumen in the outer part of Skjerstafjorden (GRÖNLIE 1940, HOLTEDAHL 1953). The two shore-lines for the highest coastline are inside this line and therefore also younger. South-east of Fauske the well-developed Finneid-moraine blocks Nedrevatnet from Fauskevika (REKSTAD 1910, HOLTEDAHL 1953). It is probable that the glacier in the main valley of Saltdalen had receded already some way up the valley at the time of the formation of the moraine at Nedrevatnet, formed by a glacier which came down another valley from the east, as indicated by the line drawn by GRÖNLIE (1940, Pl. III) for this moraine stage, which he called M^1. The relationship between the shore-lines for the highest coastline with the moraines show that the upper shore-line was formed approximately at the time of the Finneid-moraine at Fauske, when there was still a glacier in the lower part of Saltdalen, whereas the lower shore-line was formed shortly after the time of the formation of the Finneid-moraine. At Skjerstad, at the mouth of Misvaerfjord, which is a small fjord on the southern side of Skjerstafjorden, there is also a moraine (REKSTAD 1910) which could be of the same age as the Finneid-moraine. This would explain why the highest beach at Misvaer (Fig. 3), which is inside the Skjerstad-moraine, lies below the highest beaches at Breivik and Setså, which are in areas outside both moraines. The above-mentioned age relationship between the shore-lines and the moraines agrees with the conclusions by GRÖNLIE (1951). In his shore-line diagram the Finneid-moraine of the M^1 stage corresponds to the d_2 shore-line. The highest coastline in Saltdalen is immediately below the d_2 shore-line, whereas the line in the fjord outside at Setså and Breivik are above d_2, thus being the same age or slightly older than the moraine.

In dating the shore-lines in the area dealt with GRÖNLIE (1940) assumed that the ice-margin was outside the coast at the time of the formation of the Tromsö-Lyngen endmoraine in northern Norway (see Fig. 1), which in Western Troms is shown to have been formed mainly in the Younger Dryas period, partly, however, already in the Older Dryas and Alleröd periods (ANDERSEN 1968). According to these datings the formation of the main part of the Tromsö-Lyngen moraine, formed in the Younger Dryas period, can be correlated with the formation of the Ra moraines in South Norway (Fig. 1). In the shore-line diagram constructed by GRÖNLIE the shore-lines in Fig. 3 lying just below and above the d_2 shore-line would fall, if compared with the shore-lines in the Oslo-Romerike area (Grönlie 1940, Pl. IV), in the zone between the Pholas line and the Litorina line, using the classification by Öyen. This would mean that the highest shore-lines in Fig. 3 were formed at about 7500—7000 B.C. (Feyling-Hanssen 1964). If a comparison is made on the basis of the altitude of the Tapes I shore-line between the older shore-lines in Fig. 3 and the curve for the land/sea level changes in the Oslo area, determined on the basis of pollen analytically studied sediments in a series of lake basins at different altitudes and formerly connected with the sea (Hafsten 1956, 1959), the shore-lines for the highest coastline in Saltdalen and the fjord outside it would correspond to the position of the shore-line at the end of the Pre-Boreal period in the Oslo area, also about 7500—7000 B.C., as dated by Hafsten. The comparison of the shore-lines with the Oslo area is, therefore, consistent and places the upper shore-lines in Fig. 3 in the late Pre-Boreal period.

The above-mentioned dating, which was entirely based on the altitudes of the shore-lines and a comparison with the Oslo area is, however, not in agreement with the distribution of the marine clays and their fauna in the area presented in Fig. 3. At Rönvik, 1 km from Bodö, there is a clay at least 8 m thick containing shells of *Portlandia arctica* overlain by younger sediments (Rekstad 1910, p. 26; Holtedahl 1953, p. 714). A radiocarbon determination of *P. arctica* shells from the clay, which occurs at an altitude of between 7 and 10 m, gave an age of 10550±250 B.P., 8600 B.C. (T-246, Marthinussen 1962). The presence of *Portlandia arctica*, representing the high-arctic *Yoldia* fauna, at this site and also in Glomfjorden (Holtedahl 1953, p. 714) show that the ice margin must have retreated east of these areas at the time of the formation of the Tromsö-Lyngen moraines in the Younger Dryas period and could thus not have been outside the coast, as assumed by Grönlie (1940). *P. arctica* only occurs in Late Weichselian marine sediments, or in sediments representing the transition to the Flandrian, in North Norway (see Andersen 1968). The radiocarbon date supports the stratigraphical evidence and places the sediment in the Younger Dryas period. Similar dates listed by Marthinussen (1962, pl. 1) and by Andersen (1968, Table 3) from other areas agree with this dating. Further away from the coast, in the fjords, there are marine clays containing *Portlandia lenticula*, with small stones dropped by icebergs. This clay, called *Portlandia*-clay (Rekstad 1910, Holtedahl 1953, p. 713), occurs, as shown in Fig. 3, at Nygaard in Beiarn at 60 m (Rekstad 1910), at Osbak in Beiarn at 105 m (Rekstad 1910, terraces in same area mentioned by Grönlie 1951, site 369), and at Fauske up to an altitude of about 100 m (Rekstad 1917, Holtedahl 1953, p. 713). The occurrence of these clays at high altitudes and also close to the Finneid-moraine at Fauske indicate that they were deposited at a time shortly after the formation of this moraine, at a time corresponding to the lower of the two shore-lines for the highest coast-line in Fig. 3, which is about 15 m above the two highest clay-occurrences. The *Portlandia*-clay is younger than the *Yoldia*-clay mentioned above, and it probably represents the time immediately after the formation of the Tromsö-Lyngen moraine, or the Ra moraines in South Norway, *i.e.* the beginning of the Pre-Boreal period, a time about 8000 B.C., as in the Oslo area (FEYLING-HANSSEN 1964). The marine clays, mentioned above, thus show that the lower shore-line for the highest coastline in Fig. 3 is early Pre-Boreal, from about 8000 B.C. and that the endmoraine or moraines corresponding to the Tromsö-Lyngen moraine is east of Bodö and not outside the coast. This is also supported by the occurrence of *Yoldia*-clay in Glomfjord (HOLTEDAHL 1953, p. 714), which is inside the line at which the ice margin is assumed to have stood when at Saltstraumen (see GRÖNLIE 1940, Pl. III). The well-developed Finneid-moraine, perhaps including the moraine between Nedrevatnet and Övrevatnet just inside the Finneid-moraine, therefore, most likely corresponds to the Tromsö-Lyngen moraine further north. The upper shore-line for the highest coastline in Fig. 3, corresponding in age approximately to this moraine, would thus be from about 8300B.C. or somewhat older, using the datings from areas further north (ANDERSEN 1968).

The dating of the uppermost shore-line for the highest coastline in Fig. 3 to correspond to the Tromsö-Lyngen moraine means that this shore-line is at a lower altitude than suggested by GRÖNLIE (1940, 1951), but the dating is in agreement with the new results from Western Troms (ANDERSEN 1968). The relationship between the Tapes I shore-line and the shore-line formed approximately at the time of the Finneid-moraine in the area shown in Fig. 3, is almost exactly the same as between the Tapes shore-line and the Main shore-line, formed at the time of the Tromsö-Lyngen moraine, in Ullsfjord, Balsfjord and Malangenfjord areas in Western Troms if these lines are extended to higher altitudes (ANDERSEN 1968). It is also the same as between the Tapes I shore-line and the P_{12} shore-line, corresponding to the Main shore-line, in West Finnmark (MARTHINUSSEN in HOLTEDAHL 1960). Even if there are some regional variations in the inclination of the Main shore-line in northern Norway (ANDERSEN 1968), its altitude in relation to the Tapes I shore-line seems to be rather consistent in a large area. The close agreement about the age of the shore-lines in Fig. 3 with the results from Western Troms and West Finnmark supports the conclusions made on the basis of the marine clays and their relationship to the raised beaches and moraines, and shows that the comparisons made directly with the Oslo area give somewhat too young ages for the uppermost shore-lines.

As a summary of the dating of the two uppermost shore-lines above Tapes I in the area dealt with in Nordland and shown in Fig. 3, the following table can be given of the relationship between the marine clays, the moraines and the shore-lines.

Marine clays	Moraines	Shore-lines
Portlandia-clay with *Portlandia lenticula*		Highest shore-line in Saltdalen, c. 8000 B.C.
	Finneid-moraine (perhaps also Skjerstad-moraine) = Tromsö-Lyngen moraine	*Main shore-line, c. 8300* B.C.
Yoldia-clay with *Portlandia arctica* (C^{14}-date 8600 ± 250 B.C.)		

The two shore-lines in Fig. 3 for the highest coastline are older than the highest position of the shore-line in Västerbotten, in Sweden, from where the ice retreated about 7000 B.C. (Fig. 4). The position of the shore-line for this time is, therefore, in Nordland somewhere below the highest coastline, at approximately the altitude indicated in Fig. 4. It was drawn to show the age relationship between the highest shore-lines in Sweden and Norway but, as for the line for Tapes I joined with the salt-water limit in Sweden, there is no evidence for its true shape in the Scandinavian mountains.

CONCLUSIONS

The shore-lines presented in the 1090 km long profile in Fig. 4 across Fennoscandia, from Estonia in the south-east to the Atlantic coast of Norway in the north-west, were determined with the help of different methods in different parts and at different altitudes. In the determination of the altitudes of the shore-lines raised beaches, glaciofluvial delta plains, pollen analysis and diatoms, Stone Age water-side dwelling places and shellbearing marine clays or beach deposits were used. In dating the shore-lines the varve chronology for Finland and Sweden could be used. Other dates were partly supported by radiocarbon determinations, sometimes from outside the area investigated. Shore-lines in different areas were only connected with each other in those cases where their connection could be supported by stratigraphical evidence. For each area in which the shore-lines were determined, separate more detailed diagrams were first constructed, in which the methods used are mentioned. As some of these diagrams were published earlier, a table is given below in which the figure numbers are listed for all separate shore-line diagrams in earlier papers as well as in the present paper.

	DONNER 1964	1966		1969	Present paper	
Estonia		Fig. 2	Fig. 3			Fig. 4
South-western Finland	Fig. 11			Fig. 3		
Västerbotten, Sweden					Fig. 2	
Nordland, Norway					Fig. 3	

In Estonia and south-western Finland, in which shore-lines for distances of 80 km and 310 km, perpendicular to the isobases, were determined, no irregularities in their shape could be detected. In joining the shore-lines of Estonia with those in south-western Finland there is, however, a bend in the area of the Gulf of Finland. The shore-lines are clearly more steeply inclined on the Finnish side than on the Estonian side and a hinge-line or hinge zone must be assumed to exist or to have existed in the Gulf of Finland to explain this difference (see DONNER 1966). In addition to this bend, similar bends could possibly exist in the Gulf of Bothnia, the Scandinavian mountains or outside the Norwegian coast, *i.e.* in all those parts of the diagram in Fig. 4 from which there is no and could not be any evidence of the shape of the extended shore-lines. As there is no reason, on the basis of the available material, to assume that the shape of the shore-line surfaces, when extended, is irregular in those areas in which the shore-lines could not be determined, and only regular in those areas where they could, the shore-lines were joined in the way shown in Fig. 4. The uplift was, according to this interpretation, slightly asymmetrically dome-shaped with the summit of the dome in the eastern part of the Scandinavian mountains, in the area in which the last remnants of ice melted. The shore-lines slope more steeply towards the west than the east. It is possible that there is a slight curving of the shore-lines in south-western Finland but it is, however, so slight if it occurs that it was not detected. The shore-lines were, therefore, drawn as straight lines in the diagram. The rather regular dome-shaped uplift of Fennoscandia is also suggested by the isobases for the recent uplift of land, as shown in Fig. 1. The tilt of the shore-lines in Fig. 4 is not always the greatest possible because the base-line used is not everywhere at right angles to the isobases as, for instance, at the Norwegian coast.

In addition to suggesting an asymmetrical uplift in Fennoscandia, with a marginal hinge-line or hinge zone in the Gulf of Finland, the shore-line diagram in Fig. 4 shows how the withdrawal of the ice margin was more rapid on the eastern side of the Scandinavian mountains than at the Atlantic coast and in the mountains themselves. The ice margin stood at the Salpausselkä end-moraines in southern Finland at the same time, just over 8000 B.C., as at the Finneid-moraine in Nordland in Norway, but a thousand years later it had already withdrawn from Finland to Västerbotten in Sweden. The shore-line diagram also shows how the land/sea level changes in the Baltic region were affected by the development of the Baltic Sea. The fluctuations caused by the damming up of the water level of the Baltic Ice Lake and of the Ancylus Lake resulted in shore-line positions above sea-level. The altitude at which the water-level stood above sea-level during these periods is shown in Fig. 4, as well as the areas in which the rise of water-level overtook the land uplift and resulted in transgressions. Two

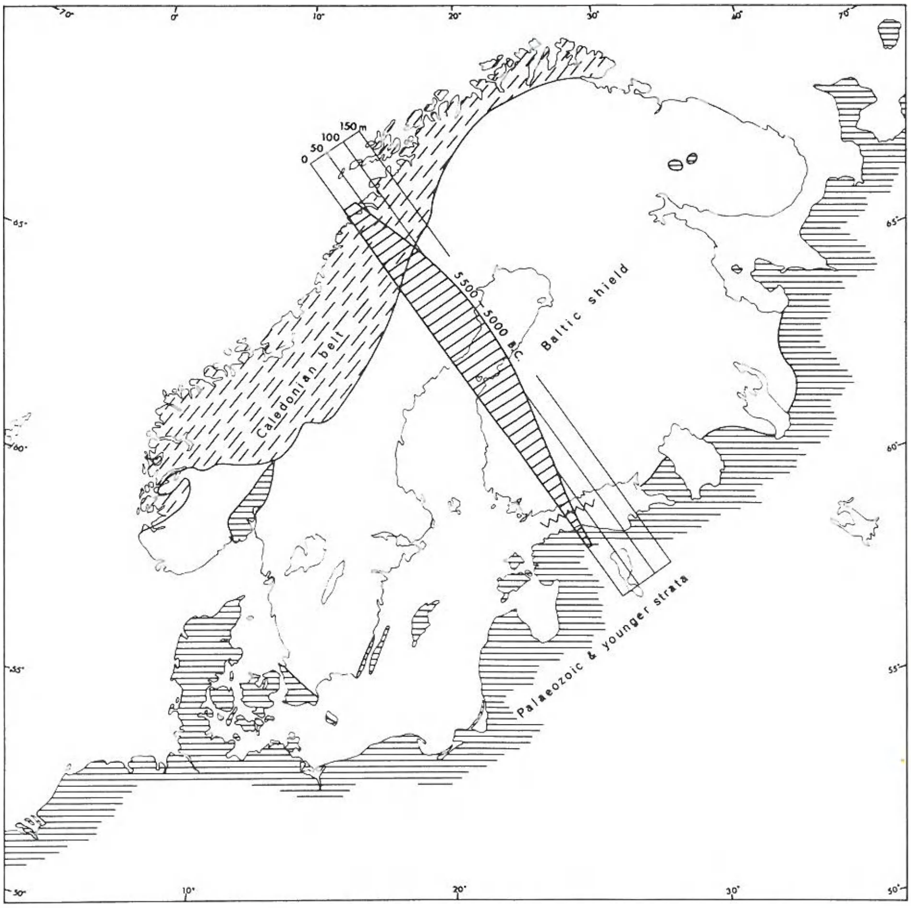

Fig. 5. The shape and altitude of the Litorina I — Tapes I shore-line from 5500 B.C.—5000 B.C. and the position of the marginal hinge zone in the Gulf of Finland compared with the main tectonic units.

transgressions, that of the Baltic Ice Lake and of the Ancylus Lake, were transgressions in the Baltic when it formed an independent lake, whereas the Litorina transgressions were caused by the eustatic rise overtaking the land uplift.

The relationship of the shore-lines in Fig. 4 to the outer limit of the Weichselian glaciation and to the Fennoscandian moraines, as well as to the isobases of the recent uplift of land, were shown in Fig. 1. In Fig. 5 the general shape of the Litorina I—Tapes I shore-line from 5500—5000 B.C., along the line studied, is shown on the map together with the main tectonic units. In the north-west, along the Atlantic coast, the Caledonian belt borders the Baltic Shield. In the south and south-east there are Palaeozoic and younger strata. Within the Shield there are younger rocks, also marked on the map, as the Devonian intrusions in the Kola Peninsula and the Permian igneous rocks in the Oslo area. No direct relationship can be detected between the shape of the shore-lines and the main tectonic units. The marginal hinge-line or hinge zone (see Fig. 5) in the Gulf of Finland, if real, is, however, likely to be tectonically controlled.

Appendix

References to raised beaches used in the shore-line diagram in Fig. 3, listed from left to right. GRONLIE 1951, sites 381, 380, 384, 378, 394, 367, 389, 386, 383, 354, 377, 375, 372, 369, 363, 360, 337, 366, 339, 334, 358, 350, 341, 320; REKSTAD 1910, Ripnes, Alsvik.

References to sites with *Portlandia*-clay. REKSTAD 1910, Osbak at 105 m, Nygaard at 60 m; REKSTAD 1917, Fauske at 100 m. The site with *Yoldia*-clay is at Bodö at 10 m (MARTHINUSSEN 1962).

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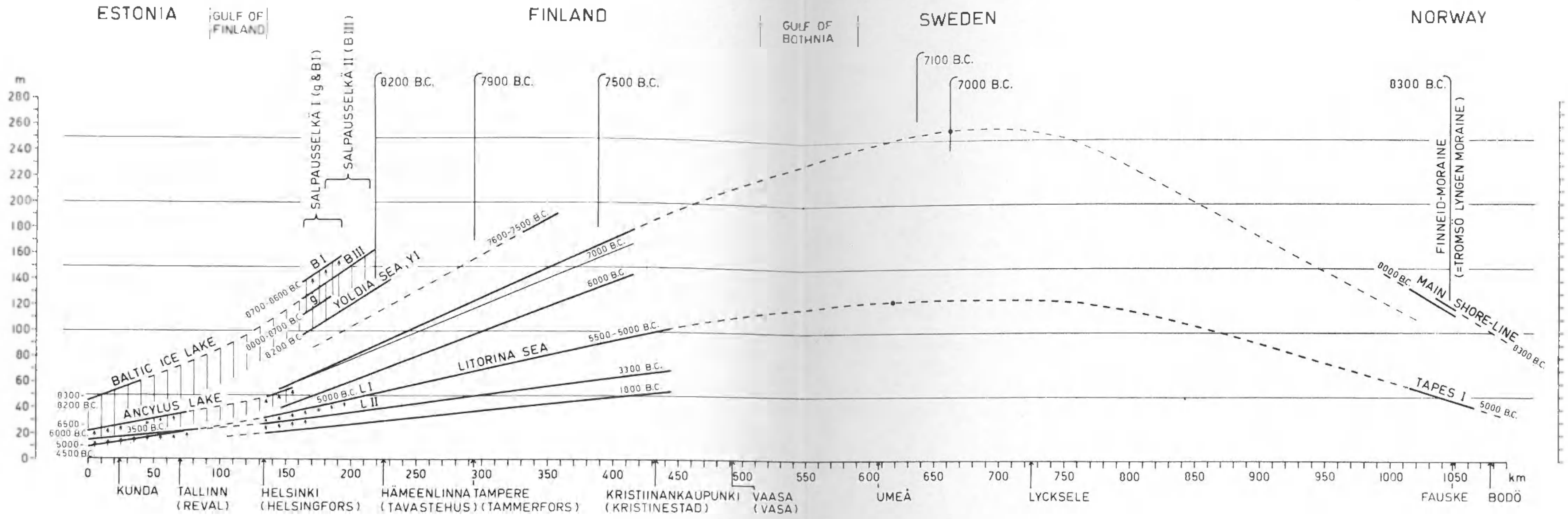

Fig. 4. Combined shore-line diagram for all areas shown in Fig. 1, showing also some positions of the retreating ice margin. Thick lines show determined shore-lines and broken lines show the connection of them. The position of the water-level of the Baltic Ice Lake and the Ancylus Lake above sea-level is shown with vertical lines and transgressions with arrows underneath the levels reached by the transgressions.