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ISBN 91-7158-465-X
ISSN 0348-1352

Textkartorna är från sekretessynpunkt godkända för spridning
Lantmäteriverket 1989-12-11

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Redigering och layout gjord på Macintosh, SGU
Tryck: Offsetcenter AB, Uppsala 1989

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ABSTRACT

Strömberg, Bo 1989: Late Weichselian deglaciation and clay varve chronology in East-Central Sweden. Sveriges geologiska undersökning. Ser Ca, No. 73. 70 pp. Uppsala 1989.

A revised varve chronology for the Late Weichselian deglaciation between Stockholm and Sundsvall is presented. More than 200 varve measuring sites have been used, and graphs from c. 150 of these are subjoined in the plates. Presented here is also a new revision of the main Swedish time scale of Gerard De Geer (1940), and of an earlier revision by Järnefors (1963). According to the new varve correlations, De Geer's recession line -1073, just to the south of Stockholm, is now dated -1191 (= 1191 varve years before the so-called zero year), i.e. it was found to be 118 years older. Based on the corrected age of the zero year = 7288 varve years B.C. (Cato 1987), the recession line -1191 can now be dated 8479 varve years B.C.

Since the revision 1963 of Järnefors implied an extension of De Geer's time scale for deglaciation between Uppsala and Sundsvall by 19 years, 99 more varve years (118 minus 19) have been added to the chronology. Of these 99 years, 64 are corrections north of Uppsala and 35 between Stockholm and Uppsala. An estimated margin of error for the 1191 deglaciation years is ±25 years. For the entire period of 8479 varve years B.C. +1950 varve years A.D. a margin of +35/-205 years should be calculated as a maximum (cf. Cato 1987).

A normal deglaciation rate was 200–300 m a year, but recorded values between 50 m and 1000 m show that local variations can be great. A notably good correspondence exists between varve based recession lines and lines constructed on information from the youngest glacial striae. This facilitates extrapolation of the equicesses in present land areas below the highest coastline, but the deglaciation of the southern Bothnian Sea can only be sketched hypothetically. It has been dated indirectly by the so-called spot zone – limestone fragments in the microvarved clay. Thus the breaking up of an ice lobe in the southern Bothnian Sea was delayed for several decades, but was then destroyed by vigorous calving during c. 100 years.

Key words: Late Weichselian deglaciation, clay varve chronology, Swedish time scale, spot zone.

Introduction

When Gerard De Geer's 'Geochronologia Suecica Principles' was accomplished in 1940, a long-desired contribution to Quaternary geology was made. A detailed chronology for the inland ice recession from Stockholm to the Indalsälven River had been worked out from about a thousand clay varve measurements made during a generation by De Geer and his many collaborators. At this time 'The Main Swedish Time Scale' was known by years, but rather few of the actual varve measurements had been published. Accordingly, the graphs printed in the 'Geochronologia' covering 1400 glacial varves – younger than De Geer's 0-year – and 2000 postglacial varves, were eagerly awaited. Quite naturally, a pioneer work such as this can hardly be completely perfect. Some weak points were cautiously touched upon already in Caldenius' (1941) review of the Geochronologia. His proposals to move graphs a few steps, and suggestions to reconsider two of the correlations, may be regarded as the first revision of the time scale.

Systematic improvements and revisions were started in the 1940's, 1950's and 1960's concerning the lateglacial part of the time scale (Fromm 1945, Borell & Offerberg 1955; Järnefors 1963; Hörnsten 1964; Bergström 1968; Nilsson 1968). Still there were strong reasons to believe that errors remained in several parts of the chronology, but a more important problem was not solved: a firm connection between the postglacial varve chronology (Lidén 1913, 1938) and the present.

When the general outlines for the Swedish participation in the International Geological Correlation Programme (IGCP) were laid down in 1975, two of the most important points were the connection of the postglacial varve chronology to the present and a new and total revision of the lateglacial time scale. Several authors had emphasized the weak connection of the postglacial time scale to present time, since it was based mainly on shore displacement data (Lidén 1938). Wenner (1968, p. 93) estimated a possible correction of this connection to be in the order of +200 to +500, probably +350 years – a good conclusion in the light of the figure known today: +365 years (Cato 1987). Fromm (1970, p. 170) counted on a correction of 0 to +500, Tauber (1970, p. 176) on +100 to +300 years. In order to get a firm link between the Swedish time scale and the present, 25 new sediment cores were taken 1978–1983 in the Ångermanälven valley by foil coring on land and by piston and gravity coring on the sea bottom (Cato 1987). The measurements and varve countings showed that the youngest part of Lidéns (1938) postglacial varve chronology had to be extended by 365 years (Cato 1987, p. 50).

To the north of Stockholm the lateglacial time scale was based mainly on the first systematical varve measurements made 1905–1906, and on a revision in form of an indepedent, new varve chronology between Uppsala and Sundsvall (Järnefors 1956, 1963). None the less, apparent or likely errors remained (J. Lundqvist 1975; Strömberg 1985). To the south of Stockholm the situation was even worse: in reality no continuous varve chronology existed, as only a few of the original graphs of De Geer and his collaborators had been published, and Nilsson's (1968) new varve chronology had a number of weak parts, some of which have now been corrected (Kristiansson 1981, 1982, 1986; Perhans 1981).

It was natural to divide the revision according to the preferences of the different co-workers, most of whom were already engaged in varve chronological work (Fig. 1; Strömberg 1985). I had earlier started varve measuring between Stockholm and Uppsala, and in collaboration with Birger Forssmark at the Department of Quaternary Geology, University of Uppsala, I also took the responsibility of making a revision between Uppsala and Sundsvall.

The most obvious of the weak parts of the lateglacial varve chronology north of Stockholm was the ice recession area Söderhamn – Sundsvall (cf. J. Lundqvist 1975). Even the new measurements made during the first years of revision work, made me sceptical of several correlations of graphs from other areas too. In fact only about 200 years of the 650-years time scale for the ice recession Stockholm – Sundsvall, according to G. De Geer (1940) and Järnefors (1963), could be regarded as fully reliable. The revision, which at first was ment to be a restricted completion, developed into an almost independent varve chronology based on more than 200 new sites.

Some preliminary reviews of the revision have been made (e.g. Strömberg et al. 1981; Kristiansson 1982; Cato 1985; Strömberg 1985) and these also include reports of the measurements and correlations which are completed (lateglacial varves in southeastern Sweden: Ringberg & Rudmark 1985; Kristiansson 1986; connection with the present: Cato 1987). When revised chronologies for the ice recession in Östergötland – Södermanland are presented, (western part, Perhans *in prep.*, E part, Brunnberg *in prep.*) most of the Swedish time scale has already been checked. But some work still remains in filling out the gap of the time scale in southeastern Sweden, as well as more measurements to strengthen the correlations for traversing the Younger Dryas zone.

There are great demands upon the reliability of a varve chronology, and it should be correct to within a very moderate margin of error, to enable its use as a time scale. In some areas this object may be obtained quite easily and without any greater problems. Very often the last obstacles towards a complete chronology are concentrated in rather restricted geographical areas, and it is hardly surprising that the old varve chronologies have their weekest points here. Smaller problem areas tend to dominate during a revision and the recurrent field works in these areas may appear to be needless repetitions.

Nevertheless, I highly appreciated the support I received from individuals and institutions throughout this period. Most important the past four years is the part time post as researcher, which I received from the Faculty of Science at the University of Stockholm. Field work during the first years, the drawing of graphs and maps as well as the printing has been economically aided by the Swedish National Science Research Council. Additional field works were supported by grants from the Carl Mannerfelt and the Hans W:son Ahlmann Funds.

Several measurements between Gävle and Sundsvall were made in collaboration with Birger Forssmark who has also contributed with some of his own varve graphs from the Ljusnan area. Among colleagues at my own department I particularly want to thank my teacher and friend Gunnar Hoppe, who has followed my efforts with interest and encouragement through the years. The project was managed in pleasant cooperation with Jan Lundqvist who, along with Jan Kristiansson and Lars Brunnberg, at the Department of Quaternary Geology in Stockholm, kindly assisted with varve data at the Geochronological Museum. Ingemar Cato, Birgitta Ericsson, Karin Grånäs, Eva Lidén and Martin Sundh, at the Geological Survey of Sweden, have been very helpful with unpublished data. Ingemar Cato has also read and made valuable comments to the manuscipt. The drawings of graphs and maps were skilfully made by Sigrid Bergfeldt and Birgit Hansson at the Department of Physical Geography in Stockholm. The English text has been corrected by Bebe Jonsson. To all these and everyone who facilitated my work, I convey my sincere thanks.

The lateglacial varve chronology Stockholm – Sundsvall: status 1975

When the revision started in 1975, the varve chronology for the ice recession between Stockholm and Sundsvall consisted of the following parts (Fig. 1):

(1) Gerard De Geer's (1940, Pl 72; 75–78; 81–83) time scale, based on the early measurements, the 'miles' (Swedish "milar") G–T, Stockholm – Gävle, and special graphs for the Ockelbo, Bollnäs and Dellen areas plus some scattered measurements, e.g. at Hudiksvall and in the Indalsälven river valley.

(2) Some more varve series from the Stockholm and Gävle areas published by Gerard De Geer in 1932 and 1938.

(3) Järnefors'(1956; 1963) revised time scale, based on new measurements on foil cored samples from the ice recession area Uppsala – Sundsvall.

(4) Additional varve graphs, covering smaller areas or sidelines, published e.g. by Öster (1943), Kulling (1948), Möller (1962b), Strömberg (1965, 1971), Bergström (1968), Nilsson (1968) and Brunnberg (1974).

(5) Unpublished graphs, primarily original measurements, stored at the Geochronological Museum in Stockholm.

All this material may seem sufficient for its purpose, but possible errors could none the less be suspected to remain. Thus J. Lundqvist (1975) examined varve correlations from the Söderhamn – Sundsvall district and suspected that the time for ice recession in this coastland probably was underestimated by, at a maximum, 200–400 years. Consequently, there was an obvious need for new revisions of the varve chronology.

Connection to the zero year

One of the main geochronological questions of the last decades concerned the correlation between the so-called zero year in the Indalsälven area and the corresponding varve among the lateglacial varves in the Ångermanälven valley. In addition to the correlation problem, this question also included a definition of the zero year. This definition was intensively discussed by E. H. De Geer (e.g. 1959) and Caldenius (1960), but it has also been examined by e.g. Borell & Offerberg (1955), Järnefors (1963), and Fromm (1985). The last-mentioned paper gives a lucid review of the most important statements which will not be scrutinized here. Briefly, these statements imply that a 980 mm thick drainage varve in a series which was measured in 1911 by Carl Caldenius at Döviken in the Indalsälven valley (Fig. 2 and 3) should be the 'real' zero varve which was intended by Gerard De Geer to be the original starting-point of his time scale. Roughly, it was formed at the transition between 'glacial' and 'postglacial' varve deposition. In reality, this transition is not a synchronous horizon, neither within the Indalsälven valley, nor in the neighbouring river valleys. Thus the 0-year, with minus-numbers of the varves on the 'glacial', and plus-numbers on the 'postglacial' side, is no stratigraphic divide.

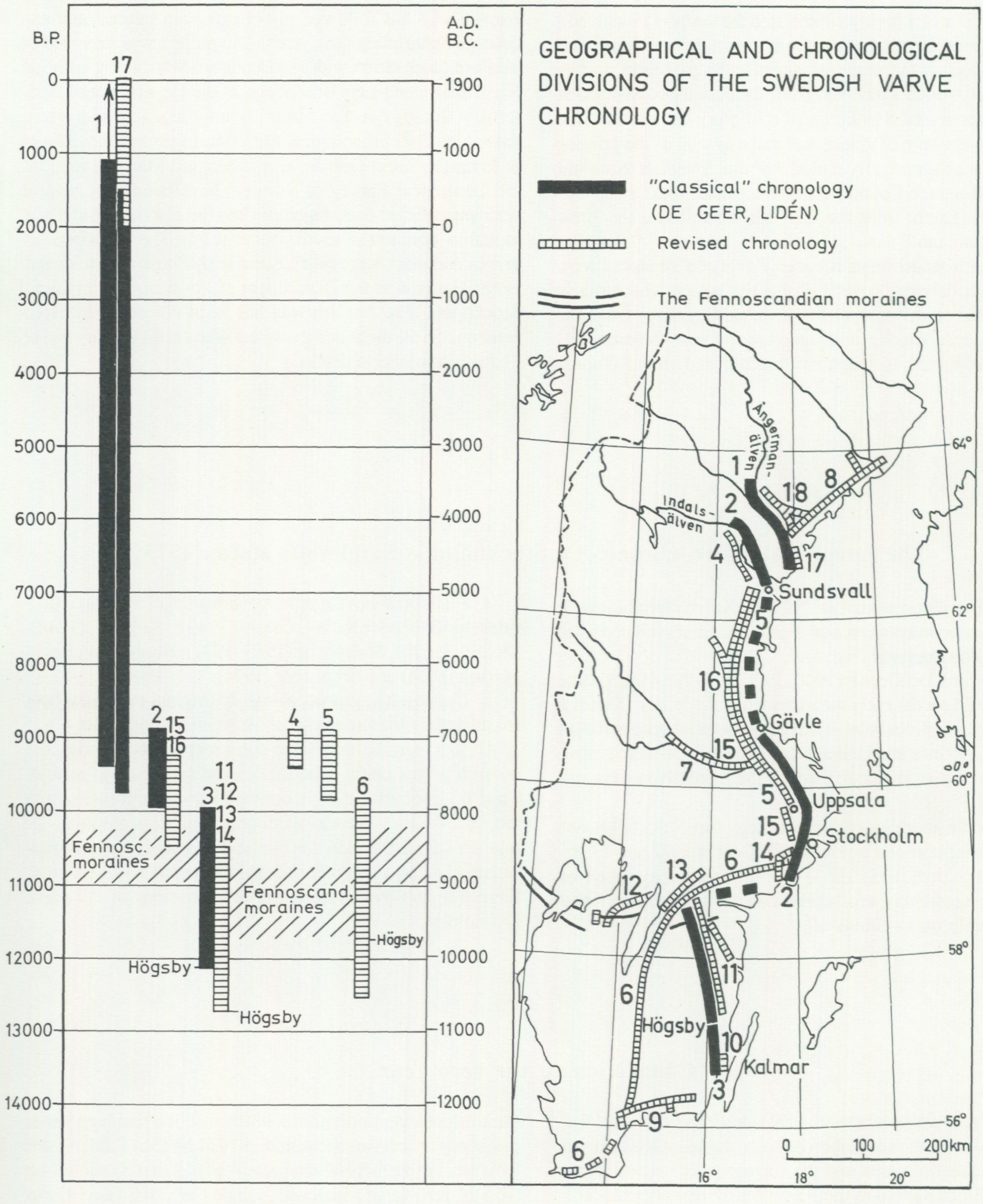


Fig. 1. The Swedish time scale (Strömberg 1985, modified from Fromm 1970), 1 = Lidén 1913, 2 = G. De Geer 1940, 3 = G. De Geer, unpublished, 4 = Borell & Offerberg 1955, 5 = Järnefors 1963, 6 = Nilsson 1968, 7 = Fromm 1964, 8 = Hörnsten 1964 and Bergström 1968, 9 = Ringberg 1979 and Ringberg & Rudmark 1985, 10 = Rudmark 1975, 11 = Kristiansson 1986, 12 = Caldenius 1944, 13 = Perhans, unpublished, 14 = Brunnberg, unpublished, 15 = Strömberg 1989, 16 = Forssmark, unpublished, 17 = Cato 1987, 18 = Fözö 1980.

The first correlation between varve series from the Indalsälven and the Ångermanälven valleys was made by Gerard De Geer (1924; 1940, Pl 76). He correlated the series Vikbäcken, measured at a site to the south of the Indalsälven at Hammarstrand, with a series from Gåsnäs, in the Ångermanälven valley, and with Lidén's (1913) series Sand from the same valley (Fig. 2 and 3). This correlation is regarded as reliable, but an annoying mistake was made by De Geer when he correlated the Vikbäcken varve series with the Döviken and other series in the Indalsälven valley. Caldenius (1941, p. 101) early realized that the correlation Vikbäcken – Döviken was incorrect, but the correction could not be fixed until extensive varve measurements had been made by Borell & Offerberg (1955). Their correlation between varve series from the valleys of the Indalsälven and the Ångermanälven has been verified by Hörnsten's (1964) and Bergström's (1968) varve chronological works in Ångermanland and Västerbotten. It was also accepted by Järnefors (1963), who connected his revised varve chronology to the zero year by a correlation of his series 110 Indal to the Borell & Offerberg (1955) series 15 Bäck.

However, at closer examination of the correlations and of the zero year position in Borell & Offerberg's (1955, p. 21 and Pl. 2–6) varve graphs, a number of minor operations are seen, especially gaps in the graphs. The authors (*ibid.*, p. 20–21) were forced to make these operations in order to get a complete correlation with Lidén's (1913) varve series from Ångermanland. In some of the graphs 20–30 varves are missing; somewhat fewer according to the tables (*ibid.*, Pl. 5–6). Also Järnefors (1963), Hörnsten (1964) and Bergström (1968) had to cut their graphs when they correlated with Borell & Offerberg's (1955) or Lidén's (1913) diagrams; e.g. Järnefors (1963, Pl 5) has opened gaps representing 15 varves in the graph 110 Indal. Most puzzling are gaps which are found in identical positions in practically all the graphs, as a section of three missing varves within the sequence -190 to -195, found in all series taken by Borell & Offerberg (1955) in the Indalsälven valley, and in most of Bergström's (1968) Västerbotten-series.

Possible explanations can be given of a divergence between two river valleys – or between different localities in a valley – concerning the number of varves. Erosion in connection with drainage from ice-dammed lakes may explain gaps, if they represent disappeared strata close to drainage varves (Borell & Offerberg 1955, p. 21). An example is given by Bergström (1968, p. 44). In one part of a varve section in Västerbotten he noticed a layer representing a high water and sediment discharge situation, and discordantly overlying older varves of which more than 20 were eroded. In another part of the section the layer rested concordantly on uneroded varves. Such observations give quite convincing evidence of erosion, and one may notice that they are facilitated by an access to open clay sections – rare today – but difficult to make on narrow clay samples.

On the other hand, additional varves may be deposited in high water situations, as during drainages of glacial lakes. The varve -48 (Fig. 2) is an example: it is a very well developed, sandy-silty drainage varve in most clay profiles in the lower Indalsälven valley and in the coastland far to the south of Sundsvall. It has been suggested that this varve was formed by the drainage of one of the glacial lakes 'Håsjöissjön', 'Mårdissjön' or 'Hammerdalsissjön' (J. Lundqvist 1959, 1973; Fözö 1980). In Ångermanland and Västerbotten, however, it is missing in most profiles (Bergström 1968), and in order to correlate with varve series from the Indalsälven valley, Borell & Offerberg (1955) and Bergström (op. cit.) were forced to cut Lidén's (1913) graphs at the -48 varve position. To all appearances Fözö (1980, p. 13, 61; Pl 1–3) regards the varve -48 as present in his varve series, and its thickness is not diverging from ordinary varves in his Ångermanland graphs.

Naturally the question must be posed if all drainage varves are included in the annual deposit, added to the 'normal' summer- and winter-layer, or if they are 'extra' deposits looking like annual varves but formed during – sometimes – violent high water situations of short duration (cf. Fromm 1970, p. 168; J. Lundqvist 1973, p. 72). I have not found any way to explain their true character: in my samples the drainage varves consist of a main, thick, silty-sandy part and of a thin clayey part, looking just like a normal winter layer. If this thin layer is a genuine winter layer, the drainage varve should be regarded as a true annual deposit with an extremely thick summer layer. But a thin, clayey, 'false winter layer', may also be formed of partly eroded clay at the end of a high water sedimentation. If the drainage is of short duration, and it occurs not too late in the season, an almost complete annual varve may be formed in addition to the drainage varve.

The only way to make corrections for 'extra' drainage varves in such situations is probably by making careful comparisons between varve series from different sedimentation areas, such as the Ångermanälven and the Indalsälven valleys. My series from a distal, outer part of the Indalsälven area are not suited for this purpose, since the varves are thin and the thickness variations too insignificant for correlation varve by varve. Still I get a rather good overall agreement, considering the thickness variations of varves, when I compare the different series, and the total number of varves, e.g. between the drainage varves -48 and -424 (Pl. 17, 18), are the same in most of the measurements. My interpretation of this fact is that the distal sites are more representative for the registration of undisturbed, annual sedimentation of varves than proximal sites in valleys, affected by local high water discharges (cf. Lidén 1913; Cato 1987).

In order to connect my own varve series to the zero year it was natural at first to correlate via Järnefors' (1963) and Borell & Offerberg's (1955) graphs. However, not only the difficulties mentioned in the last paragraphs, but also some other problems turned up. Even if the geochronological consequences of these problems are restricted, there are principal and metodical aspects of some interest, which account for a brief review.

In a revised calculation of the age of the zero year Fromm

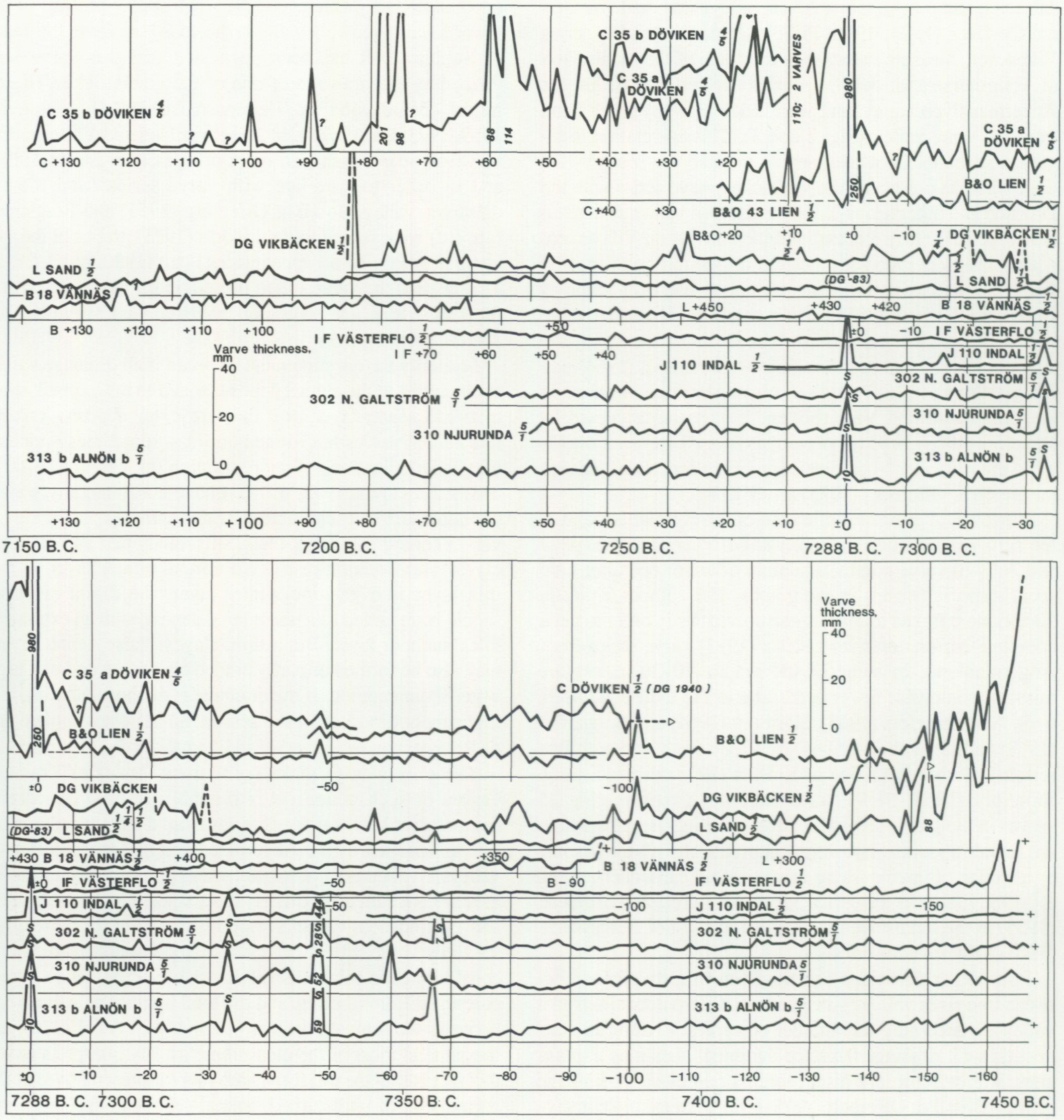


Fig. 2. Connections to the zero year varve = the 980 mm thick drainage varve of the series C 35 Döviken (Caldenius 1924, 1960), corresponding to varve 427 in Lidén's (1913) local time scale, B = Bergström 1968, B & O = Borell & Offerberg 1955, C = Caldenius (Carlzon) 1924, 1960, DG = G. De Geer 1940, IF = Fözö 1980, J = Järnefors 1963 L = Lidén 1913. 302, 310, 313: see Table 3. Time scales according to the different authors, in addition to the revised time scale (lower scale). Varve thickness according to rule; reduced (1/2, 1/4, 4/5) or magnified (5/1). + for remaining varves, triangle = till substratum, s = silt. Vertical numbers = varve thickness in mm.

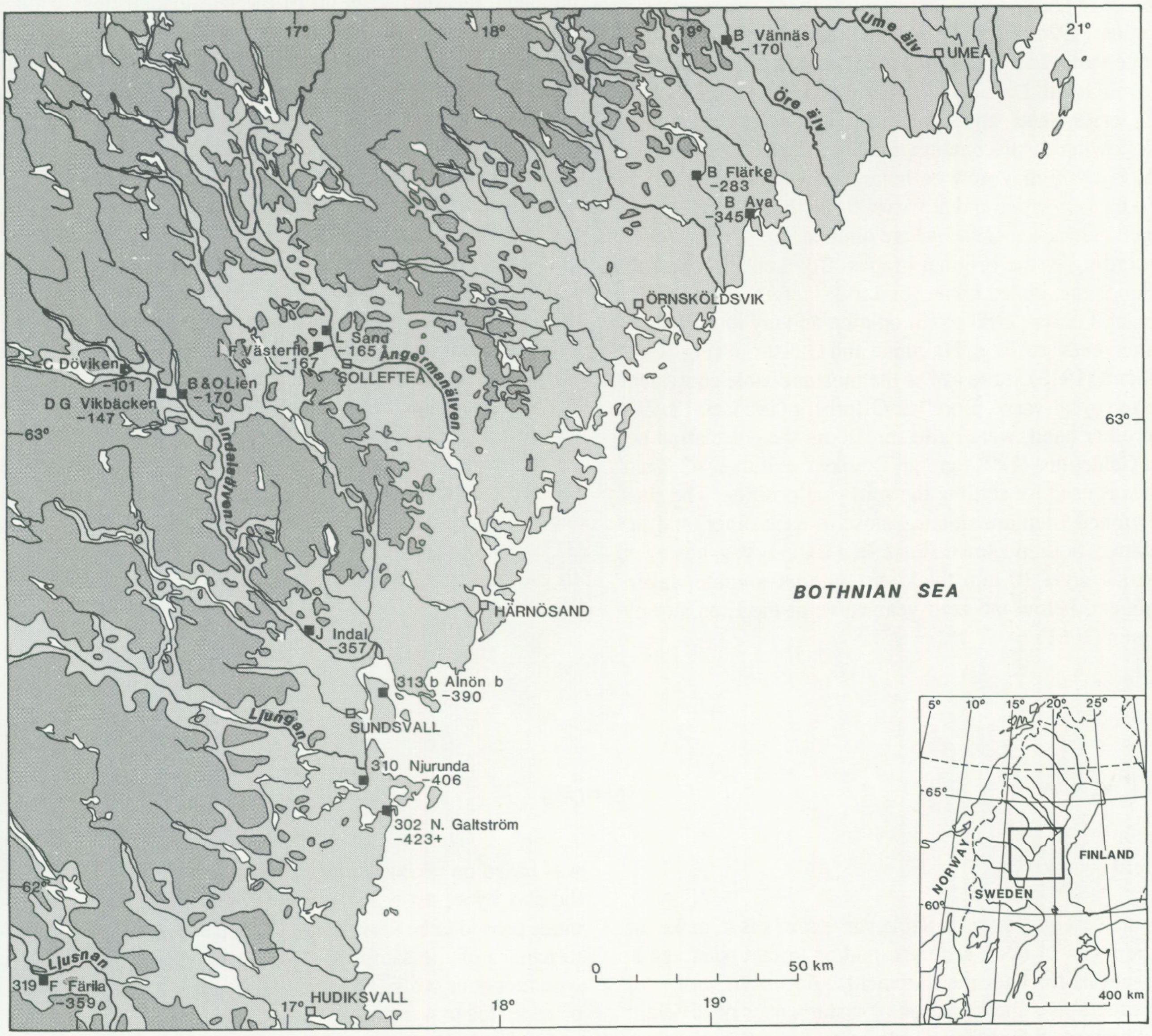


Fig. 3. Measuring sites of varve series in Fig. 2. Present land area below the highest coastline (from G. Lundqvist 1961) is shaded.

(1985 and pers. comm.) verified the correlation made by Borell & Offerberg (1955), implying that the zero year corresponds to varve 425 in Lidén's (1913) varve graphs. For reasons not given here (see e.g. Fromm 1985, p. 123), Borell & Offerberg (op. cit.) have only nine varves from zero to -10, so the real 'numerical' position of the drainage varve zero in their graphs is at -1. Bergström (1968), too, has nine varves from zero to -10 in his Västerbotten-series, Järnefors (1963) and Fözö (1980), however, ten.

According to an oral information by J. Offerberg (Järnefors 1964, p. 171) the number of varves between the zero year and -10 was incorrectly given as 8 years in the graphs (Borell & Offerberg 1955) and should be taken from the tables (*op. cit*, Pl. 5). This discrepancy between graphs and tables was also commented on by Fözö (1980, p. 13).

In order to make correlations Borell & Offerberg (1955) had to cut and open a gap in Lidén's (1913) graphs at the position of the drainage varve -48. Thus, in reality, there are three possible zero varve equivalents in Lidén's (op. cit.) graphs: varve 425 (Borell & Offerberg 1955; Bergström 1968), varve 426 (correct 'numerical' zero at Indalsälven; Fromm 1985), varve 426 or 427 (Järnefors 1963, Pl. 5, as a consequence of correlations via Borell & Offerberg's graphs with Lidén's graphs in changed or unchanged design), and varve 427 (Fözö 1980; see also Cato 1987, p. 7). As long as we cannot judge how well-grounded the different correlations, gaps etc. are in the graphs, the real age of the zero year at the Indalsälven can not be specified. The possible error is, of course, insignificant in a time scale of this magnitude.

In addition, a number of other displacements are detected when different graphs are compared, confusing the picture of correlations around the zero year. In Fig. 2 I have collected some graphs which have been used for age determination of the zero year and for correlations with other varve series, e.g. Caldenius' (1924, 1960) graphs including the 980-mm thick drainage varve at Döviken = varve zero measured in 1911; moreover Gerard De Geer's (1940) Vikbäcken-series, Lidén's (1913) series 'Sand', and some others in their original shape. The following displacements, made by Borell & Offerberg (1955, Pl. 1–2) may now be noticed: a gap at varve -35 in the Vikbäcken-series and at varve -94 in the Döviken-series, in which the varves -8 and +3 are omitted.

According to the original graphs 'Döviken', 'Vikbäcken' and 'Sand', mentioned above, and to Järnefors' (1963) series 110 Indal, Fözö's (1980 p. 13) opinion and my most distinct measurements at Alnön, Njurunda and Galtström (Fig. 2 and 3), Lidén's (1913) varve 427 is the most probable equivalent to the zero year varve. Borell & Offerberg (1955, p. 18, 21), on the other hand, were quite sure about the correlation between Caldenius' (1924) graph 'Döviken' and their 43 'Lien' which was used for settling the zero year position. The sites Döviken and Lien are situated close to each other, and the varve limits at Lien were distinct. In a later survey, however, an 'extra' varve, 10 mm thick and without a winter layer, was noticed below the zero year varve at the Lien site by Holmgren (1961).

The possible difference of only one or two years is no reason to change the starting point of the late-glacial time scale. As mentioned above, possible errors owing to erosion or double-counting at some of the drainage varves are likely, and may probably mean an uncertainty of 2–5 years, which is rather insignificant.

When the important connection to present time was accomplished, it implied a prolongation of the postglacial time scale by 365 years (Cato 1985, 1987). Since an examination of Lidén's unpublished, postglacial varve chronology indicates that it is correct (Lidén † & Cato *in press*), the lateglacial varve chronology can be dated by new, and hopefully, accurate numbers. This dating starts with the zero year which has now been designated 7288 varve years B.C. (Cato 1985, 1987) or more precisely, since one year has been added to the A.D.-B.C. scale in the calculation, the historical year -7288 (Fromm 1985).

In this paper I will use the designation 7288 B.C., as not to confuse the historical time scale with the De Geer years 'older than zero', which are also indicated by a minus sign. The total length of the postglacial period, up to A.D. 1986, was thus 9273 varves/years, if the zero year is excluded. Cato (1987, p. 50) estimates a margin of error for this value to be less than +10 and -180.

Methods

A. Field work

By far the best way to get reliable varve series is to make the measurements in open sections, and/or to take samples in open sections for later measurements. Access to wide clay profiles facilitates the detection of disturbances of different kinds which are rather frequent in some areas (fissures with faults, slided clay parts, missing varves on irregular substratum etc.). When I made my first clay varve investigations in the late 1950's and early 1960's, several brick-works were still operating in the Stockholm – Uppsala region; examining their tens or hundreds of meter sections of clay in the pits was informative. Today none of those brick-works exist, and the pits are damaged or filled. Of course many clay sections have been observed and visited at road works or other diggings, but rather few have been of any use, as they are often unfavourably located in high positions of the terrain. In fact, only 17 of my and Forssmark's measurements accounted for here (sites V-11, 27–35, 126, 129, 163, 300, 309, 318 and 319; Table 3), were made in open sections.

On the whole, since the experience from foil core sampling was good (e.g. Järnefors 1956, 1963), it was urgent to find a suitable sampling method for the current revision work, that was more simple and less expensive than the foil core boring. During the 1960's I constructed a device which was based on taking samples from the wall of holes, dug in the clay by a post-hole digger (Strömberg 1966). This technique proved to be very successful and showed almost no disturbances of the samples. However, digging of the holes was strenuous work, and the total depth for sampling had to be restricted to 4 metres.

Simpler ways than this were tested in the early 1970's, and a new device was improved during the years of fieldwork. My new clay sampler (Strömberg 1983) is a standard, 40 mm wide, U-shaped iron profile which is pressed down in the clay to the substratum (Fig. 4). This pressing down can usually be made by hand, since the clay consistency is examined during the initiate sounding, and unsuitable sites are avoided. A steel tape which is attached to a 'knife' on iron rods is now brought down, acting as a cover on the open side of the U-profile. The rods are steel pipes with pierced, threaded ends, which allows for air to enter the lowest point of the rods close to the lowest part of the sample. When the sampler is pulled up by a lever, vacuum is avoided, as the air gets access below the sample. For air to enter through the rods, a 2 mm iron thread is pushed through the rods during the first moments when the clay sampler is taken up.

A 'sampling with air access' is necessary if one aims to get a complete sample down to the substratum and including the lowest centimetres of clay. This is highly desirable for

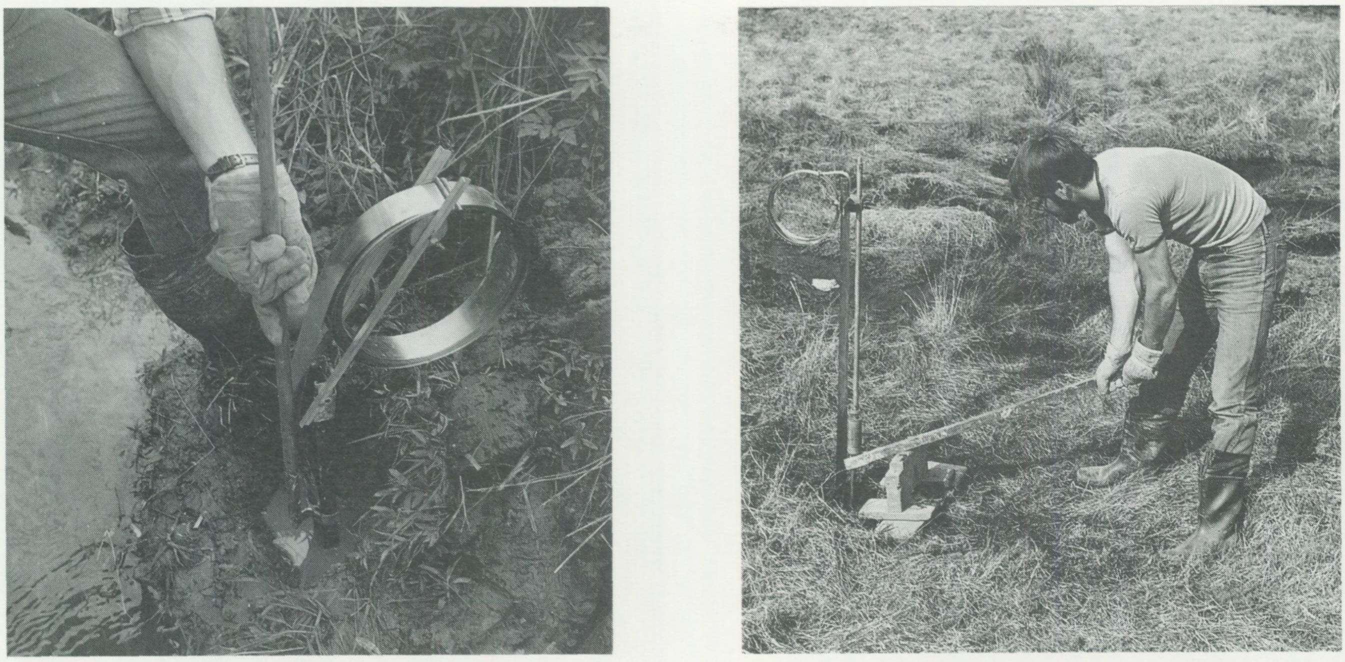


Fig. 4. Clay sampling. A knife and steel tape covers the open side of the sampler (left). The filled sampler is pulled up by lever (right).

instance in the coastland of southern Norrland, where all varves, also the lowest, are often very thin. In many areas, however, the bottom-varve is more than a decimetre thick, and a loss of some centimetres of clay – which is normally the case when the sampler is pulled up without air access – will not seriously affect the measurement.

Depending on the clay consistency, fairly obvious disturbances are noticed close to the sampler and to the steel tape. It is always necessary to cut off about a centimetre of the clay below the steel tape, but the 'core' of the sample remains undisturbed and is then measured. In very soft and/or sticky clays the steel tape pulls down the outer part of the sample by friction when the 'knife' is pressed down. This may also affect the core so that the strata dip downwards. The dipping is not a serious disadvantage in varve measuring, but it must be taken into consideration if samples are to be used for e.g. paleomagnetic measurements.

Before sampling can be made, one must first sound to determine the clay depth to the substratum and the clay consistency. Some extra soundings are made close to the future sampling point to reveal possible unsuitabilities of the site, such as a steep slope of the substratum or boulders in the clay. Sampling made in ditches, moistened with a little water, makes the pressing down of the device easy. Otherwise the dry, often sandy, topsoil with roots and humus has to be removed. In tough clays the sampler and the 'knife' with the steel tape have to be forced down with a weight which can take a few extra minutes. Getting a 4-metre sample usually takes about half an hour; longer samples require more time, especially if the iron profile has to be jointed. However, in most areas the total depth of the glacial clay is less than four metres, and if the lowest part of the terrain is avoided, 4–6 metres long iron profiles will suffice. My standard device measures four metres, and is easily transported by a private car, but can be jointed to six or eight metres if necessary. When working alone – quite possible with this sampler – the six- and eight-metre samplers must be rejointed when the upper part has been lifted above the ground surface, since the two parts are to heavy to handle as one unit.

The filled sampler is put on a 'table' – usually on the handles of two sounding rods (Fig. 5) – the steel tape is cut free from the clay, and the varve limits are made visible by a trowel. Weather and clay type permitting, the varve measuring may be made in the field, where light conditions are often very favourable. If the varve limits are indistinct, or the varves are very thin, the samples are brought home for more careful study. The sample is then transported in full length, in the sampler, or cut to one-metre pieces which are transfered to 40x20 mm plastic profiles. To avoid disturbing the sample by the transfer, a thin (0.1 mm) steel foil can be placed in the bottom of the sampler before sampling. Then one need only cut the sides of the sample to remove it. It is also possible to take out samples from a sampler without a steel foil in the bottom. After having cut the sides of the clay sample, a plastic cover (plastic film) is placed over the wet clay surface and the sampler is turned upside down over

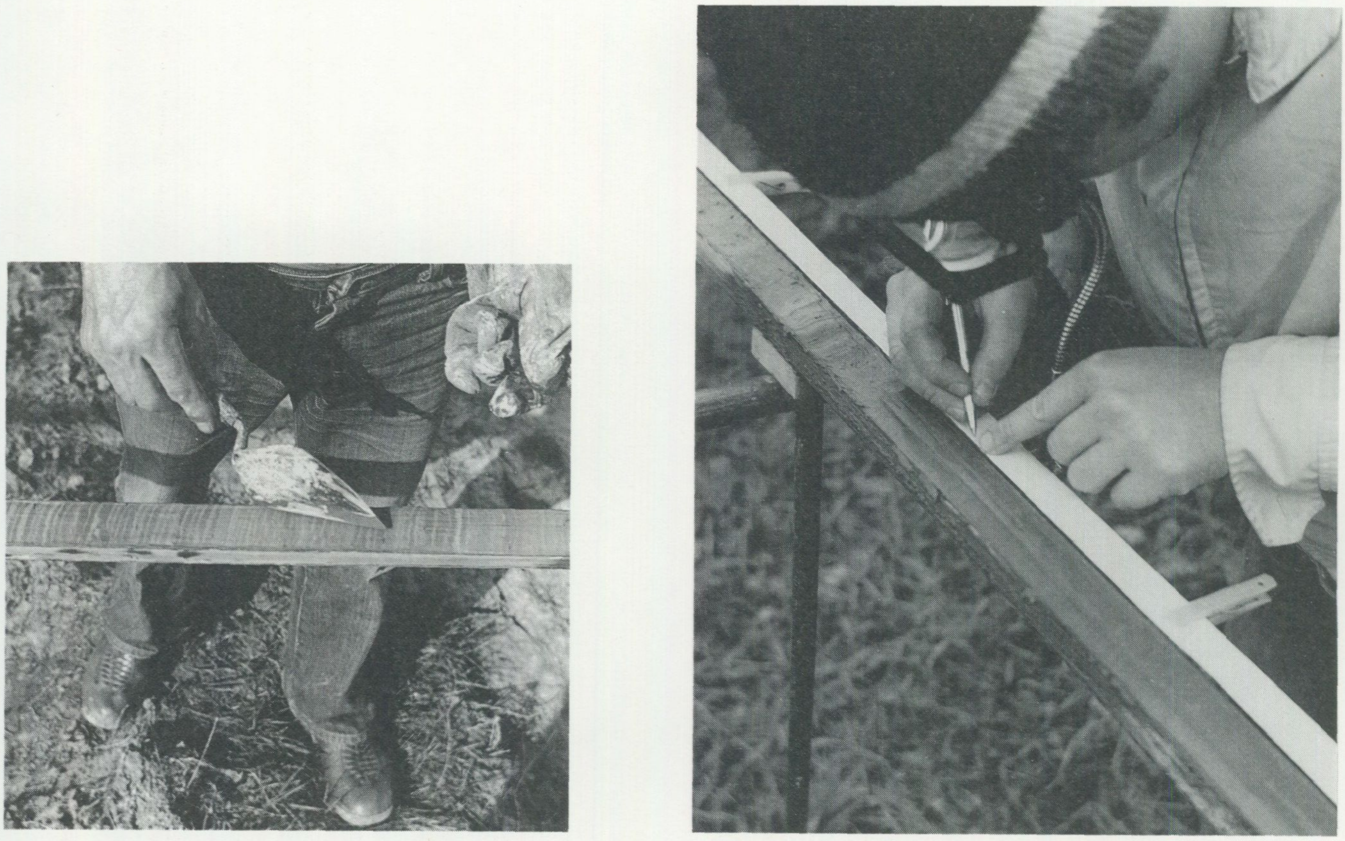


Fig. 5. A trowel is used for cleaning the clay surface (left). Varve limits are marked on a paper tape (right).

the plastic profile. With a wet stainless frying-slice, bended at the end, the sample is carefully loosened from the bottom of the sampler.

Before measuring is started, a little time is needed for the clay surface to dry. In some areas the clay has to dry for several hours or even days, as in southern Norrland. Here the varve limits may be rather distinct, but the sticky clay consistency makes the preparation almost impossible.

Varve limits, color characteristics etc. are marked with a lead pencil on a paper tape in the traditional way (see e.g. G. De Geer 1940). This may be done if the varves are thicker than about 2 mm, and even on thinner varves under a magnifying glass (Fig. 5). However, most of my varve series from southern Norrland have been measured indoors on a measuring table with binocular lens, since they contain sequences of some hundred very thin 'microvarves'.

B. Desk work

From the first years' field work in southern Norrland we soon found out that correlations between microvarved series were difficult to obtain from the graphs. However, 'drainage varves' (or other stratigraphic marks) were often recorded within the microvarved parts, and they were particularly useful for correlations. Sometimes the thin microvarves were not measured, but the number of varves below and between 'drainage varves' was noticed. At about 30 sites I took samples of the microvarved clay, which then were stored in plastic profiles and covered with plastic film. About ten years later they were remeasured along with new samples taken during the last years.

This measurement of microvarves has been made with special equipment, designed for treerings, and based on a measuring table which is moved under a binocular lens with a precision screw and a counter. Varve thicknesses may be measured by some hundreds of a millimetre, but varves are rarely of uniform thickness, so the measure depends on a subjective placing of the cross wires. To make this placing on the varve limits as good as possible, the magnifying extent should not be too great; 3–4 times is often sufficient. Double or triple measurements of the same sample, after new preparation of the clay surface, demonstrate some variation in thickness of one and the same varves, but the great advantage is not only the acquirement of accurate measurements, but also a better control that no indistinct varves are neglected.

Varve series measured in the field are generally drawn as graphs according to G. De Geer's (e.g. 1940) method, but on the scale 1:2 and 2:1 in addition to 1:1, and with the varves placed 2.5 mm apart (older, traditional printing scale). The microvarved series were drawn on the scale 5:1 or 2:1, depending on actual varve thickness. All graphs are printed with 40 % reduction and with varve thicknesses according to scales in the figures and plates.

Correlation of the varve graphs was also made in the traditional, visual way, since my attempt at correlating and/or evaluating the correlations by statistical methods have not been successful (cf. Strömberg 1971). The main reason for this seems to be that only a few of the varve series are correct in regard to the actual number of varves. Instead of evaluating inadequate correlations statistically, I have tried to take more samples in the field in order to reduce the distance between the sampling sites. This takes more time, but the result is quite satisfactory in most cases. Stratigraphic peculiarities, as the so-called spot zone, and 'drainage varves' have been very useful for the verifying of correlations to the north of Uppsala.

Quaternary maps on different scales have been used for planning field work, for compiling data on glaciofluvial eskers, highest coast-line and most of the glacial striae on the maps, Fig. 6 and Pl. 1–7. The general features of soil cover and inland ice recession is still fairly relevant on the 1:1 000 000-maps by G. Lundqvist (1958, 1961). More detailed are the Quaternary maps on 1:200 000 of the counties of Gävleborg and Västernorrland (G. Lundqvist 1963; J. Lundqvist 1987) and the 1:50 000-maps, of which 13 modern and 7 older sheets cover the area between Stockholm and Gävle.

Area of investigation

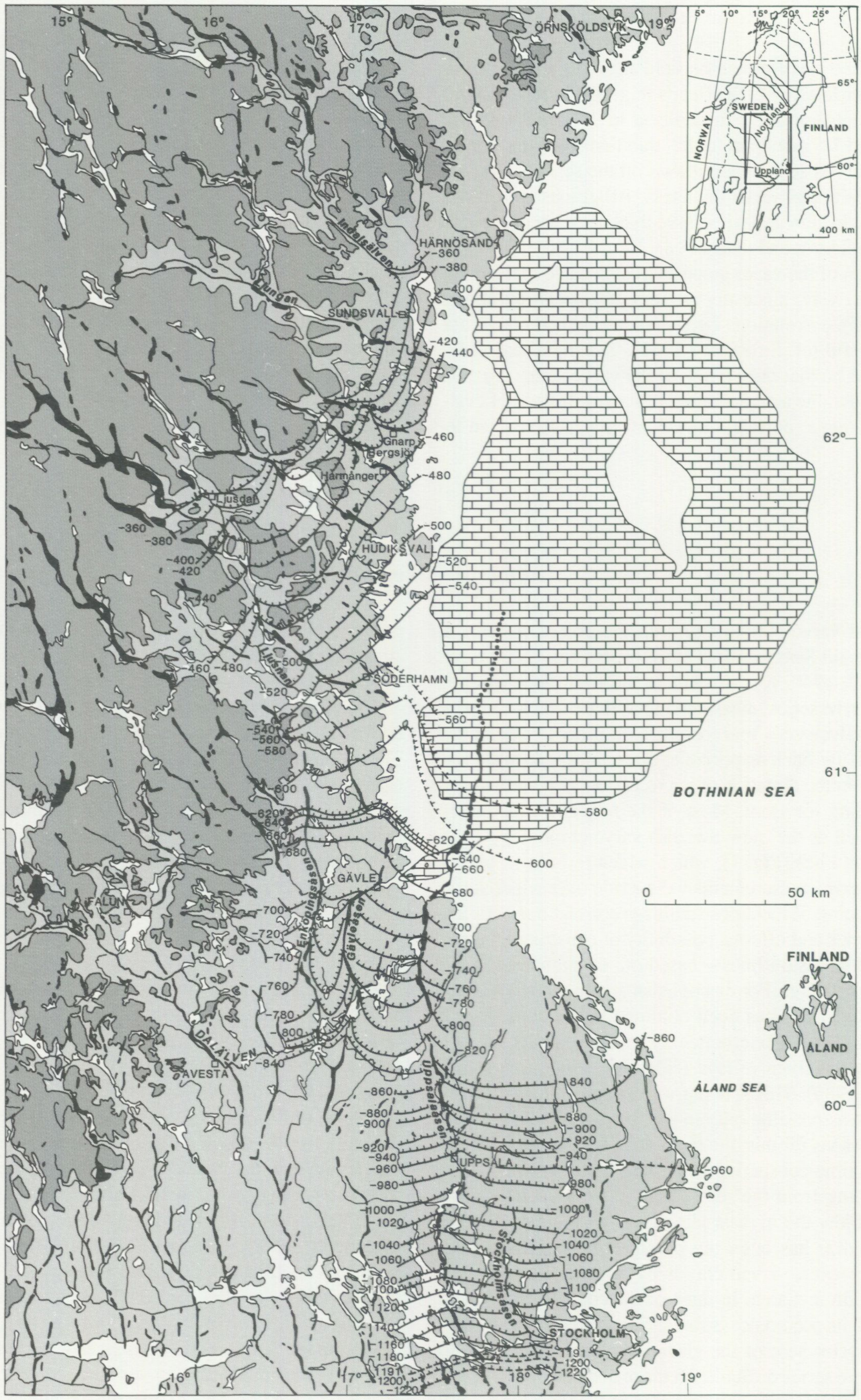
A lateglacial varve chronology with the object of being a part of the main Swedish time scale (*sensu* e.g. G. De Geer 1912, p. 252, 1940, p. 235) will in the first place contain correlated varve series, measured along lines which end near to the Indalsälven zero year localities. In order to extend the time scale as far back as possible, these lines will often run more or less in the direction of ice recession, perpendicularly to the receding ice front. Most of the measuring points of the old as well as the new Swedish varve chronology were located along lines (Fig. 1), which widen to belts in places where the varve measurements were made over wider areas. An areal spacing of localities stabilizes correlations between the varve series and offers a possibility of constructing equicesses – ice recession lines – based on, or strengthened by, bottom varve datings. For example, an areal spacing of varve measuring localities has been obtained in the coastland of Ångermanland and Västerbotten by several parallel lines of localities in the river valleys (Hörnsten 1964; Bergström 1868; Fözö 1980). This spacing was the goal during the revision, but was possible only in parts of the area. There are two main reasons for this: the restricted occurrence of varved clay and the time-consuming field work.

As sampling from the sea bottom has not been in practice, land below the highest lateglacial coast-line (HK; see e.g. Cato 1982) has been the potential investigation area (Fig. 6). However, varved clay is by no means evenly distributed within this area. In most of the coastland of southern Norrland its occurrence is rather restricted, and the microvarved character here of the glacial clay makes correlation between varve series difficult. To make correlations between those varve series, they should comprise many varves and, preferably, include distinctive stratigraphic marks, such as 'drainage varves'. Some of these marks are only found high up in the series, 200–300 varves above the bottom.

The water depth was rapidly reduced, however, as the land uplift was intense during the first centuries after deglaciation. The shore displacement was probably in the range of values calculated for the coastland of Ångermanland: 10–15 metres/ century (Lidén 1913; Hörnsten 1964). This means that the theoretical upper limit for clay sedimentation, a couple of centuries after the deglaciation, is some tens of metres below the highest coast-line. It seems that a water depth of 40–70 metres is required to obtain calm sedimentation conditions, which in turn seems to be essential to the formation of undisturbed microvarves.

Proterozoic rocks completely dominate in the basement of all land areas, but there is an extensive deposit of Cambro-Ordovician strata in the southern part of the Bothnian Sea (Winterhalter 1972; Axberg 1980; see Fig. 6). Fragments of Ordovician limestone from this deposit have played an important role as a check for correlations of varve series.

From a gross morphological point of view most of the area is lowland, but there are differences in the detailed bedrock morphology which could affect the sedimentation of clay. Three morphological regions are represented within the investigation area: fissure valley (joint valley) landscape, plain, and undulating hilly land (Rudberg 1970). Varve series from the fissure valley landscape between Stockholm and Uppsala are difficult to correlate for several reasons, one being the 'local' thickness variations of the varves which partly could have been affected by variations of turbidity currents over an uneven bottom of the sea (Kuenen 1951). In any


15°
16°
17°
19°
ÖRNSKÖLDSVIK
HÄRNÖSAND
Indalsälven
Ljungan
SUNDSVALL
Gnarp
Bergsjö
Harmånger
Ljusdal
HUDIKSVALL
Ljusnan
SÖDERHAMN
BOTHNIAN SEA
GÄVLE
Enköpingsåsen
Gävleåsen
FALUN
DALÄLVEN
AVESTA
Uppsalaåsen
UPPSALA
Stockholmsåsen
STOCKHOLM
FINLAND
ÅLAND
ÅLAND SEA
62°
61°
60°
0
50 km
-360
-380
-400
-420
-440
-460
-480
-500
-520
-540
-560
-580
-600
-620
-640
-660
-680
-700
-720
-740
-760
-780
-800
-820
-840
-860
-880
-900
-920
-940
-960
-980
-1000
-1020
-1040
-1060
-1080
-1100
-1120
-1140
-1160
-1180
-1191
-1200
-1220
5°
10°
15°
20°
25°
65°
60°
NORWAY
SWEDEN
Norrland
Uppland
FINLAND
0
400 km

case, this kind of correlation problem does not affect varve series from the plain north of Uppsala, or from the undulating hilly land area. This may seem strange, as the relative heights are greater within the hilly landscape than in the fissure valleys. On the other hand, a possible decisive factor is the more densely cut and less gentle landscape of the fissure valleys combined with differences in sedimentation conditions for the clay (brackish – fresh water).

The Quaternary deposits are typical for an area with subaquatic ice recession. As a rule, a rather even till cover, wave-washed in exposed positions, hides the bedrock. The bedrock surface, especially the top surfaces, is bare in places, partly as an effect of intensive wave washing during the postglacial shore displacement. However, bedrock exposures are few in extensive parts of the county of Gävleborg, for instance, and this may indicate a regional difference in thickness of the till within different parts of the area.

The distribution of glacial clay is also irregular. Generally, this clay is found as a cover on till and bedrock in lower terrain to the south of the river Dalälven. To the north of this river the clay occurrences are more restricted to valley-, lake-, or mire-depressions. There is no sharp limit between the northern and the southern areas, rather a successive transition to the northern one, poor in clay sediments. Not even the depressions are reliable clay sites here. The margin of bogs, for instance, which is usually a reliable site for clay, is often empty: the sounding rod records a very thin layer of gyttja and/or clay beneath the peat and over a stony-bouldery bottom. Occasionally, the peat would lie directly on a hard, sandy layer, which is a normal secondary deposit of wave-washed material, and clay could be found below this layer. The stony bottom below the peat could also be a redeposited, wave-washed material – this would be a logical explanation of a seemingly lack of clay.

In many sites, however, I have had difficulties in understanding the origin of this coarse material, if it was not till. An extensive distribution of 'till rafts' (e.g. G. De Geer 1940, p. 161) at a later stage of the deglaciation is a possible, alternative explanation. This iceberg-transported till should then hide the clay varves, which had been deposited earlier, and constitute a 'false' bottom. As a matter of fact, some observations of till on varved clay were made during the geological mapping of the Gävle area, and they were the ingredients in an intense discussion for some decades: had there been an extensive readvance of the inland ice in the area or not? (See e.g. Sandegren 1946.) Thus a 28 m wide section of till on disturbed varved clay was described by Sandegren (1929, p. 575) who was convinced that the till indicated a real ice advance, while G. De Geer (1929, p. 567) maintained that it was a till raft. In course of time the discussion about the 'Gävle oscillation' has been settled in favour of De Geer (e.g. Hoppe 1948; Järnefors 1963; Strömberg 1981a), and strengthened by this the till rafts gained credence.

A primary lack of clay in parts of an open area, where complete varve series are found in places, is of course quite puzzling. The most probable explanation is that the clay-free surfaces were hidden by something that disappeared after some decades or a century. Grounded icebergs or marginal parts of the inland ice which were left behind when the coherent inland ice retreated, fulfil the requirements of discreet disappearance. The anomalous ice recession lines in this area, which are based on clay varve data, are indications of 'dead-ice remnants' which were left behind the 'living' inland ice in the area.

Most prominent of the Quaternary deposits are the glaciofluvial eskers. In this east-central part of Sweden they run as quite regular, winding ridges or strings of beads, some of which extend more than 100 km (J. Lundqvist 1979). The biggest esker of the area, the Uppsala esker ('Uppsalaåsen', Fig. 6), extends for about 250 km, if the underwater parts in the Bothnian Sea are included (Hoppe 1961; Axberg 1978). Smaller tributary eskers join the main eskers, particularly on their eastern sides (Hjulström 1944; G. Lundqvist 1954). As mirrors of the most important meltwater courses, the glaciofluvial eskers are also important to complete the picture of clay sedimentation. Since the main, subglacial meltwater courses are normally oriented approximately in the direction of the last ice movement, and perpendicularly to the retreating ice front, they can be used for reconstructions of the ice recession, even in areas below present sea-level (Hoppe 1961).

Characteristic till ridges in the southern part of the area are De Geer moraines, mainly oriented parallel to the receding ice margin (G. De Geer 1932, 1940; Möller 1962b; Strömberg 1965, 1971). Even if they are characteristic, they are restricted to some limited occurrences. This is also true for a different kind of till ridges which are found in the central part of the area between the rivers Dalälven and Ljusnan. These more or less distinct moraines are oriented in about the youngest ice movement direction (see e.g. G. Lundqvist 1963, p. 37; Strömberg 1981a). The genesis of the ridges is still obscure. According to ice recession lines based on clay varve data, they occur in areas covered by protruding ice lobes, separated by deep calving bays which existed during the last stages of deglaciation. The lobate parts of the ice margin were probably deeply crevassed, and disintegrated ice remnants could be left behind when the inland ice margin retreated (Strömberg 1981a, p. 153). Ridges of this kind are not known in other parts of Sweden, and obviously they require a very special deglaciation condition.

Fig. 6. Late Weichselian deglaciation in east-central Sweden. Glaciofluvial eskers, 'åsar' (black), mainly after G. Lundqvist 1958. Continuation of the Uppsala esker in the Bothnian Sea, after Hoppe 1961 and Axberg 1978 (dots). Area of Ordovician limestone on the bottom of the Bothnian Sea according to Axberg 1980 (cross-ruled). Ice recession lines; years before the zero year (±0 = 7288 B.C.; Cato 1987); cf. Plate 1–7. Present-day land area below the highest coast-line (from G. Lundqvist 1961) is shaded.

The clay varve chronology

A. General aspects

The first planning of new varve measuring sites was made with experience from earlier investigations in the Uppsala area (Strömberg 1965, 1971). A scrutiny of Gerard De Geer's (1940, Pl. 72, 75–83) and Björn Järnefors' (1963, Pl. 5–11) time scales had revealed weak parts, which were most obvious when I tried to correlate my own graphs with the published diagrams. Thus the varve chronology for the ice recession between Stockholm and Uppsala which was entirely based on De Geer's (1940) 'miles' (Swedish "milar"), may seem quite firmly correlated within most of the diagrams. The different 'miles', however, are not everywhere convincingly correlated (Fig. 7). As this part of the time scale had not been revised earlier, I decided to attempt at a new and independent, parallel varve chronology.

From Uppsala and northwards Järnefors' (1963) new time scale was reliable at least up to the Dalälven river. Almost all correlations of graphs from the many localities in this area are convincing. However, north of the Dalälven, especially north of Gävle (Oppala), only few and vacant graphs were used in poor correlations (cf. J. Lundqvist 1975). A new and independent varve chronology for the ice recession between Gävle and Sundsvall was desired, and it was even more urgent than for the Stockholm – Uppsala area.

Most clay varve chronologists have probably met the problem of incongruity between planning and reality. There are few exceptions to the rule that it is impossible to know in advance how the pattern of measuring sites will look. In the current investigation more than twice the assumed amount of sites were needed in the Stockholm – Uppsala, Gysinge – Hedesunda and Söderhamn – Sundsvall areas. On the other hand, a denser pattern had been desired in other places as well, such as between Gävle and Söderhamn, but the small amount of sites here was due to the lack of clay. As an alternative, we tried to bridge over the Gävle – Söderhamn gap in a parallel belt between Sandviken and Bollnäs. In this area I have made eight and my collaborator Birger Forssmark over thirty varve measurements, but in most sites only thin microvarves are found, and they are difficult to correlate.

The same problem with microvarved clay exists in most areas north of Gävle. Frequently, the only way to get reliable correlations between varve series here is to compare the so-called drainage varves, which are found in identical positions within a 'sedimentation area'. However, the sedimentation area for a drainage varve may be restricted to one river valley, and only few drainage varves have a 'regional' distribution. Normally, they are useful only for correlation of varve series in limited areas, and thus correlations between separate river valleys may be insecure. This was evident in a wide belt, situated between the Ljusnan and the Ljungan – Indalsälven valleys. The pattern of measuring sites in this area became more and more concentrated after several field work occasions, but only few of the varve series can be correlated convincingly with series from the distant river valleys.

Mainly three different types of glacial clay are met with in the investigated area. From Stockholm to Uppsala a stiff, brownish clay of the 'Stockholm type' was deposited in brackish water ('symmict' clay from the Yoldia Sea stage of the Baltic; cf. e.g. Sauramo 1923, p. 82; Caldenius 1941, p. 90). Indistinct varve limits are characteristic in sections of most of the clay profiles here, and in the southern part of this area it is often impossible to distinguish with confidence more than about 50–60 varves. The younger (distal) varves generally constitute a more or less homogenous clay. The prospects of also distinguishing distal varves increase towards the north, and according to Caldenius (1941, p. 89) clay of the 'Stockholm type' stopped in its formation somewhat to the south of Uppsala. However, in several of my samples, taken to the east of the Uppsala esker, indistinct sections of varves in the older (proximal) parts of the clay are found also to the northeast of Uppsala (Strömberg 1971). A rather characteristic sequence of symmict varves, which are not only indistinct but also thin in places, appear in many profiles between the years -890 to -930 (Pl. 13–14). Not until after the year -890, when the ice front had receded 20 km to the north of Uppsala (Fig. 6), was the 'Stockholm type' of clay replaced by the 'Uppsala type' in the older (proximal) varves.

The glacial clay of the 'Uppsala type' is red-brown in colour, with generally distinct blue-gray winter layers and a high content of calcium. The Uppsala-clay has been the subject of many investigations; e.g analysis of calcium, organic content, grain size, colour etc. (e.g. Högbom 1889; Arrhenius 1947). The varve limits are usually as distinct as in diatactic clays, deposited in fresh water, but it is regarded as a special kind of symmict clay which was deposited in a slightly brackish water with a high concentration of calcium ions (Arrhenius 1947; Hörner 1948; cf. Sauramo 1923, p. 82). The same characteristic varve thickness variations in synchronous varve series are often seen over a rather extensive area, and this has been useful for demonstrating good varve correlations (Järnefors 1963, Fig. 2; Strömberg 1983, Fig. 112). Not only the distinct varve limits are responsible for the good agreement between the varve series, but also the flat topography which evidently promoted a uniform sedimentation.

Clay of the Uppsala type turns over gradually into the 'South Norrland type' about the year -580. This occurs when the ice front had retreated to a position about 10-20 km to the south of Söderhamn (Fig. 6). At this ice front position the so-called 'spot zone' (or spotted zone) in the clay has its lower limit; and in addition, it has been suggested that the change-over from the' Yoldia' to the' Ancylus' stage of the Baltic happens at about this time (Sauramo 1929, p. 71; Sandegren 1948, p. 56 ; Järnefors 1956, p. 312; G. Lundqvist 1963, p. 81). From a varve chronological point of view a border between the Yoldia sea and the Ancylus lake at this ice front position would be easy to recognize as the 'spot zone' is quite distinct in most of the varve series in northern Uppland and in the coastland of southeastern Norrland, to the south of an ice recession line about -600. However, according to diatomé analyses of glacial clay in the coastland of Ångermanland and Norrbotten, brackish water conditions were indicated at least until the deposition of varve -400 (Fromm 1938, 1949; Hörnsten 1964, p. 203).

The transition to the 'South Norrland type' of clay occurs by way of a sequence of indistinctly limited varves in the coastland. In the inland, however, the red-brown Uppsala-clay is replaced by a thin-varved and micro-varved, grey-coloured 'South Norrland-clay'. This 'diatactic', distinctly varved clay prevails to the north, as well as in the coastland north of Söderhamn. Characteristic of this area is the very limited total thickness of the glacial clay: 1–2 metres may contain 200–400 varves! The varves are not only very thin; their thickness variations are small, and most correlations have to rely on the presence of special stratigraphic marks. Only in the deep river valleys and close to coarse glaciofluvial deposits can the glacial clay be several metres thick (Borell & Offerberg 1955; J. Lundqvist 1987).

B. Stockholm – Uppsala

Samples from more than 100 varve measurement sites have been used in the Stockholm – Uppsala area and almost all of these were needed to get a reliable time scale. Most of the sites are shown on a preliminary map (Strömberg 1981b) with ice recession lines dated from the old De Geer-year -1073 (see below). Some measurements, e.g. short series or partly disturbed varve sequences, are less useful and only of 'local' interest. These have been omitted, but the remaining, about 80, are now recorded in the varve diagrams, Pl. 8–14 and Fig. 8. As mentioned above, this dense pattern of measurement sites was needed, since only occasionally more than 50–60 distinct varves were seen in the samples.

The lower 20–30 varves are usually very distinct, but in the distal (younger) sequences all degrees of indistinctness are recorded. The most prominent exception is the series 152 Ekbacken, with about 100 reliable varves. In addition, I have measured some more of the distal varves at Ekbacken, ten of which are probably correct and thus reproduced (Pl. 9). The same consideration has been taken with regard to all varve series: not only distinct varves but also indistinct ones are reproduced when the varve limits are faint but probable. Only the distinct, proximal parts can be used for correlations, but a long series, such as 152 Ekbacken, may disclose – more or less firmly – that also distal parts of other correlated series are reliable. Naturally, mistakes have been made concerning some of the varves, which one can suspect when the diagrams are examined. To make a 'total' correlation, parts of some varve sequences have to be displaced one or two steps (years), and this must be included in the margin of error. Thus some varves in different correlated graphs are not absolutely synchronous, even if they are reproduced in synchronous positions. This is one of the reasons why statistical methods for evaluating varve correlations are difficult to practise.

A suitable starting point for my revision would be the De Geer-year -1073, i.e. the transition from grey fresh-water varves (diatactic) to brown brackish-water varves (symmict) at an ice recession line just to the south of Stockholm (G. De Geer 1932, 1940). However, Gerard De Geer's (1932, p. 24) supply of over 700 varve measurements in the Stockholm area should not necessitate that new measurements had to be made all the way from the -1073-line. Examinations of published varve diagrams demonstrated rather good correlations between the graphs, and I decided to connect my varve chronology to the 'G-mile' (G. De Geer 1940, Pl. 72) in the vicinity of Djurgårdsbrunnsviken where the first correlated varve series were measured (see e.g. G. De Geer 1940, p. 142).

Closer examination of the correlation from the 'F-mile' to the 'G-mile' over the -1073-line and northwards, revealed that the correlations within the diagrams are good, but the bridges over the two 'milar' – geographically corresponding to the bridges from S to N Stockholm – are weak (G. De Geer 1932, Fig. 30, 1940, Pl. 72, 78). Irrespective of 'telecorrelated' varve series from far away countries, they are founded only on two series longer than 10 years, one of which is a combination of different measurements ('S. Stockholm'). Attempts at extending the new chronology further towards the southwest has not been quite successful (Fig. 8). However, with the help of varve series measured by Lars Brunnberg (unpubl.), the new measurements support De Geer's original correlations and the connection to the -1073-varve, now revised to -1191, should be correct.

Fig. 7 exhibits some of the weak parts in the old varve chronology for the ice recession between Stockholm and Uppsala, the 'miles' G–L (G. De Geer 1940, Pl. 72):

1. A very weak correlation between the G and H diagrams.
2. Weak correlations between the H:1 and H:2 diagrams.
3. Rather weak correlation between the H and the I diagram.
4. Weak correlations between some of the graphs in the I–L diagrams.

The differences when I try to correlate graphs from the G–T 'miles' and from G. De Geer's (1940) Pl. 77 and 81–83 with my graphs in the new time scale, Pl. 8–18, are exemplified in Table 1. Eight of these graphs are reproduced in the plates, but also the eight others are probably correctly correlated with the new time scale within a ±2 years margin of error.

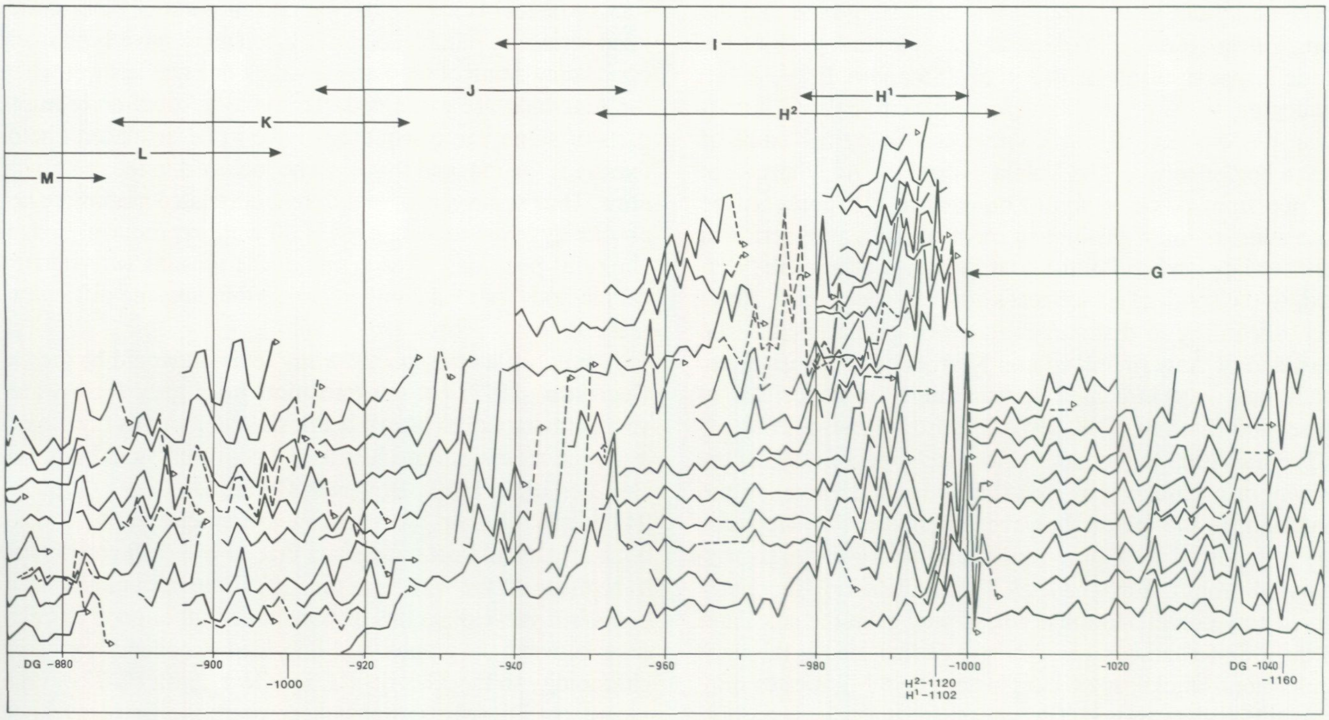


Fig. 7. Gerard De Geer's (1940, Pl. 72) varve chronology between Stockholm and Uppsala; 'the miles' G–M, redrawn. Varve thickness: see G. De Geer 1940. Upper time scale according to De Geer, lower scale: approximate, revised scale. Years before zero (±0 = 7288 B.C.; Cato 1987). Triangle = till substratum.

TABLE 1

Site	De Geer year	Revised	Diffence
Fresh-brackish water transition	-1073	-1191	+118
DG B	-1045	-1163	+118
H 2 Kummelby	-1003	-1127	+124
H 7:4 Pommern	- 990	-1114	+124
H 11 Överby	- 997	-1103	+106
K 4 Kråklund	- 923	-1014	+ 91
K 6 Knivsta stn	- 916	-1006	+ 90
K 7 Gredelby	- 914	-1004	+ 90
K 9 Knivsta tegelbruk	- 913	-1003	+ 90
L 7 Söderby	- 898	- 989	+ 91
Up. 25 Bergsbrunna	- 893	- 976	+ 83
Up. 34 Tierp	- 681	- 796	+115
Up. 40 Älvkarleby	- 620	- 710	+ 90
Gl. 6 Råhällan	- 575	- 682	+107
Hl. 13 Bollnäs stn	- 428	- 502	+ 74
Me. 2 Ovansjö	c. - 620	c. - 410	c. -210
Me. 7 Indal	c. - 420	c. - 360	c. - 60

Evidently the difference between De Geer's (1940) and the new time scale increases from about 90 years at Uppsala – Knivsta to about 120 in Stockholm. In this ice recession area most discrepances are found in correlations between the H, I, J and K diagrams.

The new varve chronology for the ice recession between Stockholm and Uppsala should be reliable on the whole, since most doubtful correlations have been checked by new measurements in the field. As mentioned previously, smaller adjustments between the graphs have to be done, in order to get 'complete' correlation. The main reason for this is the presence of indistinct varves in the distal (younger) parts of the series, sometimes in the proximal parts as well. The 'local' differences in varve thickness variations have also contributed to correlation problems in places; though less in this area than in southern Norrland, where the silty, proximal varves are more susceptible to variations in the sediment deposition (cf. Cato 1987, p. 42).

I have no indications, however, that synchronous varves about a half to some centimetres thick, in a uniform sedimentation area, should vary so much in thickness that correlating should be impossible. Varve thickness variations are met with, but usually some orderliness exists (Strömberg 1983). However, Järnefors (1956, p. 304–305, 1963, p. 12) reported that proximal parts of several varve series in the Uppsala area were difficult to correlate: as many as 33–75 proximal varves did not agree concerning their thickness variations. In my opinion the general reason is not irregular varve thickness variations in this area, i.e. that one and the

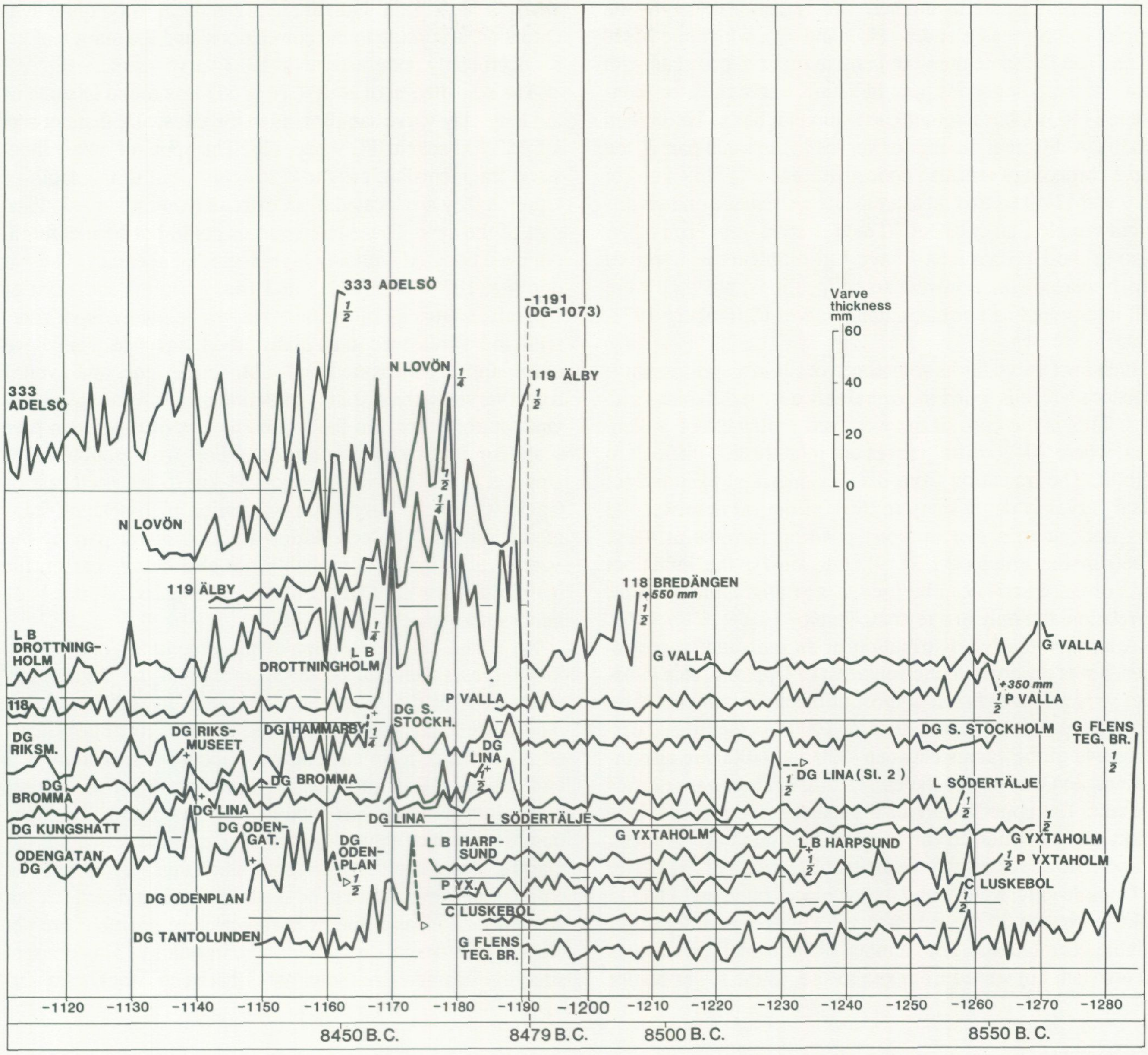


Fig. 8. Suggested correlations of varve series in the Stockholm area and to the south of Stockholm. LB = Brunnberg, unpublished, C = Caldenius 1941, DG = G. De Geer 1932, 1940, G = measured by J. Grufman 1918, L = measured by R. Lidén 1909 (G. De Geer 1932), N = Noël 1976, P = Perhans, unpublished, 118, 119, 333; see Table 3, + for remaining clay, triangle = till substrtum, 1/2, 1/4 = reduced varve thickness.

same varve should be thick or thin without any orderly manner. Instead, I believe that the lack of correlation is a consequence of unintended comparisons between varves which are not synchronous. To all appearances, varve delimiting problems were the main reasons for correlation problems in the Uppsala area: indistinct varve limits and/or 'pseudovarves' erroneously interpreted as annual varves, make a classification of synchronous varves difficult (Fig. 9; Strömberg 1971, p. 76–78). This problem is met with in all symmict clays, as in the Stockholm – Uppsala area, and it is reinforced by the topographical influence on varve sedimentation in the fissure valley terrain.

Discrepances between correlated varves may be seen for instance in the graph 132 Skälby, concerning varve -1094 and -1095 (Pl. 10), -1130 in 121 Nälsta and/or 123 Barkarby (Pl. 9), and a couple of varves between -950 and -1000 in several of the varve series taken to the southeast of Uppsala (Pl. 13 and 14) can not be correlated at all. These discrepances affect proximal varves, and even samples taken only a few metres from each other may differ (134 Fäboda a, b; Pl.

9–11). Some synchronous varves may be distinct in one part of an area, indistinct in another. This is demonstrated by the graphs 163 Sigtuna a and b (Pl. 9 and 11), which are based on one and the same measurement: in order to correlate with some of the other series, one indistinct varve must be considered (163a), but in other correlations it has to be omitted (163b). A different number of varves in the same part of the varve chronology was also noticed at Lotteräng (159 a and b; Pl. 9 and 11). The two measurements were made on two different samples, taken about 20 metres apart from each other. Also in the Uppsala area I have had problems with varves which were distinct only in some localities, but they were still interpreted as normal, annual varves (Strömberg 1971, p. 79).

Indistinct varve limits sometimes occur in a specific varve sequence which is found in several series from different localities. This is the case to the west and northwest of Sollentuna, where 20–30 distal varves are more or less difficult to delimit. The transition from distinct proximal to indistinct distal varves is rather sharp in three of the varve series, and was noticed in a synchronous position (arrows at varve -1060 in the graphs on Pl. 9). Obviously, the indistinct parts of these series can be used as a stratigraphic mark for correlation, but only in a restricted area.

A more extensive distribution of an indistinct varve sequence was observed to the southeast of Uppsala. This indistinct sequence was found in most of the measurements here, above the proximal varves -950 to -1000. As mentioned earlier, some of the varves between -950 and -1000 are also indistinct, and this makes the correlating of short varve series difficult. The upper border of the indistinct sequence which marks the transition to the distinct 'Uppsala clay' is much sharper. However, to the southeast of Uppsala distal varves of 'Uppsala clay' were found in few places only, and I had to make more than 20 measurements in this area in order to get reliable correlations. The number of indistinct varves was not constant but varied from site to site, as the lower border above the more distinct proximal varves, did not show a sharp limit. Yet the indistinct varves seem to be quite synchronous, according to the correlations, and the margin of error is probably not greater than ±2–3 varve years.

The so-called 'spot zone' (see p. 21) was found in some of the long clay varve samples, as in the unusually distinct series 152 Ekbacken (Pl. 9 and 11). The spots of small limestone fragments are easy to distinguish, but to the south of Uppsala they are located in an extremely microvarved, distal part of the clay. These microvarves could not be measured, not even counted with any high degree of accuracy. Only at one site, 187 Vidbo (Pl. 13 and 15a, b), to the southeast of Uppsala, almost all of the microvarves below the 'spot zone' seem to be preserved in an undisturbed sequence. They have been carefully measured under binocular lens, and even if some varves were difficult to delimit, they form an important control series. On the whole, they verify the main time scale for the 400 years ice recession from southeast of Uppsala to an ice front position 35 km to the northeast of Gävle where the intense transportation of limestone fragments started. The correlation for this distal part of the Vidbo varve series is probably not absolutely correct; the margin of error may be about ±5 varve years, but this is of minor importance.

As stated above, smaller displacements of one to two 'steps' (years) have to be made, mostly in the distal parts, when some of the graphs are correlated. In addition to this flaw, correlations between varve series from localities situated at a distance from each other of about 5 km or more, are less convincing in some cases. This is true for measuring points located in an east-west as well as north-south direction, i.e. parallel as well as transverse to the retreating ice margin. There are some exceptions to this rule though, as correlations obviously can be made over wider distances, but generally all measurements in rather close positions are necessary in order to strengthen the chronology. This unusual situation characterizes vast areas between Stockholm and

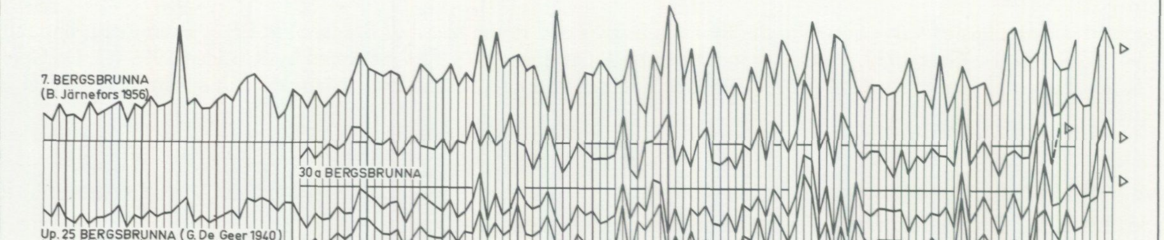


Fig. 9. Some varve series from Bergsbrunna, southeast of Uppsala (Strömberg 1971). About 10 varves were indistinct during my measurement. My interpretation of varve limits result in graph 30a, which is rather well correlated to Järnefors' (1956) 7. Bergsbrunna, but not to De Geer's (1940) Up. 25. However, if changes of some indistinct varves are made (see small arrows in graph 30b), the correlation with De Geer's Up. 25 is excellent.

Uppsala, and the cause seems to be the symmict clay, with indistinct varve limits, and/or the 'local' varve thickness variations. An implication is also that graphs on separate diagrams, covering identical parts of the time scale, cannot always be correlated; this must be done step by step, via intermediate varve measurements.

C. Uppsala – Gävle – Söderhamn

After about the year -890 in the revised time scale the typical 'Uppsala clay' was deposited during the following 300 year period when the ice margin retreated to the north of Uppsala. Especially the first 150 years of this deglaciation can be reconstructed rather closely by more than a hundred varve measurements (G. De Geer 1938, 1940; Fromm 1945, 1964; Järnefors 1963; Strömberg 1971, 1981a). In a wide belt, from the river Dalälven valley in the west and 50 km to the east of the Uppsala glaciofluvial esker, varve limits of the glacial clay are generally distinct concerning this 150-years period. As a rule reliable correlations between the varve series are not difficult to obtain if the varve sequences are long enough.

To the east of this belt, however, Järnefors (1963, p. 40) was not able to get measurable varve series, probably owing to waning distinctness of the varves. Glacial clay is found in almost all lower parts of the terrain, but the number of indistinct varves may be great in places (Strömberg 1971). I have reproduced some of my old diagrams from this area with revised datings in Pl. 19–20, as they may be used for a reconstruction of ice recession lines and for a future connecting with the Finnish varve chronology. Some of Järnefors' (1963) graphs are reproduced in Pl. 15, and dated according to the revised time scale. The correlations on these diagrams were made between many successful measurements, and they are reliable. Together with the most distinct of the varve series from Uppsala – Högsta (Pl. 2; Järnefors 1956; Strömberg 1971), they constitute about 200 years of the time scale not essential to revise.

Already at the beginning of my attempts to get new and more reliable varve measurements from the Dalälven river and northwards, I was faced with some of the characteristics of the clays in southern Norrland. In the first place, the varves are very thin and their variations in thickness are rather small in the younger parts, above about -720 in the revised time scale (Pl. 15). Only some tens of the proximal (older) varves show more pronounced thickness variations, but there is also an annoying, repeated periodicity in about ten to twenty varve years (11–22 years? ; cf. Möller 1962 a), making some graph 'correlations' possible in two or three alternative positions. Secondly, the occurrences of glacial clay are often restricted to few and small areas only. Thirdly, the varve limits which are generally sharp in southern Norrland, are indistinct in and around the 'spot zone', affecting several varve series in the time span about -600 to -425. In fact, a reliable time scale did not exist until a sufficient amount of series with the 'spot zone' and/or other stratigraphic marks were collected.

In addition to these difficulties I was rather confused by the preliminary correlations as they resulted in anomalous ice recession lines, and by the incongruity in opinion between me and Järnefors (1956, 1963) about the time for deposition of the 'spot zone'. This zone, or rather sequence of varves with limestone spots, is most characteristic in northern Uppland and in southern Norrland, south of the ice recession line -600 (Fig. 6). Especially when it is found in a distinctly microvarved clay, its lower limit is rather well defined within about ±5 varve years. Thus it may be used as a correlation control and for a verification if suspected disturbances in some of the varve sequences are real or not. It has been an important stratigraphic mark in most of my correlations in this part of the investigated area.

D. The spot zone

Gustafsson (1905, p. 271–273) and Järnefors (1956, p. 310–314, 1963, p. 58–59) gave rather detailed descriptions of the 'spotted zone' or 'spot zone' in the Uppsala area. Here it is noticed in deeper clay deposits as a 5–10 cm thick, thin-layered part of the distal glacial clay. The spots are white, grey, red-brown or green, angular or rounded fragments of Ordovician limestone and in a lower percentage (Gustafsson 1905, p. 273) of sandstone and Precambrian rocks (Fig. 10). If the concentration of particles is high, the spot zone may be registered as a 'sandy' layer during sounding and sampling, even while the tools are pressed down. This is the case at many sites between Uppsala and Gävle – Sandviken. To all appearances almost every square metre in this area is densely powdered with rock fragments, and the total bulk of particles is considerable.

A common opinion about the spots is that they are morainic material which was transported and deposited by drifting icebergs (e.g. Gustafsson 1905; Munthe 1940; G. Lundqvist 1963). Since limestone is the predominant part of the spots, it must have been incorporated in the bottom of the inland ice in the southern Bothnian Sea, where Ordovician limestone constitutes an extensive part of the sea bottom (Fig. 6). In all probability the icebergs were derived from a part of the inland ice that earlier covered this bedrock and its till cover. Järnefors (1956) believed at first that other, unknown explanations had to be given, since the spot zone seemed to be thickest near the Uppsala glaciofluvial esker. However, he later agreed with the iceberg transport theory (Järnefors 1963) when his number of observation sites was increased. According to the present survey, a transport by and deposition from icebergs is a logic explanation.

A large amount of icebergs was the result of an exceptionally intense calving from the retreating inland ice in the southern Bothnian Sea. The material in the spot zone has not melted out of icebergs that were grounded, but dropped down from floating icebergs. In any case, this was true at all

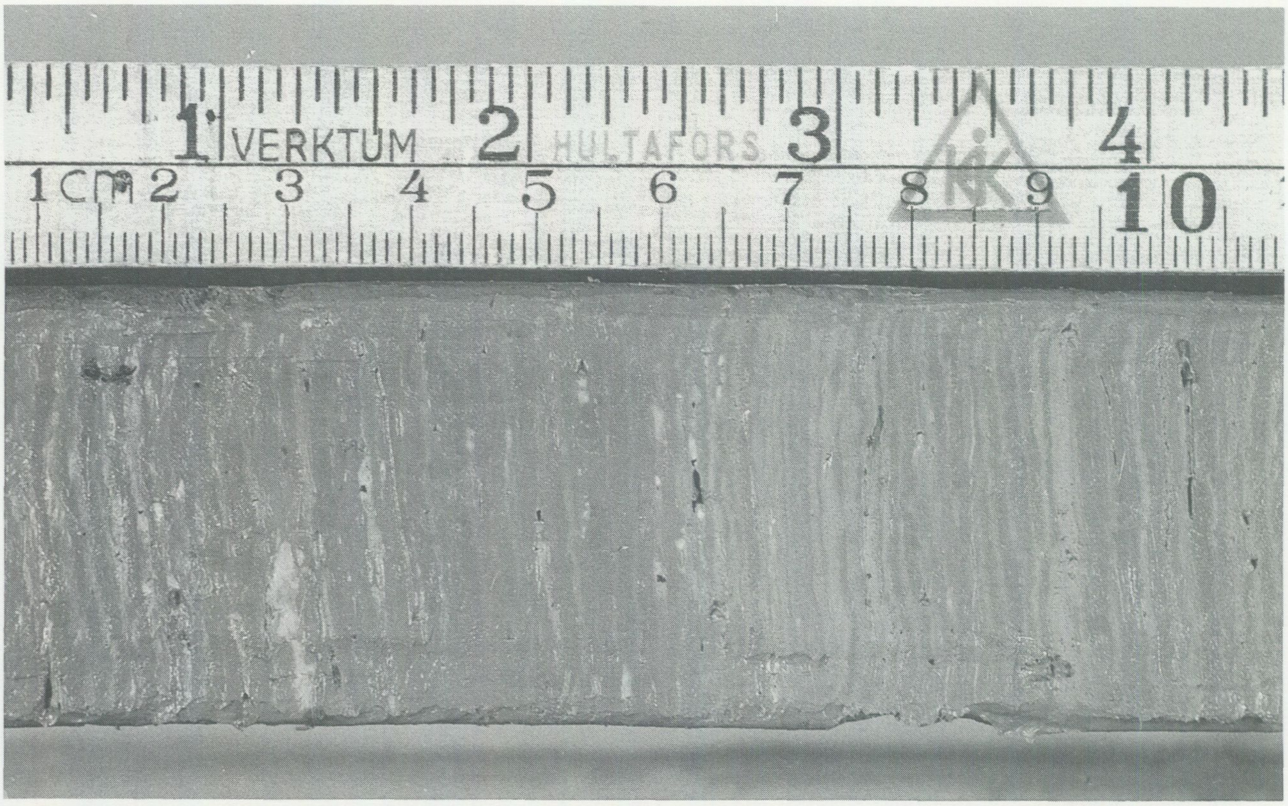


Fig. 10 Thin microvarves and a part of the 'spot zone' – limestone fragments – in a clay sample from the Gysinge area. The lower boundary of the spot zone (about -580 on the time scale) below 6.8 cm on the rule.

sites where successful sampling was made: no signs of disturbances were observed. I must admit that I am puzzled by the comparatively few signs of disturbances in the glacial clay in this area. Clay occurrences are sparse in southern Norrland, but when they are found, the frequency of unsuccessful samples is not higher than elsewhere. Probably the few occurrences of glacial clay were the only spots escaping the shelter of grounding icebergs or parts of the inland ice margin left behind when the 'living' inland ice receded.

The chronological position of the spot zone was calculated by Järnefors (1956, 1963) to be around the varve year -600 in the old time scale. He informs that the zone usually appears 20–30 cm above the last visible microvarve. Evidently he was never able to count the actual number of interjacent varves. Instead, his calculation was based on an assumption of evenly declining intensity with time of the sediment deposition (Järnefors 1956, Fig. 5). A spot zone at about varve year -600 (old time scale) can also be seen in G. De Geers (1940, PL. 81) correlation of two series of microvarves with 'micro-boulders' (Fig. 11). This correlation locates the appearences of spots to the varve years about -560 to -450 in De Geer's time scale, equal to about -600 to -490 in Järnefors' (1963) revision.

Both datings are wrong, however, and so are the conclusions concerning the onset of the intense calving in the southern Bothnian Sea. Moreover, all three microvarve series on De Geer's (1940, Pl. 81) special graphs from the Ockelbo area are incorrectly correlated (Fig. 11). A completely wrong correlation of the series Me. 2 (Ovansjö; Sundsvall area), by at least 200 years, is commented on later. The series Gl. 4 and Up. 26 are probably correctly correlated in themselves, but the correlation to the Ockelbo varve graphs is faulty. A strange and incorrect matching exists between the graph Gl. 4 mi., representing microvarves from Hagaström, (a site to the west of Gävle), on the scale 10:1, and the Hagaström graph published by Gerard De Geer in 1938. According to the time scales, an overlap of 30 years between the graphs should be present, but they cannot be connected in this position. Instead of the overlap, a sequence of about 80 varves is probably missing between the two graphs.

It is often possible to count and/or measure the microvarves, which are quite distinct beneath the spot zone in several sites, especially in the lower Dalälven area. The lower limit of the spot zone was noticed close to the varve years -575 to -580 in about 20 varve series, according to the new time scale (Pl. 15–16). Compared with Gerard De Geer's (1940) and Björn Järnefors' (1956, 1963) datings, the spot zone turned out to be about 80–90 years younger: -575 in the new time scale corresponds to -511 in Järnefors' (1963) revised time scale, and the lower limit for spots is thus closer to Järnefors' varve year -510, and not to -600.

There are occasional spots also in lower (older) varves,

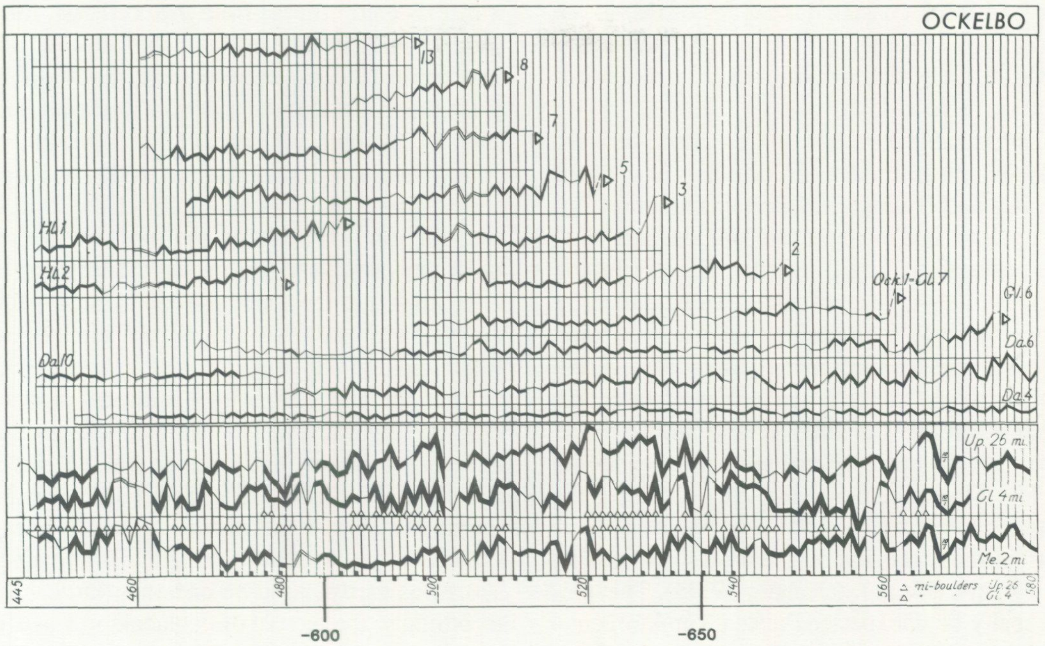


Fig. 11. G. De Geer's (1940, Pl. 81) special graphs from Ockelbo (reduced). Some correlations between the short Ockelbo-series are doubtful, and so are also the correlations to the graphs Da. 4 and 6. The microvarve series Up. 26, Gl. 4 and Me. 2 are, most probably, incorrectly dated. Triangle = till substratum. Varve thicknesses and upper time scale; see G. De Geer 1940. Lower time scale, revised, applies to the Da. 4 and 6 series, but e.g. Ockelbo Gl. 6 is probably 8 years younger. Years before zero (±0 = 7288 B.C.; Cato 1987).

but the transition to the zone with abundant limestone spots is generally sharp. In most cases this transition was observed within a margin of about ±5 varve years, probably indicating a sudden change from a 'normal' to an intense calving at the ice front, and/or a change from small to large amounts of limestone fragments carried by the icebergs. This may indicate that the ice lobe in the southern part of the Bothnian Sea had been frozen to the ground until the latest stages of deglaciation.

When the transition to the spot zone was noticed outside the varves around -575, its divergent dating can probably be explained, for instance, by difficulties to delimit some of the microvarves or a sparce occurrence of spots on the surface of the sample. Since the samples are only 4 cm wide, a sharper limit might be expected to be seen on wider clay sections.

An upper limit of the spot zone is missing, or at least difficult to see, as the number of spots gradually decreases distally. A concentrated 'spot zone' is found in about 90–110 varves, but occasional limestone particles are met with all the way up to the drainage varve -424 in clay samples from the coastal area between Hamrånge and Hudiksvall. Proximal (older) varves in samples from this coastal area (e.g. 241 Forsbacka, 248 Långvind and 265 Sivik; Pl. 17a, b) contain several spots of more or less well preserved limestone particles in a sticky, calcareous matrix. Thus the spot zone may be traced along the present coast northwards to the Hudiksvall area (Fig. 6). It is probably found further to the north too, where it is represented by a less spotted but sticky clay at some sites with bottom varves older than -424, as at Björkön, to the southeast of Sundsvall.

Notes about a spot zone were not made during the varve measurements unless a frequent occurrence of limestone particles was found. As the number of sampling sites is also restricted, the western border of the spot zone cannot be stated more precisely. However, G. Lundqvist (1963, p. 82) reported a possible occurrence at Torsåker, 20 km to the southwest of Sandviken, and it was found at almost all of my sampling sites to the southwest and south of Sandviken (Pl. 3-4, 15-16) and to the south of Ockelbo (e.g. at site 225 Slåttmuren). To the northwest and west of a border between Ockelbo – Maråkerby – Trönö – Enånger – Hudiksvall – Njurunda, the spot zone was indistinct or absent in my samples. For obvious reasons the occurrence agrees fairly well with a zone of high percentage of calcium in the glacial clay on maps by G. Lundqvist (1935, p. 293, 1963, p. 25; cf. also Järnefors 1963, p. 59).

The varve sequence between about -600 and -424 contains varves that are difficult to delimit with confidence in many of the sites. The 'symmict' character of these varves is probably an effect of a high concentration of calcium ions in the water when the clay was deposited (Arrhenius 1947), and also of the disturbances by drifting icebergs on the clay sedimentation (Sauramo 1923, p. 119). A symmict glacial clay in the older varves, also at coastland localities further to the north, was reported by Hörnsten (1964, p. 193). According to the ice recession lines, this symmict clay is somewhat younger than the varve year -424.

When the most probable correlations were made between graphs from my first measurements at localities north of the Tärnsjö – Östervåla and Gysinge – Hedesunda areas (Pl. 3), some ice recession lines had to be sketched almost parallel to the glaciofluvial eskers. At first I regarded these recession lines as unlikely, but the varve correlations were verified by a corresponding chronological position of the spot zone when the different graphs were compared. Many more measurements were necessary to get a denser net of sampling sites, and to make careful soundings at and around these sites, to confirm that the sampler really went down to the bottom of the clay. Also these new varve data supported the anomalous recession lines, and they formed a picture of deep calving bays at the main courses of glaciofluvial drainage, now represented by the eskers (Strömberg 1981a). This picture should not really be unexpected, since a similar reconstruction of an irregular ice margin with deep calving bays had been made in an area to the west by Fromm (1945, 1964). Naturally, the complicated form of the ice margin can be sketched only roughly (Fig. 6).

Deep calving bays with protruding ice lobes in between were probably also characteristic for the retreating inland ice margin further to the north, but the varve data is too sparse for a detailed reconstruction. A calving bay may have existed at the course of the glaciofluvial drainage to the north of Gävle, represented by the Gävle esker, and it may have developed into, or united with a deep ice bay or fracture zone which was sketched by Järnefors (1963, p. 59 and Pl. 1).

A calving bay also existed at parts of the glaciofluvial drainage course of the Uppsala esker. The varve data is not sufficient for detailed reconstructions, but some bottom varve datings indicate 'anomalous' recession lines near the esker in the Vendel – Tierp area (Pl. 3). I have used them for sketches of a calving bay on the map (Pl. 3; cf. Strömberg 1981a). The sketch of a deep calving bay in this position is also supported by the information of the youngest striae. Further to the north the Uppsala esker runs in a northerly-northeasterly direction, as an underwater ridge (Hoppe 1961; Axberg 1978). Since no varve or striae data exist in this area, reconstructions of the icefront positions are hypothetical (Fig. 12).

The calving bay of the Gävle esker developed into an important border zone between a vast part of the inland ice to the east, which stayed in the southern part of the Bothnian Sea, and the NE–SW-oriented ice front which retreated in the west, over present land. Prerequisites for a reconstructing of the form of this ice mass in the Bothnian Sea are weaker towards the east, but there are reasons to believe that it was shaped as a lobe (cf. Punkari 1978, 1980, and J. Lundqvist 1980). Most probably this ice lobe was active during the last deglaciation stages, and its movement towards the southwest was registered in striae from the northeast, found only at the present coast and on islands southeast of Söderhamn (G. Lundqvist 1963 ; Martin Sundh, *personal information*). Since the ice lobe in the southern Bothnian Sea was situated upon the Ordovician bedrock (Fig. 6), an extensive distribution of limestone by drifting icebergs was dependent on vigorous calving and a breaking up of the lobe. According to the spot zone chronology, the most intense calving started about the varve year -580, when the ice margin over present land was just to the south of Söderhamn. By then and during the following 100 years or so, the ice lobe was gradually broken up into a floating mass of icebergs.

Thus the new chronology indicates an accentuated and long-staying ice lobe in the southern Bothnian Sea (cf. Järnefors & Fromm 1960; Hoppe 1961; Järnefors 1963; Aartolahti 1972; cf. also J. Lundqvist 1975 and Mörner 1980). Gerard De Geer (1940) made a sketch of a very pronounced ice lobe in the western part of the Bothnian Sea (Fig. 12), but it was partly based on erronous varve correlations, and accordingly, the picture of deglaciation was incorrect. What is now indicated by the proposed recession lines (Fig. 6) is an image in a larger scale of the reconstructed deglaciation in the Åland Sea (Strömberg 1971). The retreat of the ice front was delayed over 'thresholds' in the bottom topography, as over the southern and northern threshold of the Åland Sea, and irrespective of the fact that the water was deeper over the thresholds than over the sea bottom to the west and east at that time.

The varve chronology for the ice recession north of Gävle – Hamrånge (Pl. 3–4) was difficult to establish on the basis of the dominating, rather vacant microvarve series. However, a few series of some hundred mm-thin microvarves in the Ockelbo – Hamrånge area were very distinct, and it was easy to see that occasional varves were lighter in color, thicker and more silty than the others. When these microvarved sequences were measured and correlated according to varve thickness variations and to the position of the spot zone, most of the thicker, silty varves in different graphs turned out to be in synchronous positions (Pl. 15c, 17a and Fig. 13). The most important mark is varve -424, which is represented in all varve series between Hamrånge and Björkön that are long enough and contain proximal varves older than -424. It was also found in the Ockelbo series 225 Slåttmuren and in two of the series from localities to the south of Sandviken, 214 S. Byn and 213 Litens (a measurement of a series with disturbed proximal varves at a site 30 m from the one reproduced in Pl. 16). This remarkable, wide distribution of a silty varve in a belt more than 200 km long, and parallel to the retreating ice margin, will be commented on later. As a control of the correlations this and other so-called drainage varves were important means of assistance.

A comparison between the chronology presented here and Järnefors' (1963) is made in Table 2, p. 29.

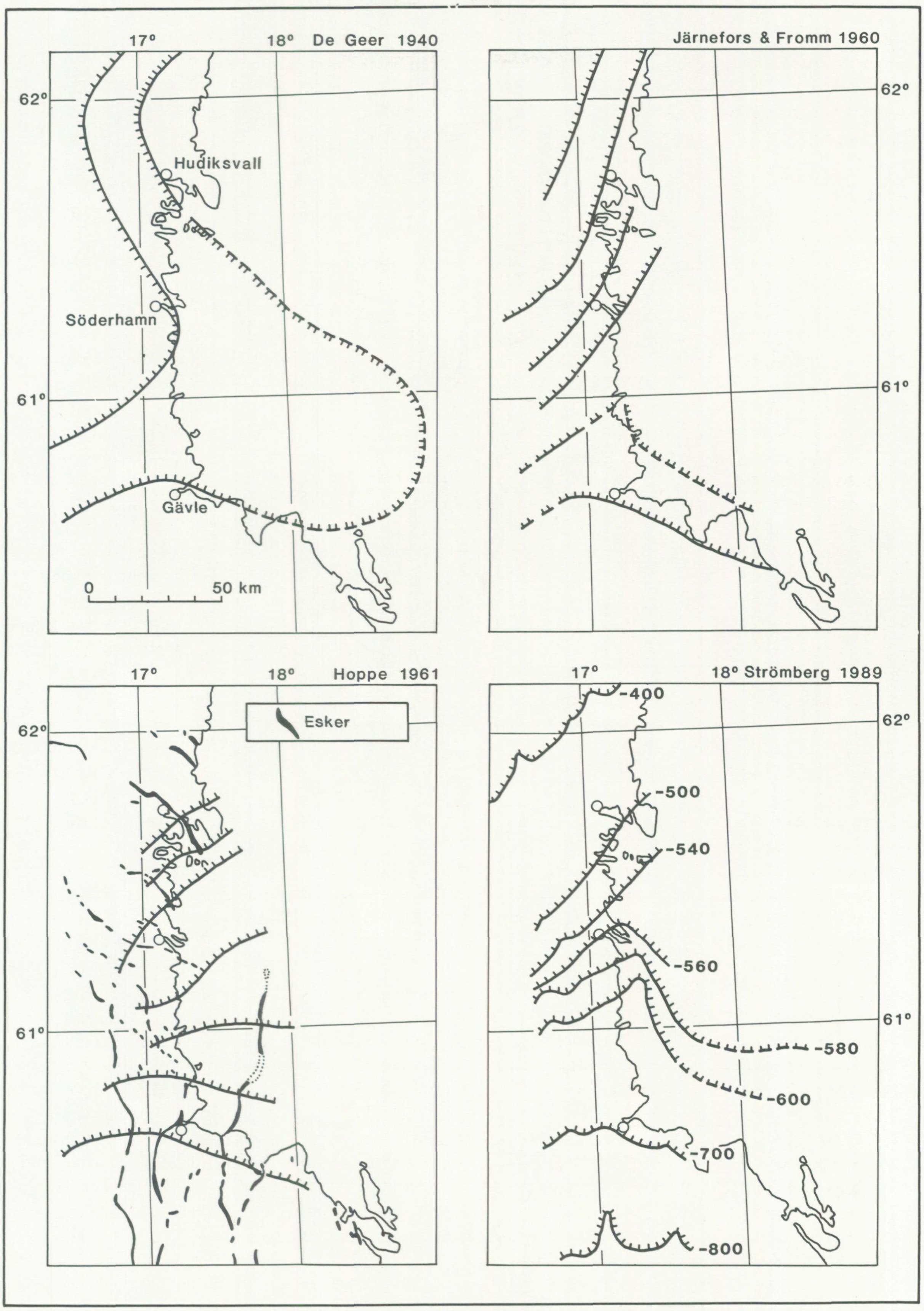


Fig. 12. Ice recession in the Gävle – Hudiksvall area according to different authors (partly redrawn from Hoppe 1961). Dating in years before zero (±0 = 7288 B.C.; Cato 1987).

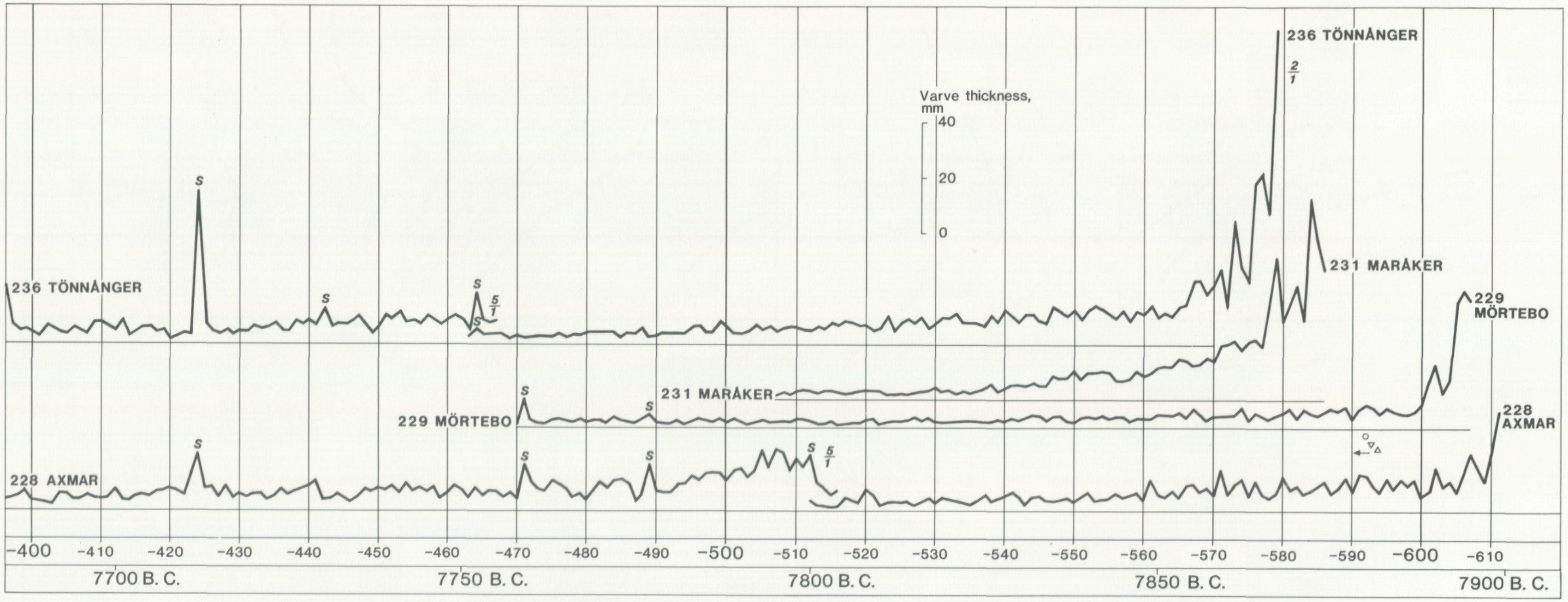


Fig. 13. Suggested correlation for the Axmar, Mörtebo and Maråker graphs. Legend: see Pl. 8.

E. Söderhamn – Sundsvall

Gerard De Geer's (1940) chronology for the ice recession between Ockelbo and Sundsvall (Pl. 4–7) was based on graphs from three measuring lines, each line consisting of varve measuring points that were situated comparatively close to each other. These measurements along the Ockelbo, Bollnäs and Dellen lines were made by different cooperators 1906–1938 (G. De Geer 1940, Pl. 81, 82, 83, and p. 252–253). Also varve measurements from the Gnarp area were placed at De Geer's disposal by Öster (1943, p. 245; cf. G. De Geer 1940, p. 159). Several of the graphs from these measurements are probably correctly correlated themselves, but the distances between the separate 'lines' are too great for reliable correlations to be made between the different areas.

A number of graphs from the Ockelbo and Bollnäs lines have been connected to the present revised varve chronology. I think the new correlations are reliable, and they exhibit the order of necessary corrections (Table 1). According to these correlations, De Geer's (1940) time scale should be shortened between Uppsala and Ockelbo by about 15 years, but it should be extended by about 30 years between Ockelbo and Bollnäs. Quite erroneous is the connection of the Gnarp graphs, which were dated 180 varve years too old, and of the series Me. 2 Ovansjö, 'teleconnected' to the Bollnäs series, and probably dated about 210 years too old. The Dellen graphs are numerically dated about 66 years too old, but they were placed in a position relative to the Bollnäs graphs which is 140 varve years wrong. To a large part the difference of 74 varve years (140 minus 66) is due to the change of zero year.

Consequently, most of the old correlations between graphs from the river Ljusnan area on one hand and Ljungan – Indalsälven on the other were confused. The main reason seems to have been the use of the microvarve series from Ovansjö, Njurunda (Me. 2; Pl. 7), which demonstrated quite striking resemblance in varve thickness variations on the scale 15:1, compared with the Bollnäs-series Hl. 13 on the scale c. 10:1 (G. De Geer 1940, Pl. 82). The 'telecorrelation' was based only on the resemblance between two graphs, irrespective of its consequences for the ice recession lines. Remarkably enough, it was supported by Caldenius (1941, p. 99). My experience of magnified microvarve series is that the graphs almost never show a particularly good agreement, since the 'local' varve thickness variations are exaggerated. One must have other criteria for correlation in addition to adaptable graphs. The Ovansjö microvarve series is probably very special, and it is divergent from other measurements in this area. I have not succeeded in correlating it to any other series from the Njurunda area.

Järnefors' (1963, Pl 1, 5, 6) picture of the deglaciation between Söderhamn and Sundsvall is more plausible, with reference to the ice recession lines. However, he only made seven new measurements in the 100 km wide belt between the two towns, and some of the graphs are short, insignificant, and difficult to correlate (cf. J. Lundqvist 1975). Almost all glacial clay is microvarved in this area, and even the proximal varves may be very thin. Järnefors (1963, p. 27) probably never tested to measure the distal microvarves and to use the 'drainage varves', which are often seen in the distal microvarved parts, for correlation.

The areas especially between the river valleys are poor in glacial clay, and it takes time to find the occurrences. More difficult, however, is finding varve sequences long enough for correlation and with all proximal varves represented in the samples. That is, the silty proximal varves, which are frequent in sites with bottom varves older than -424, are difficult to penetrate with the sampler, and even with the sounding rod. We were aware of this property of the Norrland clays (cf. Hörnsten 1964; Bergström 1968), and we tried to make careful soundings in order to reach the clay bottom. In most sites the sampler had to be forced down vigorously, and in order to get a complete sequence of proximal varves the 'air penetration mode' of sampling had to be put into practice.

In spite of all efforts, one or several varves were nevertheless missing in some of the samples. This was verified when duplicate samples were taken; a technique which was practiced in many of the localities. In some cases, the sampler could not be forced all the way down to the bottom, but the sounding depth was known, and we could calculate how much we missed. This is marked in the graphs with a mm-figure. Other cases of suspected, disappeared proximal varves are indicated with + or question marks in Table 3.

Several varve measurements between Söderhamn and Sundsvall have been very difficult to correlate. Many samples contain only 100–150 thin varves, with insignificant thickness variations beneath an unvarved postglacial clay. The problems were not solved until series with long sequences of microvarves were found. Why comparatively few sites in this area are provided with a sufficient number of distal microvarves is puzzling. After about 100–200 years of varve sedimentation, these localities seem to have received very little glacial clay.

Among the microvarves there were more or less distinct, silty 'drainage varves', some of which turned out to be in definite positions when the most reliable correlations were found. Most useful for the verifying of correlations are varves -424, -200 and -48 (Pl. 15, 17, 18), with a wide regional distribution. Also useful are e.g. varves -186 and c.-168, c. -140 and -67, but they are less widespread. In the most distinct microvarved series from different sites, two or more 'drainage varves' are often noticed in definite positions, with exactly the same number of varves in between. The correlation between the graphs may also look good for some parts of the varve sequences, when the visual examination is put into practice. Divergences are met with, however, and even negative correlation is seen when some of the varves or shorter parts of the graphs are compared (Pl. 17, 18). In the case when the same number of varves were noticed between the 'drainage varves', a poor correspondence between the graphs is no indication that the compared varves should not be synchronous. I think the 'local' influence on the thickness variations was considerable at times during the deposition of microvarves. A contributary factor is the magnifying of 'local deviations' from 'normal' varve thickness variations by the measuring technique.

In some varve series the 'drainage varves' were not in exactly the same position as in other series. The most probable explanation is that occasional varves were incorrectly measured, and sometimes a correction can be made with the aid of question marks on the measuring tape. Loss of varves due to erosion in the high water discharge situations, when 'drainage varves' are deposited, must also be considered (cf. Bergström 1968). However, when no guidance is at hand, I have preferred not to make subjective changes. The somewhat different positions of some silty varves, e.g. c. -168, -140 and -67 in the graphs is probably an effect of measuring difficulties or a loss by erosion of the clay, not an indication of lacking synchronism of these varves.

As mentioned above some of the 'drainage varves' have a very wide regional distribution. Varve -424 is most exceptional, with occurrences in all possible sites from the river Dalälven area to Björkön, southeast of Sundsvall. It is prominent in Gerard De Geer's (1940, Pl. 82 and p. 159) Bollnäs-graphs as the varve year -350 in De Geer's time scale, and indicated 'Drainage varve Ljusnan V.' on the map 'Ice recession through Helsingland'. It is also represented in Öster's (1943, p. 243) graphs from the Gnarp area as the varve year -604 (see Fig. 16), and in Järnefors' (1963, Pl. 5) Gnarp-graphs as varve -425, i.e. almost correctly correlated (cf. Table 2).

A well developed varve, particularly in the river Ljusnan's valley, is -200, but it is also found towards the south as far as at Tönnånger and Hamrånge and towards the north at Långvind and Sivik (Pl. 4 and 6). It probably also exists at Hassela (Pl. 18) as the silty varve -201 if the faulty position is a result of a minor measuring mistake. Remarkably enough it was not observed at Tränö and Rengsjö, northwest of Söderhamn, not far from the Ljusnan valley. The reason may be that these two localities are situated in side-valleys, partly sheltered by rather high terrain from the main Ljusnan valley when the drainage varve was deposited, 300 years after the deglaciation. This is not the only reason, however, since two other of the silty varves in the Ljusnan valley, c. -168 and -140, are well developed at Rengsjö and Tränö.

The most widespred of the 'drainage varves' in the Indalsälven valley is -48, which is better developed at the present coast than the zero year varve. It has also been deposited in the Hudiksvall area, according to the varve measurements at Hede and Sivik. Other thick, silty varves that have been noticed seem to have a more limited occurrence. This is true for the zero year varve and for some of the silty varves in the Ljusnan valley. Such a restricted occurrence, and a decreasing thickness from the drainage area and outwards should be expected from 'normal' drainage varves formed by more or less catastrophical discharges from ice-dammed lakes (see e.g. Borell & Offerberg 1955, p. 19 and Fözö 1980).

Naturally, the drainage of an ice-dammed lake is a logical explanation of the cause of a drainage varve when a mutual relation is likely to exist. This kind of relation can often be sketched and it is probably true in a number of cases. However, some silty-sandy deposits which look like drainage varves, should rather be related to rapid changes of the glaciofluvial discharge or to turbidity currents caused by other events than drainage catastrophes (Bergström 1968; Strömberg 1977; Shaw & Archer 1978; Axelsson 1983; Cato 1987; Catto 1987; cf. also Kuenen 1951). The deposition of thin, clayey microvarves presupposes a calm sedimentation environment which did not always exist. Sites not distant from the ancient shore receive wave washed material during storm events, and silt layers in the clay with a limited distribution may be related to transport and deposition by wind generated currents (cf. Catto 1987). This is suspected to be the explanation for a number of thin, sandy or silty layers in microvarved clay found e.g. at Gårdsjön, north of Gnarp, and Älvsund, southeast of Hassela (unpubl. series), both localities quite close to the ancient shore line.

The varve -424 is not only widespread but also strongly developed. It contains silt or even fine sand at sites in the river valleys as well as in the interjacent areas and far from the main meltwater courses, now represented by eskers, as at Tränö, Sivik, Galtström and Björkön (Pl. 6 and 7). The silty-sandy part of the varve is thicker at the river valleys (often some centimetres to a decimetre), thinner in the interjacent areas (some millimetres to a centimetre). Probably this means that the material was delivered via subglacial meltwater courses, not parallel to the icefront. At many sites between Hudiksvall and Sundsvall the varve was deposited rather close to the receding ice front, and it contains a hard silt or fine sand which is difficult to pierce with the sampler. In the series 301 Galtström this varve was deposited above 15 cm of a dark, almost homogenous clay with indistinct varve limits. At other sites it was frequently but incorrectly interpreted as the clay bottom, and the varves beneath were impossible to take with the sampler.

I questioned the synchronism of this remarkable varve for a long time, and tried alternative correlations, not least in the light of the old datings reported above. However, there is no doubt about its simultaneousness, as convincing correlations could be made with the help of microvarved series taken between the river areas of Ljungan-Indalsälven and Ljusnan. When series from these areas are correlated with e.g. 275 Hede and 287 Harmånger, varve -424, as well as younger 'drainage varves' (c. -48 and -67), are in identical positions (Pl. 18).

Considering its thickness and grain size one would prefer a powerful drainage as the cause of varve -424, but it is difficult to understand how this drainage could affect several parallel river valleys. It is also hard to explain how a huge drainage could occur at this comparatively early stage of the deglaciation when a considerable part of the inland ice is supposed to remain in central Sweden. Are J. Lundqvist's (1973, p. 164–165) approximate dates of the deglaciation in Jämtland and Härjedalen roughly correct, then there should be no conditions for any of the known glacial lakes in this area to have existed 423 years before the zero year.

An alternative interpretation of the genesis of varve -424 is the one given by Bergström (1968) for an analogous 'drainage varve' in Västerbotten and Ångermanland: occasional, thick silty-sandy layers may form during a year with an exceptional high water and sediment discharge from the inland ice, affecting the deposition from several meltwater rivers. The basis of Bergström's (1968, p. 45) analyses is the varve -189 in Västerbotten – Ångermanland, probably corresponding to -186 in the graphs on Pl. 17, and some of the successive, younger varves. This part of the time scale is characterized by exceptionally thick varves, or even by erosion, in Västerbotten – Ångermanland as well as in the Indalsälven and the Ljusnan valleys (cf. also Borell & Offerberg 1955). Obviously, there was a period when water discharge and sediment transport was high in a very wide region. This could be a consequence of climate affecting the water discharge in several meltwater rivers.

Varve -424 can be traced outside the Ljusnan – Ljungan area, but it is exceptionally thick only within this area. This could be interpreted as a result of a substantial increase of the normal, glaciofluvial drainage, which occurs when a glacial lake is suddenly drained subglacially (cf. J. Lundqvist 1973, p. 117). Subglacial 'jökelhlaups' were probably frequent, and they could penetrate considerable distances below the ice, if only the glaciofluvial drainage was well developed. As a rule, the drainage should be restricted to one drainage course, but in this case the subglacial flow affected both the Ljusnan and the Ljungan valleys and probably also drainage courses in the area situated in between.

The younger 'drainage varves' can easier be correlated with plausible drainages from glacial lakes. Obviously 2–5 thick, silty varves were deposited between the varve years c. -200 and -110 in and around the Ljusnan valley, and between c. -70 and ±0 in the Ljungan–Indalsälven area (Pl. 17–18). In the Ljungan – Indalsälven area there are no or very few traces of the characteristic silty varves in the Ljusnan area and vice versa. This is an indication that the high water discharges, responsible for the silty varves, were concentrated outflows from a specific valley or drainage area. Attempts at correlating these outflows with drainages from some of the glacial lakes which have been reconstructed (e.g. J. Lundqvist 1959, 1975) will not be dealt with in this paper.

A consequence of the correlation of the graphs is a chronology for the ice recession which differs from that of Järnefors (1963) in many respects (Table 2). The necessary corrections can only be given approximately, as none of the series from the Sundsvall – Söderhamn area in Järnefors' (1963, Pl. 5 and 6) diagrams include any distal microvarves. His graphs are too insignificant for correlation, and they have gaps, indicating disturbances in the varve sequences.

TABLE 2

Site	Järnefors year	Revised	Difference
J 103, 112 Njurunda	–430	c. –400	c. –30
J 99 Gnarp	–443	–442	–1
J 96 Forsa	–430	c. –460	c. +30
J 95 Trönö	–468	c. –520	c. +50
J 88 Ockelbo	–593	c. –647	c. +54
J 81 Strömsbro	–616	c. –692	c. +76
J 39 Smedsbo	–719	–783	+64
J 3 Högsta	–848	–912	+64

Noteworthy is the divergent but almost correct correlation of the Gnarp-series and the good varve chronology for the Uppsala – Gävle area. The Strömsbro-graph is correctly correlated, but about 12 proximal varves are probably missing. My first sampling at this site, situated not far from Järnefors' (1963, p. 31), did not reach the bottom, and some decimetres of the silty proximal varves were lost. The second sample was complete, and as the varve sequence seemed to be undisturbed, it was used for the graph 222 (Pl. 15).

F. Correlations with external areas

Some attempts to correlate my varve series with graphs representing measurements outside the investigated area have already been mentioned. Correlations which seem rather convincing are, for instance, those with series from Ångermanland and Västerbotten, as Sand (Lidén 1913), Vännäs (Bergström 1968) and Västerflo (Fözö 1980) – see Fig. 2 and 3. These comparisons are mainly based on the synchronous appearance of 'drainage varves'; not on the correspondence varve-by-varve between the graphs which is less clear in some parts of the varve series.

The inclusion on Pl. 17 of the two series Ava and Flärke from Västerbotten (Bergström 1968), together with series mainly from the Ljusnan valley, was made as an illustration of a probable, long-distance correlation. In spite of the fact that the measuring sites Ava and Flärke are situated in different sedimentation areas, 150–250 km apart from the Ljusnan area, there is a good agreement between some of the graphs. This is especially true for the Ava and the 319 Färila graphs, the latter having been measured in the Ljusnan valley by Birger Forssmark. 'Drainage varves' are not necessary for the guiding of this correlation, but it is important to notice that the position of the different graphs in the two time scales is a result of stepwise correlations; not of long distance connecting at a venture.

There also exists a step-by-step correlation from western Uppland to the Avesta – Falun area in southern Dalarna (Järnefors & Fromm 1960; Järnefors 1963; Fromm 1964). According to the map with dated bottom varves (Fromm 1964), the agreement between the ice recession line -750 (Järnefors' revised time scale = -814 in the present chronology) and a corresponding, extrapolated recession line from my map, Pl. 3, is good. A comparison with a map and diagram published by Kulling (1948) over varve measurements in the Hedemora – Falun area demonstrates a correction of the dates, made by Fromm (1964) by about 30 varve years. I have the same indication: the dates on Kulling's (1948) map and diagram in G. De Geer's (1940) time scale, are about 30 years too young (e.g. Kulling's -549 should be corrected to c. -581 = -600 in Järnefors' time scale of 1963, and -664 in the present, revised chronology). This long-distance correlation of graphs from the Säter - Falun area to my diagram must be regarded as preliminary.

G. Margin of error

Estimation of possible errors in delimiting annual varves and in correlating graphs was treated on pp. 16–29. Naturally, the basic assumption has been that varves in the investigated area are normally annual deposits (see e.g. Fromm 1970; Strömberg 1971; Cato 1987, p. 40). There is no reason to question this assumption with regard to the 'Uppsala clay' and to the diatactic clay to the north of Uppsala. In the symmict clay between Stockholm and Uppsala, however, there were sometimes problems in delimiting indistinct varves, and in determining whether 'pseudovarves' are present and should be omitted. This fact, and local differences in clay sedimentation within the fissure valley terrain are probably the main reasons why some of the correlations in Pl. 8–14 are less convincing. Even if I do not believe that any correlations are faulty, a margin of error of ±10 varve years should be calculated for the Stockholm – Uppsala section of ice recession.

Most correlations of graphs from sites between Uppsala and Gävle are quite convincing, and doubtful cases can be tested by the onset of the 'spot zone' in the varve series. This should also mean that the main time scale between c. -1000 to -600 is correct within a limited margin of error, probably ±5 varve years. Occasional varve series with an indistinct spot zone, and some of the many thin-varved series without a spot zone in the Ockelbo area may have less reliable datings.

The correlating of varve graphs from a number of sites to the north of ice recession line -600 was sustained by 'drainage varves', found within extensive areas and appearing in definite positions in the varve sequences. Thus the correlations between varve series in the river Ljusnan's and Ljungan – Indalsälven's sedimentation areas should be correct within a ±5 varve years margin of error. Correlations between the two areas were at first doubtful, since 'drainage varves' in the river Ljusnan's sedimentation area are normally absent at Ljungan - Indalsälven, and vice versa. In two series, however, (275 Hede and 287 Harmånger; Pl. 18) 'drainage varves' from both areas are present, and strongly support the correlations. Even if the correlations are correct, some of the bottom varve datings may be too young, since the proximal varves at several of the sites between the ice recession lines c. -500 and -424 were very difficult to take with the sampler. These doubtful bottom varve datings do not affect the main time scale.

In summary, the time scale for ice recession between Stockholm and Sundsvall should be correct within a ±20 varve years margin of error; within ±25 varve years for the 1191 years before the zero year, if possible errors in the connecting to the zero year are less than ±5 varve years.

The total, maximum margin of error for the period from the zero year up to 1950 A.D. (= 9238 varve years) was estimated at +10/-180 calendar years (Cato 1987). Thus the time scale from varve year -1191, on an ice recession line to the south of Stockholm, to 1950 A.D. covers 10 429 varve years, with an estimated margin of error of +35/-205 years.

The ice recession

A. Varve data, striae and ice recession lines

For a detailed deglaciation picture a dense net of varve measuring sites is required. G. De Geer's (1940, Fig 23, 24 and Pl. 56–57) ice recession maps of the Stockholm area are good illustrations. His ice recession lines for central, northern, and western Stockholm were based on several hundred varve measurements. According to them, the retreating ice front was irregular, with local bays and projecting lobes; phenomena which are often seen on visible parts of present-day calving glaciers.

The demand for a dense net of measuring sites is met only in the southern part of the investigated area, as between Stockholm and Uppsala, but not in southern Norrland. Since the primary purpose was to get a reliable time scale, the varve measurments were generally not made in a wide belt, transverse to the direction of ice recession. Thus the possibilities are limited to sketch ice recession lines which are strongly guided by varve data, particularly in the northern part of the area. There are also fewer clay deposits in the northern part, which makes the fieldwork rather time-consuming. In addition, the ice recession lines are more complicated to reconstruct when parts of the terrain were deglaciated supra-aquatically.

It is a well known fact that the ice movement in marginal parts of glaciers and inland ice sheets are mainly directed perpendicularly to the ice front (e.g. Chamberlin 1883; G. De Geer 1897; Hedström 1901; Sauramo 1923; Hoppe 1948). Varve chronological works made at sites situated transversally to the direction of ice recession, i.e. parallel to the retreating ice front, show a good agreement between recession lines based on varve data and on information from the youngest glacial striae (see e.g. Järnefors 1963, p. 59; Hörnsten 1964, p. 193; Bergström 1968, p. 51, Strömberg 1971, p. 111, 1981a, p. 152). There are, of course, local deviations in some restricted areas where this agreement is not as good, for example close to some of the glaciofluvial melt water courses. Within a short time an intensive calving over the melt water courses can change the direction of the ice front, and this is not always registered by the glacial striae (G. De Geer 1940, p. 44; Strömberg 1971, p. 91). On the other hand, the adjustment of the ice flow is good even when the ice front – according to varve and/or striae data – locally and temporarily changes its orientation at larger calving bays (Järnefors 1963; Strömberg 1981a). A width of the bay or the lobe of about two km seems to be enough, in order to change the direction of ice flow. These conditions are distinctly illustrated at some parts of the glaciofluvial eskers: the Uppsala esker at Ekoln and at Björklinge – Tierp, and at parts of the Gävle and Enköping eskers (Pl. 2–3).

These alterations of ice flow direction, in a late final stage of the deglaciation, were of short duration, but they were evidently registered by the youngest striation. Not only striae were formed; one can also find new stoss sides and/or erosion of the older sets of striae on these sides (cf. Frödin 1956). Consequently, the eroding marginal parts of the ice pressed the underlying substratum in some parts of the terrain. A prerequisite for erosion is, of course, that the ice is warm-based and not frozen to the bottom in its marginal belt. The complete varve and striae material now at hand, and the large, coherent eskers (cf. J. Lundqvist 1987) clearly show that this was normally the case in the investigated area during Late Weichselian deglaciation time. This must be stressed since convincing data have been presented indicating cold-based ice during deglaciation of the northern, supra-aquatically melting parts of the Scandinavian inland ice (J. Lundqvist 1981; Lagerbäck 1988; Sollid & Sørbel 1988, Fig. 5).

In some cases an amazingly strong erosion took place during these short stages: about 10 years of ice erosion has given a partly new bedrock sculpture (Frödin 1956, p. 46; Strömberg 1971, p. 54). Apparently this erosion was 'stiff' and gave a non-plastic striation. Only exposed parts of the roches moutonnées were striated, and the youngest striae are missing in lee-side positions, even when these positions are only slightly lower than the exposed surfaces. Locally, the ice margin was probably floating and lost its bottom contact (J. Lundqvist 1987, p. 315), but there are no indications that floating ice margins had any large extent, except in the deep 'fjärdar' or channels in the present river valleys of southern Norrland. Deep calving bays are indicated by the sparse varve data from these valleys but not clearly indicated by the striation. The observations of striae are few, however, and they are mostly made in the higher terrain surrounding the valleys. Possibly a revision and completing of the striae observations can give a similar result as in the Gysinge – Hedesunda and Björklinge – Tierp areas, where my striae investigations gave a partly different picture from the one obtained by the geological surveys (Pl. 3).

The possibility for buoyancy of the ice margin in the deep valleys could also lead to a subglacial sedimentation of silty proximal varves. In that case, varve data will give a false picture of the ice front direction. This process is probably not a general source of error, since the topographic situation in the valleys was particularly favourable for a formation of deep calving bays.

Thus there are strong reasons to believe that the use of information from the youngest glacial striation for an extrapolation of equicesses will give a very reasonable reconstruction of the retreating, calving ice margin.

B. Ice recession rates

According to the equicesses, the rate of the ice recession seems to have been rather regular: 200–300 m a year are typical average values. Local deviations are frequent, however, which is obvious if the datings from individual measurement sites are compared. For instance, north of Stockholm between the sites 126 and 129 (Pl. 1), the annual retreat of the ice front was about 500 m, but it was only about 100 m between sites 129 and 133. In the coastland of southern Norrland the annual ice front retreat accelerated up to about 800–900 m in places, but in the more broken topography north of Bergsjö – Gnarp and in the Sundsvall area a normal value seems to be 300 m (Fig. 6). An extremely rapid retreat of about 1 km annually occurred between Hamrånge (Pl. 4, site 227) and Granön (site 230), after a short period of very slow retreat, 50–100 m annually.

This slow retreat is the only sign of a possible 'Gävle oscillation' in the varve chronology. It is plausible that a real oscillation happened at a stage of deglaciation when the ice margin retreated in the Ockelbo – Hamrånge area, but in that case it was of small extent and lasted only some decades. The mechanism behind such an oscillation may very well have been a surge (see below). Unfortunately, the area is poor in clay deposits and I have not found any useful glacial clay southeast of Hamrånge, where the possible oscillating ice margin should have been located. It must also be emphasized that varve data, suggesting the retarded recession and the succeeding accelerated retreat, are few.

No other oscillations, not even of short duration, can be seen in the varve material. A reason may be that an oscillation of restricted extent in space and time will not be revealed by varve measurements other than as an exceptionally slow retreat of the ice margin. Proximal varves which are overrun by an advancing ice front are normally eroded or covered by till, and they are only registered as 'missed'. Thus smaller oscillations may very well be hidden within ice recession belts with unusually slow annual retreat values. It should be surprising if no shorter retardations or oscillations took place during the 800-year long deglaciation time in the surveyed area. Actually, observations have been made in a few cases (Frödin 1956, p. 43; Möller 1962b, p. 142) of till on varved clay, where the till was probably not deposited by floating icebergs ('till rafts').

C. The ice lobe in the southern part of the Bothnian Sea

The most remarkable part of the deglaciation is the retreat in the southern Bothnian Sea at the time of deposition of the so-called spot zone (p. 21). The steering of ice recession lines outside the present coast (Fig. 6) cannot be made with the direct assistance of varve data, and only few striae observations on the easternmost islands give some indication of this. The recession lines are based almost exclusively on the indirect dating by the appearance of the spotted zone in the varved clay at a number of localities southwest of Gävle. As said earlier, the only adequate explanation of the concentrated appearance of limestone fragments in the glacial clay between c. -580 and -490 in the revised time scale, is a deposition by icebergs descending from calving ice over the Ordovician limestone area in the southern Bothnian Sea.

An intense breaking up of the large ice lobe that to all appearances stayed in the southern part of the Bothnian Sea did not start until the retreating ice front reached the present coast south of Söderhamn. The ice front was then oriented towards the southwest over the present land area, but it was directed towards the SSE over the limestone bedrock of the sea bottom. This western flank of the ice lobe may have turned off towards the northeast 30–40 years later, since almost all of the youngest striae on the easternmost islands north of Söderhamn are directed from the northwest. However, the striae observations were made to the west of the Bothnian Sea limestone area, and exceptional northeast-striation has, in fact, been observed (in the Agö-group of islands and at Gran; G. Lundqvist 1963, p. 22 and 25).

A complicated ice recession some decades after varve year c. -560 is suggested by a strange pattern of ridges found by seismic mapping of the sea bottom to the north of lat. 61° (Axberg 1978), and by difficulties in finding the continuation northwards of the underwater ridge of the Uppsala esker (Hoppe 1961). This may indicate the disintegration of a remaining remnant of the Bothnian Sea ice lobe, but a sketching of recession lines would be pure guesswork.

The real spot zone is preceded by some tens of varves with scattered limestone particles, probably deposited by icebergs from the area close to the present coast outside Gävle. It is succeeded by clay with limestone particles in the varves c. -490 to -425, i.e. during the time of iceberg calving over the northwesternmost part of the limestone area.

Judging from the abundance of limestone fragments in the spot zone icebergs appeared at an exceptional frequency during the c. 90 years of spot zone deposition. This effective breaking up would be facilitated by a strongly fractured ice which is chacteristic of surging glaciers (Robin & Barnes 1969; Schytt 1969). Until now this exceptional calving after a time of slow retreat is the only indication of a surging ice lobe in the southern Bothnian Sea.

D. Calving bays

The presence of deep calving bays at some of the glaciofluvial meltwater courses is indicated by varve data and striae information, as said above. Still this is not true everywhere, and the possibilities for making reconstructions are rather few. Even though varve, as well as striae localities are generally missing close to larger meltwater courses, it seems probable that calving bays were formed in these localities and also at places other than those sketched on the maps, Pl. 1–7. By special effort, a basis for the reconstructions was obtained in the Gysinge – Hedesunda area (Pl. 3; Strömberg 1981a). Very accentuated calving bays – 'glaciofluvial estuaries' – were indicated by varve data and striae information in this area. Here the calving of icebergs must have been effective, while protruding ice lobes between the bays receded slower or were even cut off as remaining ice remnants.

In some places where calving bays have been reconstructed varve data suggest a rather irregular ice recession: more rapid retreat of the ice front in the inner part of the bay, while the ice front on the flanks receded slower or even advanced for some years. For instance, varve data at Tärnsjö – Gysinge (Pl. 3) suggest a very slow retreat, especially at Buckarby, where the ice margin seems to have retreated less than one km in 15 years. This behaviour of an ice margin at a deep calving bay is quite plausible (cf. e.g. Brown et al 1982). Yet another explanation of a slow retreat could be 'a false clay bottom'. This is probably the case at a site in the vicinity of Buckarby. Thus at Tärnsjö there is an apparent anomaly in my varve measurement, as some varves obviously are missing in my series 203 from this site when compared with Järnefors' (1963) series 72, from a site just close by. Since I noticed a very distinct till bottom beneath my bottom varve, the anomaly must be explained in some other way, for instance by a stranded iceberg or remaining remnant of the ice, which prevented clay sedimentation for some years.

At Ekoln, to the south of Uppsala (Pl. 2), the western

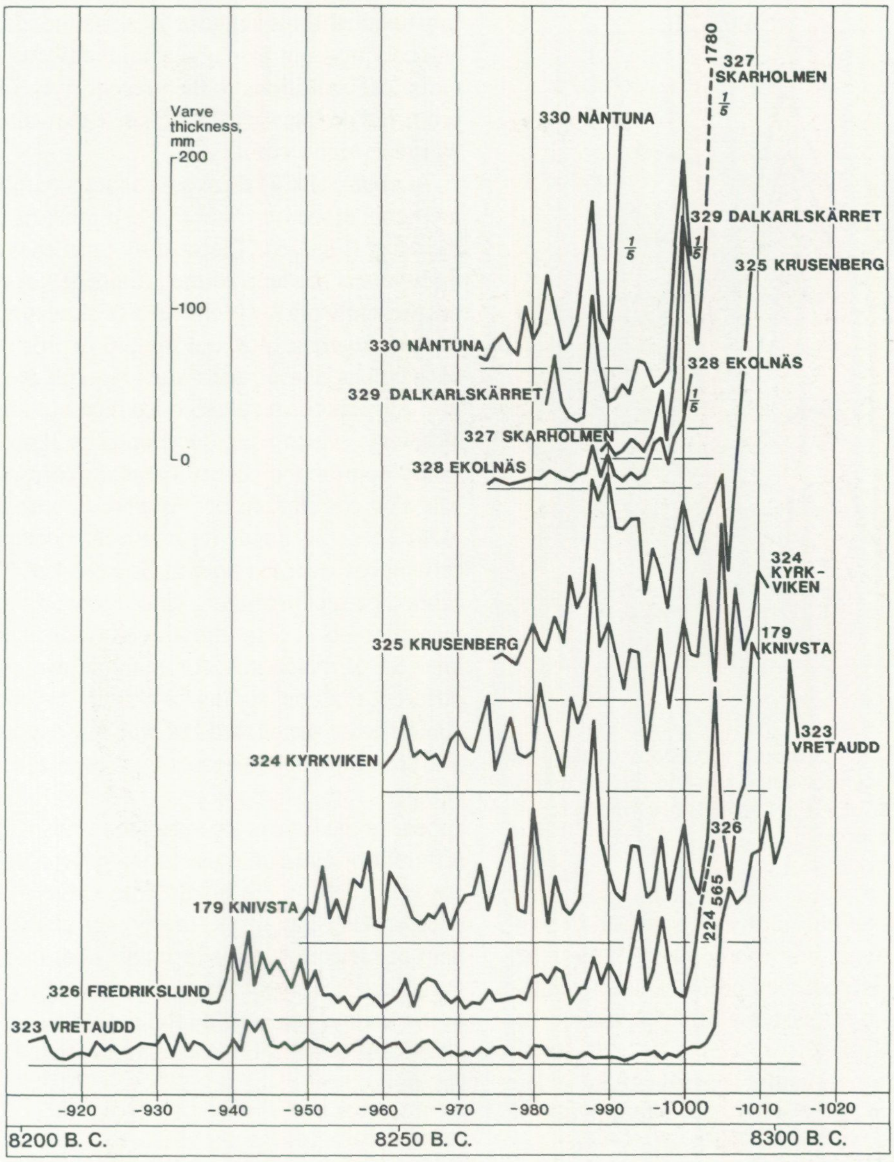


Fig. 14. Suggested correlations for varve series from the Ekoln area, S of Uppsala. The proximal varves at sites close to the glaciofluvial esker are exceptionally thick and the correlation of some short graphs is uncertain. Legend: see Pl. 8.

flank of the deep 'glaciofluvial estuary' probably advanced over earlier deposited glacial clay (Frödin 1956, p. 43). Unfortunately most of my varve measurements made close to the esker in this area resulted in short diagrams (Fig. 14) which are no good basis for reliable correlations. The proximal varves are very thick, and the distal varves are generally indistinct and not measurable. However, the striae observations (mainly after Frödin 1956) indicate a very deep calving bay towards which the ice front advanced on both sides. During this short stage of deglaciation a partly new sculpture was eroded on the roches moutonnées. The calving bay of the Uppsala esker can be traced from varve data and striae information also to the north of Ekoln, towards Uppsala – Gamla Uppsala, 5 km to the north of the present town.

Further north the varve data are insufficient for detailed reconstructions of the ice front orientation, but the direction of the youngest striae (cf. Frödin 1956, p. 52) indicate the presence of a more or less deep calving bay during the deglaciation up to the Tierp area (Pl. 3). Also varve data from the localities J 33, J 31, J 32, and DG Up. 34, suggest that this bay existed. Bedrock outcrops are sparse on the eastern side of the esker, but there are some striae observations indicating an ice movement from the northeast. On the few exposed and non-weathered bedrock outcrops to the west of and close to the esker the direction of the youngest glacial striae vary from site to site between NW to WNW and N. When the youngest striae are directed from the north, older northwest-striae in rather exposed – or less well protected – positions

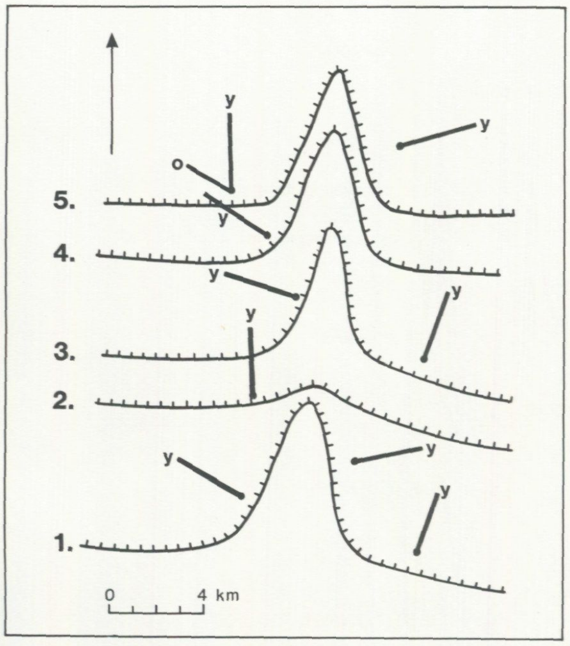


Fig. 15. Successive stages (1–5) in the ice recession at a deep calving bay, and the probable ice movement close to the ice margin, pictured by the younger sets of glacial striae. Y = youngest, O = somewhat older direction of striae.

may also exist along with an old northwest-striation in protected leeside positions. According to my interpretation the age difference between older, not well protected, and youngest striation is small, and both systems of striae should be related to a late deglaciation stage.

Fig. 15 shows how 'submarginally' formed glacial striae close to a calving bay may be oriented, and why the directions vary from site to site. When the ice front successively retreated from ice margin position 1 to 5, the youngest striae to the west of the calving bay would be oriented from the northwest when the calving bay is accentuated and from the north when it is temporarily less deep. Between ice margin stage 4 and 5 the ice front has advanced on both sides of the calving bay, and this has resulted in the striae direction from WNW on the western side. The conditions are analogous on the eastern side of the calving bay. Thus the youngest ice movement and striation over the northernmost locality came from the north, and the somewhat older ice movement from the northwest will be registered by only partly eroded striae in rather open positions. During the short time of changing ice movement the older striae were not completely eroded.

From the Gävle area and northwards varve and striae data are insufficient in most cases for the reconstructing of eventual 'glaciofluvial estuaries'. Still I have marked the likely occurrence of some of them, such as in the Ljusnan and Indalsälven valleys (Pl. 5, 7 and Fig. 6). Deeper bays were probably formed in places even more accentuated than the hypothetical lines suggest. Besides the effect on ice melting and calving from the subglacial meltwater streams, the topographical conditions in the present river valleys should have promoted an intense calving, since the valleys are surrounded by rather high terrain.

At Gnarp (Pl. 7) there are in fact a number of varve measurements made by Öster (1943); most of them just close to the esker (Fig. 16). These varve profiles were correlated primarily with the help of the ' drainage varve' -604 (= -424 in the present work), which had a thickness of 11-56 cm in several of the sites. Without the aid of this stratigraphic mark correlations of the micro-varved series are difficult to make. The correlations resulted in ice recession lines running about west–east, which were questioned by Järnefors (1963, p. 61). In my opinion they are in the main correct, at least the ones based on correlations between series with the drainage varve -424. These lines may represent the northern flank of a deep calving bay over the present Gnarp esker. The southern flank cannot be reconstructed, since varve data are lacking. Our own attempts at clay sampling at Gnarp's church and about 4 km ESE of the church, for example, were not successful for different reasons; at Gnarps church the thick drainage varve could not be penetrated but was interpreted as sand bottom. The sketching of equicesses here, especially of -420 and -440 (Pl. 7) is rather hypothetical, and if reliable varve data is to appear in the future, the recession lines will probably have a different orientation close to the esker. The same conditions are applicable in the Indalsälven valley: I have suggested a deep calving bay in the lower part of the valley – with the help of measuring sites at Indal – but this bay was perhaps even deeper. The existence of a calving bay further upstream in the valley, just outside the map area on Pl. 7, is supported by observations of the youngest striae (J. Lundqvist 1987, fig. 63).

SUMMARY

Among the most urgent points for Swedish participation in the International Geological Correlation Programme (IGCP) was an improvement of the varve based Swedish time scale. This improvement denoted a firm connection of the postglacial varve chronology to the present and new revisions of the lateglacial time scale, i.e. of the Late Weichselian deglaciation chronology in south and east-central Sweden. When the work started in 1975, as part of the IGCP Project 24, it was devided on different principals: the Geological Survey of Sweden was responsible for the connecting of the postglacial varves to the present and for revisions in southern Sweden, the Departments of Physical Geography and of Quaternary Geology at the University of Stockholm for revisions in south-central and east-central Sweden. Some revisions are completed (Ringberg & Rudmark 1985; Kristiansson 1986), and also the connection to the present has been executed (Cato 1987).

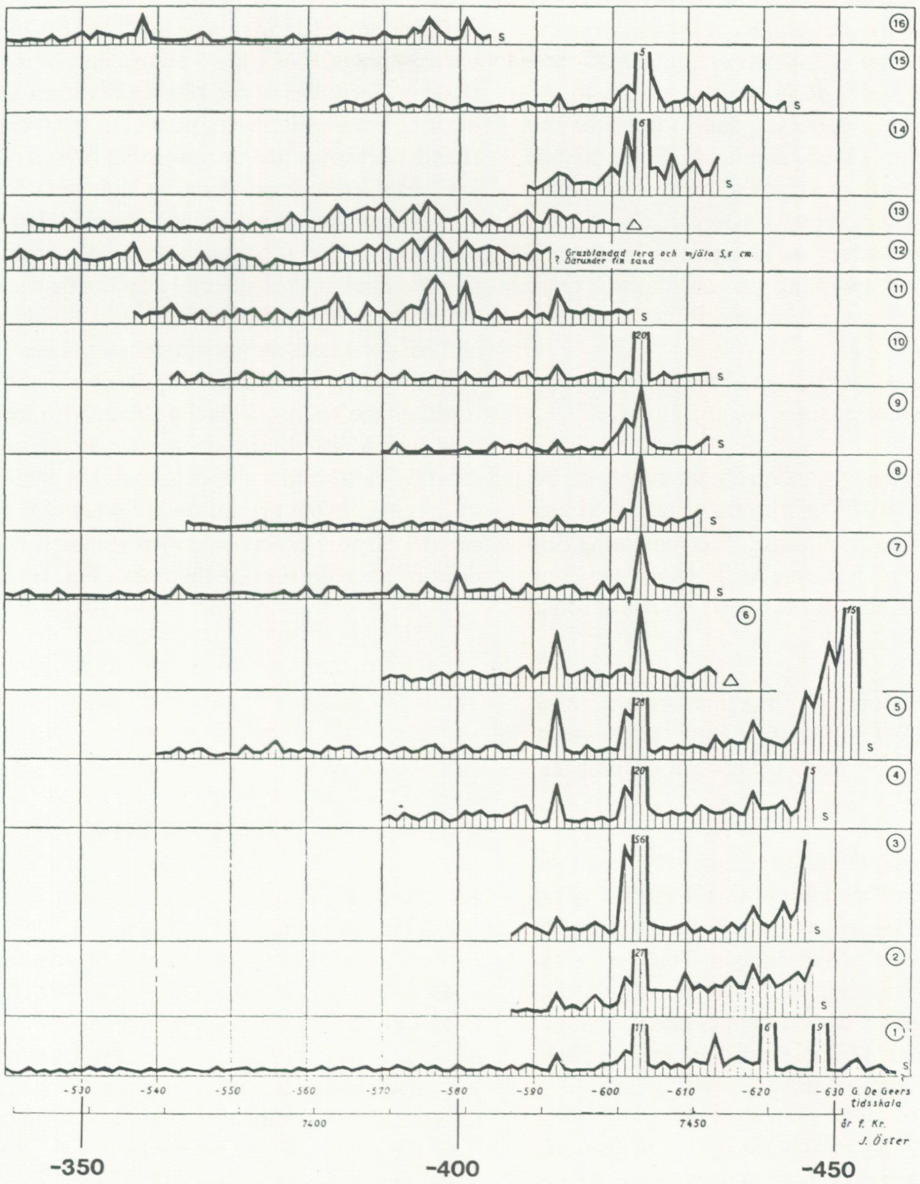


Fig. 16. Graphs of annual varves in northeastern Hälsingland (Öster 1943). Triangle = till substratum, s = sand. Varve thickness on the scale c. 1/3; figures in cm. Upper time scales according to G. De Geer 1940, lower scale revised. Datings in years before zero (±0 = 7288 B.C.; Cato 1987).

The present revision applies to a chronology of the deglaciation between Stockholm and Sundsvall, including the connecting of this lateglacial time scale with the so-called zero year. This ±0-year is a drainage varve in the Indalsälven valley intended to mark the transition between 'glacial' (minus-varves) and 'postglacial' (plus-varves) in Gerard De Geer's (1940) time scale. Since the postglacial time scale was elaborated in the Ångermanälven valley, a correlation between varve series from the two river valleys had to be done. On the whole, the old correlations have been verified, and the most likely equivalent to the zero year varve was found to be number 427 in Lidéns (1913) local, glacial varve chronology in the Ångermanälven valley. Recently this varve was proved to have been formed 7288 years B.C. (Cato 1987).

Varve measurements from more than 200 localities have been used for the present revision, and about 150 of these are recorded as graphs in the diagrams, Figs. 2, 8, 9, 13 and Pl. 8–20. In reality, it is a new chronology for the deglaciation between Stockholm and Sundsvall. Most of the measurements were made on clay samples taken by a simple, handworked devise (Strömberg 1983). Thin varves – microvarves – were measured under a binocular lens on a measuring table with a counter. Throughout, to the north of Gävle microvarved clays dominate; such varve series are difficult to correlate, but this is facilitated by stratigraphic marks such as the 'spot zone' – a concentration of limestone fragments – and 'drainage varves'. Varve series from the flat terrain to the north of Uppsala are easy to correlate, and in this area the earlier revision by Järnefors (1963) is reliable. In the fissure valley landscape to the south of Uppsala, local topographic influences on clay sedimentation and a 'symmict' character of the clay make correlation between varve series difficult, even when the distances between sampling sites are short. A great number of sites were necessary to obtain reliable correlations.

By comparing De Geer's (1940), Järnefors' (1963), and the new time scale, the main discrepances are as follows:

1. The revised part covers a deglaciation chronology from De Geer's ice recession line -1073, just to the south of Stockholm, to c. -360 in the Sundsvall area. The remaining 360 years on the minus-side of the time scale have also been checked. The -1073-line is now dated -1191, i.e. it was found to be 118 years older.

2. 19 of these 118 years extension of the time scale were reported by Järnefors (1963). Of the remaining 99 varve years, 64 are corrections north of Uppsala, 35 between Uppsala and Stockholm.

3. Locally, there are considerable discrepances between the old and new deglaciation chronology. One example is the chronological position of the 'spot zone' which was found to be 80–90 years younger than earlier thought. Thus the breaking up of an ice lobe in the southern Bothnian Sea by intense calving, which was the cause of spot zone formation, did not start until the main ice front receded over present land area just to the south of Söderhamn.

4. A margin of error for the 1191 varve years of the time scale has been estimated at ±25 years. For the period from the zero year up to 1950 A.D. – 9238 years – the maximum margin of error was estimated at +10, -180 calendar years (Cato 1987). The new time scale now contains 10 429 varve or calendar years from the recession line -1191 south of Stockholm, 8479 B.C., to 1950 A.D., with an estimated margin of error within +35, -205 years.

Generally, the ice recession rate was 200–300 m a year, but there were local deviations in the annual retreat from 50 to 1000 m. No oscillations have been detected, but small ones may be hidden behind the lower retreat values, and they cannot be revealed by varve measurements. The most complicated ice recession seems to have taken place when the ice lobe in the southern Bothnian Sea broke up during c. 100 years. During this time huge masses of calving icebergs drifted away and transported limestone fragments from the Ordovician bedrock of the sea bottom. The fragments were successively dropped, and deposited in the varved clay as a 'spot zone'.

Other complications are indicated by anomalous bottom varve datings. Thus too young dates were obtained when some or even tens of the proximal varves were missing, indicating sites which were protected from clay deposition by stranded icebergs and/or remaining frontal parts of the inland ice: dead ice masses. Occasionally, such dead ice remnants are not restricted to supraaquatic terrain, but were left behind the 'living ice' in subaquatic areas. According to varve data, this occurred most frequently outside the deep calving bays at the glaciofluvial drainage courses.

There is a notably good agreement between ice recession lines based on varve data – equicesses – and reconstructions based on the youngest glacial striae. Also local, deep calving bays which lasted for a comparatively short time, are registered by striae and varve data, but this data is often difficult to get close to the glaciofluvial eskers. Thus the presence of calving bays is probably underestimated in the reconstructions of ice recession on the maps, Fig. 6 and Pl. 1–7.

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TABLE 3

VARVE SERIES

Datings (negative values) issue from the zero year = 7288 B.C. (Cato 1987).

+ Proximal varves are missing.
c Uncertain dating of the bottom varve.
? Uncertain correlation.

B = R. Bergström 1968; LB = L. Brunnberg (unpubl.); DG = G. De Geer 1932, 1938, 1940;
F = B. Forssmark (unpubl.); J = B. Järnefors 1963; M = H. Möller 1962b;
N = M. Noël 1976; Ö = J. Öster 1943.

1) Strömberg 1965, 2) Strömberg 1971, 3) Möller 1962b, 4) G. De Geer 1940, 5) Järnefors 1963.
Co-ordinates in the national Swedish grid.

	Plate/Fig (F)					
Site	Map	Graph	Year	Location	Co-ordinates	
V-1 SW Ängstorp	2	1)	-973	350 m SW Ängstorp	66353	15891
V-8 S Källberga	2	1)	-965	200 m S Källberga	66365	15888
V-11 Åltomtabro	2	19	-954	100 m E Åltomtabro	66387	15881
27 Finnsta	2	19	-954	300 m NW Finnsta	66397	15908
28 Mellanbo	2	19	-954	50 m N Mellanbo	66402	15939
29 Broby	2	19	-951	1.2 km S Broby	66419	15972
30 Bergsbrunna	2	14	-983	400 m SE Bergsbrunna stn	66340	16080
31 Säby	2	19	-976	600 m NNW Säby	66378	16070
32 Kumla	2	19	-970	500 m NE Kumla	66384	16082
33 Vaksala tegelbruk	2	20	-964	1.6 km NW Vaksala k:a	66422	16044
34 Berget	2	19	-958	350 m SE Berget	66428	16037
35 Eke	2	19	-957	400m SE Eke	66427	16058
36 Funbo	2	20	-957	600 m E Funbo k:a	66391	16155
37 Brunnby	2	20	-957	100 m NE Brunnby	66392	16120
38 Bred	2	20	-956	150 m NNE Bred	66390	16170
41 Halmby	2	20	-953	250 m W Halmby	66411	16119
42 Halmbyboda	2	20	-951	200 m W Halmbyboda	66421	16105
44 Östanå	2	20	-906	300 m ESE Östanå	66498	16319
45 Abrahamstorp	2	20	-901	250 m SW Abrahamstorp	66498	16245
46 Östersursta	2	20	-891	1.4 km SE Faringe k:a	66528	16331
– Lina (DG Sl. 2)	1	F8	-1232	300 m S Lina gård	65672	16027
118 Bredängen	1	F8	-1208+	1.5 km ESE Viksberg	65708	16048
119 Älby	1	F8	-1191	250 m SSE Älby	65746	16088
– Lovön (N)	1	F8	-1179	650 m SSE Lovö k:a	65790	16161
– Tantolunden (DG)	1	F8	-1174	500 m SE Högalids k:a	65791	16274
– Drottningholm (LB)	1	F8	-1167	1.8 km NW Drottningh. slott	65814	16178
– DG A	1	8	–	200 m SE Djurgårdsbrunn	65810	16325
– DG B	1	8	-1163	300 m SE Djurgårdsbrunn	65810	16326
– Odenplan (DG)	1	F8	-1162	200 m E Gustav Vasa k:a	65824	16283
– Nora (DG)	1	–	-1159?	700 m SSW Nora	65850	16048
120a Kaknäs a	1	8	-1159	350 m SE Kaknästornet	65814	16324
120b Kaknäs b	1	8	-1159	350 m SE Kaknästornet	65814	16324
121 Nälsta	1	9	-1154	1.1 km NE Vällingby k:a	65848	16184

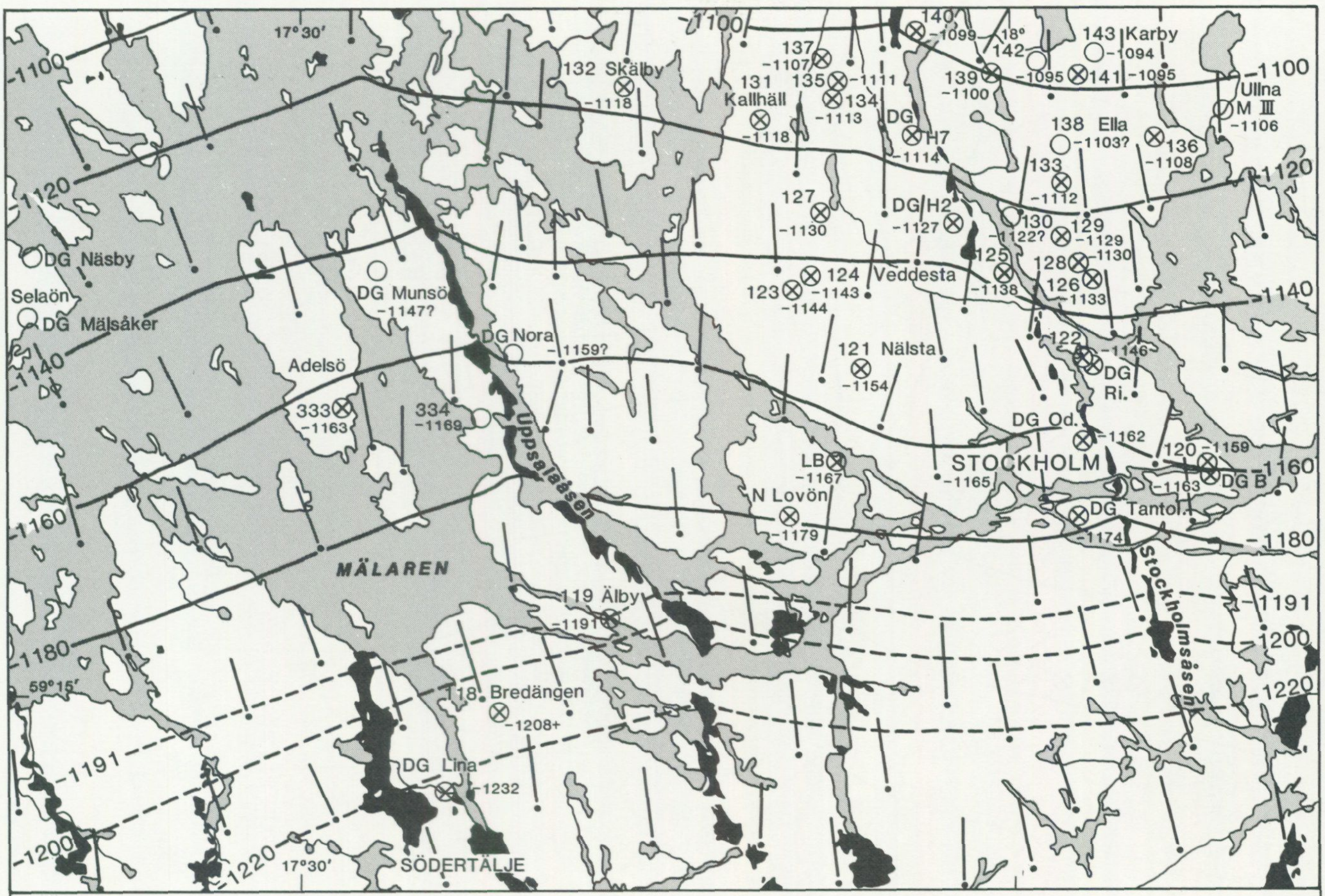
	Plate/Fig (F)					
Site	Map	Graph	Year	Location	Co-ordinates	
– Munsö (DG)	1	–	-1147?	Väsby, W Munsö k:a	65882	15992
– DG Ri.	1	8	-1138+	Riksmuseet	65852	16278
122a Bergianska tr. a	1	8	-1146	350 m WNW Riksmuseet	65853	16275
122b Bergianska tr. b	1	8	-1146	350 m WNW Riksmuseet	65853	16275
123 Barkarby	1	9	-1144	2.3 km SW Järfälla k:a	65879	16155
124 Veddesta	1	10	-1143	1.4 km SW Järfälla k:a	65885	16163
125 Sörentorp	1	11	-1138	600 m NW Sörentorp	65889	16237
126 Djursholm	1	8	-1133	250 m WNW Dj. Ösby stn	65887	16278
127 Säby	1	9	-1130	350 m SW Säby gård	65911	16163
128 Danderyd	1	8	-1130	400 m ESE Danderyds k:a	65893	16271
129 Danderyds h.h.	1	8	-1129	600 m NW Danderyds k:a	65901	16265
– Kummelby; DG H2	1	10	-1127	1.3 km SSE Turebergs stn	65905	16221
130 Sätra	1	–	-1122?	100 m S Sätra gård	65910	16247
131 Kallhäll	1	10	-1118	800 m NE Kallhälls stn	65947	16141
132 Skälby	1	10	-1118	2 km SW Kungsängens k:a	65957	16086
– Pommern; DG H7:4	1	10	-1114	1.8 km S Sollentuna k:a	65942	16202
133 Enebyberg	1	8	-1112	200 m E Enebybergs gård	65925	16263
134a Fäboda a	1	10	-1111	150 m ESE Fäboda	65955	16171
134b Fäboda b	1	11	-1113	150 m ESE Fäboda	65955	16171
135 Mulltorp	1	10	-1111	100 m W Mulltorp	65962	16172
136 Viggbyholm	1	8	-1108	500 m W Viggbyholms stn	65942	16296
137a Klubbacken a	1	9	-1107	200 m N Klubbacken	65972	16164
137b Klubbacken b	1	11	-1108	200 m N Klubbacken	65972	16164
– Ullna III (M)	1	3)	-1106	850 m SSW Ullna	65955	16328
138 Ella	1	–	-1103?	100 m NW Ella krog	65939	16264
139 Smedstorp	1	10	-1100	200 m NW Smedstorp	65966	16235
140 Rotsunda	1	9	-1099	1.5 km NE Rotebro stn	65981	16204
141 Lövbrunna	1	8	-1095	100 m S Lövbrunna gård	65965	16270
142 Hagby	1	–	-1095	350 m NW Hagby gård	65970	16253
143 Karby	1	–	-1094	200 m E Karby gård	65975	16275
144 Skålhamra	2	8	-1090	600 m SW Skålhamra	65993	16246
145 S. Harby	2	10	-1088	400 m E Borgby	65999	16229
146 Ed	2	11	-1087	500 m NE Ed k:a	66008	16172
147 Harva	2	9	-1086	150 m NE Harva gård	66012	16157
148 Runby	2	9	-1085	1.1 km NE Ed k:a	66013	16176
149 Harby	2	10	-1084	500 m NE Borgby	66003	16226
150 Smedby	2	–	-1083	500 m E Smedby	66013	16249
151 S. Fresta	2	10	-1083	700 m S Fresta k:a	66010	16217
152 Ekbacken	2	9	-1080	400 m NNE Fresta k:a	66021	16220
153 Gällsta	2	9	-1074	600 m W Gällsta	66030	16242
154 Grana	2	10	-1073	350 m S Grana	66037	16238
156 Hällsta	2	11	-1069	150 m S Hällsta	66046	16234
157 Vallentuna	2	8	-1068	1.2 km NNE Vallentuna k:a	66045	16296
158 Runsa	2	9	-1067	900 m SE Runsa	66053	16147
159a Lotteräng a	2	9	-1059	400 m NNE L. Mellösa	66065	16237
159b Lotteräng b	2	11	-1059	400 m NNE L. Mellösa	66065	16237
160 Krogsta	2	10	-1058	1.6 km W Norrsunda k:a	66099	16163
161 Veda	2	11	-1057	500 m W Veda	66073	16297
163a Sigtuna a	2	9	-1054	950 m WSW Sigtuna k:a	66121	16074
163b Sigtuna b	2	11	-1054	950 m WSW Sigtuna k:a	66121	16074
164 Sälna	2	9	-1053	300 m S Sälna	66075	16234
165 Valsta	2	13	-1049	1.7 km SW Märsta stn	66125	16149
166 Tullstugan	2	13	-1042	50 m NE Tullstugan	66141	16131
167 Tadem	2	12	-1042	600 m SSW Tadem	66110	16228

Site	Plate/Fig (F)		Year	Location	Co-ordinates	
	Map	Graph				
168 Kimsta	2	12	-1040	250 m SE Kimsta	66121	16236
169 S. Arlanda	2	12	-1038	350 m ESE Tomta	66144	16186
170 Lövstaholm	2	–	-1032?	750 m NNE Lövstaholm	66174	16096
171 Herresta	2	13	-1030	300 m W Herresta	66165	16147
172a Arlanda a	2	12	-1030	250 m E Kolstatorp	66150	16196
172b Arlanda b	2	12	-1030	250 m E Kolstatorp	66150	16196
173 Långeken	2	12	-1021	100 m N Långeken	66183	16180
174 Hemtorpet	2	12	-1019	100 m W Hemtorpet	66187	16181
175 Forsby	2	13	-1017	400 m W Forsby	66200	16126
176 Söderby	2	14	-1015	300 m SE Söderby	66194	16178
– Kråklund; DG K 4	2	4)	-1013	1.5 km SSE Knivsta k:a	66215	16128
177 L. Rickeby	2	13	-1011	250 m NE L Rickeby	66210	16182
178 Lundby	2	12	-1011	150 m ENE Lundby	66208	16188
179 Knivsta	2	13	-1010	400 m SSE Knivsta k:a	66226	16123
180 Svanängen	2	13	-1010	400 m E Svanängen	66233	16091
181 NW Lundby	2	12	-1009	450 m NW Lundby	66212	16185
– Knivsta; DG K 6	2	4)	-1006?	Knivsta stn	66245	16115
183 Hagelstena	2	13	-1004	500 m SE Hagelstena	66255	16097
184 Ockelsta	2	–	-1004	400 m NE Ockelsta	66221	16277
– Gredelby; DG K 7	2	4)	-1004	300 m W Gredelby	66255	16111
– DG K9	2	4)	-1003	400 m N Knivsta stn	66249	16115
– Trunsta; DG K 8	2	4)	-1002	Trunsta	66259	16108
185 Timmerbol	2	12	-1000	250 m W Timmerbol	66242	16170
186 Vidbo k:a	2	–	-1000	250 m NE Vidbo k:a	66234	16240
187 Vidbo	2	13	-997+	400 m WSW Vidbo k:a	66232	16234
189 Ledinge	2	13	-996	550 m SSW Ledinge	66250	16151
190 Brunnby	2	14	-996	350 m S Brunnby	66263	16134
191 Vrå	2	14	-995	650 m S Alsike stn	66274	16113
192 Valloxsäby	2	–	-992?	600 m W Valloxsäby	66267	16142
193 Dalbo	2	14	-990	200 m SE Dalbo	66284	16120
194 Eggebyholm	2	–	-989	600 m ENE Eggebyholm	66277	16165
195 N. Alsike	2	14	-989	1 km NNE Alsike stn	66291	16103
– Söderby; DG L 7	2	4)	-988	600 m SSW St Söderby	66327	16089
196 Hälleby	2	–	-987	250 m N Hälleby	66292	16187
197 Högantorp	2	13	-984	650 m NW Eggebyholm	66278	16154
198 Moralund	2	14	-976+	400 m NE Moralund	66306	16111
– DG Up. 25	2	F9	-976	300 m SE Bergsbrunna stn	66342	16080
– Bergsbrunna; J 7	2	F9	-978	800 m E Bergsbrunna stn	66342	16085
199 Olunda	2	14	-983	400 m NNE Olunda	66302	16147
200 Norrby	2	–	-978	500 m N Norrby	66340	16121
201 Lövsta	2	–	-972?	150 m NE Lövsta	66367	16122
– Högsta; J 3	2	15	-912	300 m W Högsta	66517	15981
– Tärnsjö; J 72	3	5)	-858	2 km NE Nora k:a	66724	15635
202 Lakbäck	3	15	-849	250 m S Ö. Lakbäck	66735	15658
203 Tärnsjö	3	15	-848	3 km NE Nora k:a	66728	15643
– Buckarby (LB)	3	15	-846	1 km SSW Buckarby	66750	15667
204a Buckarby a	3	15	-831	500 m SE Buckarby	66755	15675
204b Buckarby b	3	15	-806+	500 m SE Buckarby	66755	15675
– Mälby; J 73	3	15	-828	1 km SE Mälby	66820	15646
205 Backa	3	15	-825	400 m NW Backa	66743	15717
206 Horsskog	3	15	-816	300 m NE Horsskog bygdeg.	66793	15722
– Hedesunda; J 75	3	16	-801	800 m SW Hedesunda k:a	66956	15654
207 Gnupen	3	16	-799	400 m SE Sevedskvarn	66835	15617
– Tierp; DG Up. 34	3	15	-796	Halls, 2 km NW Tierp k:a	66895	15909

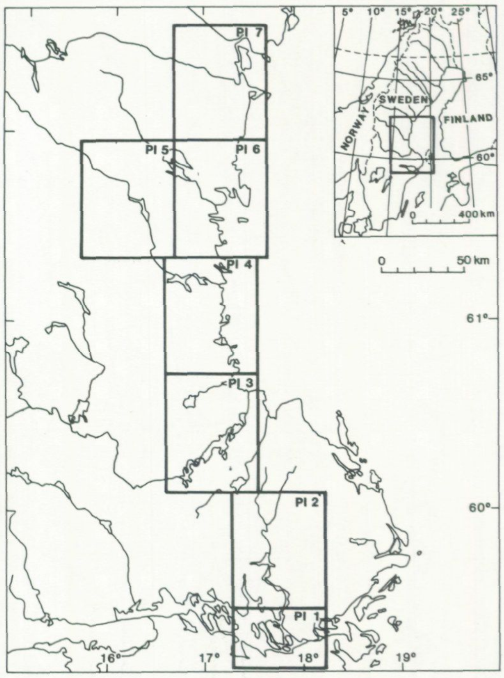
	Plate/Fig (F)					
Site	Map	Graph	Year	Location	Co-ordinates	
208 Balsta	3	16	-783	100 m E Balsta	66902	15531
– Smedsbo; J 39	3	15	-783	300 m SE Smedsbo	66916	15888
209 Gysinge	3	16	-780	2 km NNE Gysinge skola	66878	15608
– Jössäng; J 76	3	16	-776	1 km NE Jössäng	67017	15640
210 Vista	3	16	-769	200 m NNW Vista	66908	15519
211 Ölbosjön	3	–	-762?	2.1 km NNE Ölbo	67024	15691
212 Stav	3	16	-761	550 m ESE Östanhede	67076	15630
213 Litens	3	16	-760	300 m SW Litens	67084	15489
214a S. Byn a	3	16	-756	1.2 km SE Byn	66955	15577
214b S. Byn b	3	15	-756	1.2 km SE Byn	66955	15577
215 Västanhede	3	16	-756	500 m ENE Västanhede	66979	15464
216 Byn	3	16	-752	1 km NNE Byn	66973	15573
217 Ysjön	3	–	-743?	900 m ESE Björnmyra	67053	15586
218 Lingbo	3	16	-735+	500 m WNW Lingbo	67063	15483
219 Jordåsen	3	–	-735?	400 m SSW Jordåsen	67149	15682
– DG Up. 40	3	15	-710c	Kungsgården, W of the river	67193	16900
220a Ginborn a	3	16	-706	800 m SSE Ginborn	67179	15465
220b Ginborn b	3	15	-706	800 m SSE Ginborn	67179	15465
221 Säveränge (F)	3	15	-692	150 m N Säveränge	67353	15554
222 Strömsbro	3	15	-692	900 m SE Strömsbro k:a	67321	15748
223a Fäbodfjärden a	4	15	-685	500 m S Höstbodarna	67430	15548
223b Fäbodfjärden b	4	15	-677+	500 m S Höstbodarna	67430	15548
224 Björke	4	–	-680+	3.3 km NNE Hille k:a	67390	15764
– DG Gl. 6	4	15	-682	Råhällan	67450	15619
225 Slåttmuren	4	15	-668	150 m W Slåttmuren	67473	15510
– DG Gl. 7	4	4)	-667?	Kolforsen	66483	15568
226 Vansjön	4	–	-647?	3.4 km W Vittersjö	67517	15557
– Ockelbo; J 88	4	5)	-647c	1 km E Ockelbo k:a	67527	15505
227 Hamrånge	4	15	-617	1.6 km SSE Hamrånge k:a	67559	15675
228 Axmar	4	F13	-611	400 m SW Sälgbäcken	67645	15690
229 Mörtebo	4	F13	-607	100 m E Mörtebo	67627	15537
230 Granön	4	15	-602	150 m NE Hakvik	67751	15722
231 Maråker	4	F13	-586?	600 m NNW Maråker	67842	15717
235 Viksmyra (F)	4	15	-583	200 m W Viksmyra	67789	15493
236 Tönnånger	4	17	-579	100 m E Lake Norn	67781	15535
241 Forsbacka	4	17	-559	400 m ESE Fridsbacka	68002	15698
242 Verkmyra (F)	4	–	-556c	50 m E Verkmyra	67913	15553
243 Florskvarn (F)	4	–	-550c	350 m WNW Florskvarn	67974	15538
246 Svartvik (F)	6	–	-542c	200 m S Svartvik	68054	15669
248 Långvind	6	17	-528+	1.6 km SSW Långvinds bruk	68151	15692
253 Trönö	6	17	-520	1.1 km SSE Trönö gla k:a	68072	15578
258 Losjö	6	–	-519	400 m W Losjö	68128	15636
264 Rengsjö	5	17	-498	1.4 km SW Rengsjö k:a	68044	15418
265 Sivik	6	17	-490	1 km SW Sivik	68292	15651
266 Idenor	6	–	-444+	650 m SE Idenor k:a	68428	15699
275 Hede	6	17	-473	400 m NW Hede	68486	15662
281 Steg	6	–	-443+	400 m SE Steg	68586	15729
283 Masksjön	6	–	-471	1.2 km NW Masksjöberget	68629	15730
286 Forsa (F)	6	–	-462	2 km ESE Forsa k:a	68463	15618
287 Harmånger	6	18	-456	500 m SW Harmånger k:a	68685	15742
– Milsbro; Ö 4	7	F16	-447	400 m E Milsbro	68814	15808
289 Björkön	7	18	-445	5 km W Lörudden kap.	69036	15910
295 Torpen	7	–	-423+	50 m N Torpen	68903	15850
– Åckne; Ö 6	7	F16	-434	1.7 km NNE Gnarp k:a	68840	15764

	Plate/Fig (F)					
Site	Map	Graph	Year	Location	Co-ordinates	
– Ö 10	7	F16	-433	6.5 km WNW Gnarp k:a	68848	15697
300 Stene (F)	5	17	-431	700 m SE Järvsö k:a	68434	15203
301 Galtström	7	18	-424+	800 m NNW Galtström k:a	68965	15876
302 N. Galtström	7	F2	-423+	1 km N Galtström k:a	68967	15878
309 Delsbo (F)	5	17	-412	750 m S Delsbo k:a	68550	15403
310 Njurunda	7	F2	-406	1.3 km S Njurunda k:a	69047	15815
311 Ulvberg (F)	7	18	-406	1.3 km S Njurunda k:a	69047	15815
312 Gårdsjön	7	–	-388	800 m NW Gårdsjötorp	68916	15738
313a Alnön a	7	18	-390	700 m SW Stornäset	69276	15858
313b Alnön b	7	F2	-390	700 m SW Stornäset	69276	15858
314 Alnön, myren	7	–	-390	2.4 km SE Alnö k:a	69258	15845
318 Ljusdal (F)	5	17	-363	1.2 km ENE Ljusdal k:a	68573	15153
319 Färila (F)	5	17	-359	200 m NE Färila k:a	68543	15024
– Indal; J 110	7	18	-357	200 m S Indal k:a	69408	15663
– Indal (DG)	7	18	-355+	?	?	?
– Ava; B 4	–	17	-345	1.2 km SW Ava	70481	16754
320 Attmar	7	18	-333?	400 m SSW Attmar k:a	69114	15647
321 Hassela	7	18	-318?	750 m SE Hassela k:a	68884	15477
– Flärke; B 2	–	17	-283	100 m N Flärke	70562	16599
322 Håbo-Tibble	2	–	-1065	600 m W Håbo-Tibble k:a	66092	16042
323 Vretaudd	2	F14	-1015?	300 m N Vretaudd	66283	16006
324 Kyrkviken	2	F14	-1011	950 m S Alsike k:a	66242	16057
325 Krusenberg	2	F14	-1009	350 m NW Krusenberg	66257	16034
326 Fredrikslund	2	F14	-1004?	1 km S Fredrikslund	66277	16031
327 Skarholmen	2	F14	-1004?	1.9 km ESE Uppsala-Näs k:a	66309	16024
328 Ekolnäs	2	F14	-1001?	1.5 km ENE Uppsala-Näs k:a	66314	16019
329 Dalkarlskärret	2	F14	-1001?	1.4 km SSW Uppsala-Näs k:a	66298	16000
330 Nåntuna	2	F14	-992?	750 m E Nåntuna	66342	16060
331 Gåvastbo	3	–	-839	1.7 km W Gåvastbo	66749	15681
332 Skoby	2	–	-863	1 km NE Skoby	66593	16245
333 Adelsö	1	F8	-1163	800 m SW Adelsö k:a	65827	15978
334 Kärsösund	1	–	-1169	150 m S Kärsösund	65826	16034

Plate 1



LEGEND, PLATE 1–7



Scale
0 5 10 km

▮ Glaciofluvial esker

\ Youngest glacial striae

121 ⊗ -1154 Varve measuring site 121 (see Table 3); bottom varve dated −1154 years before zero (±0 = 7288 B.C.; Cato 1987). Graph: see Plate 8–20.

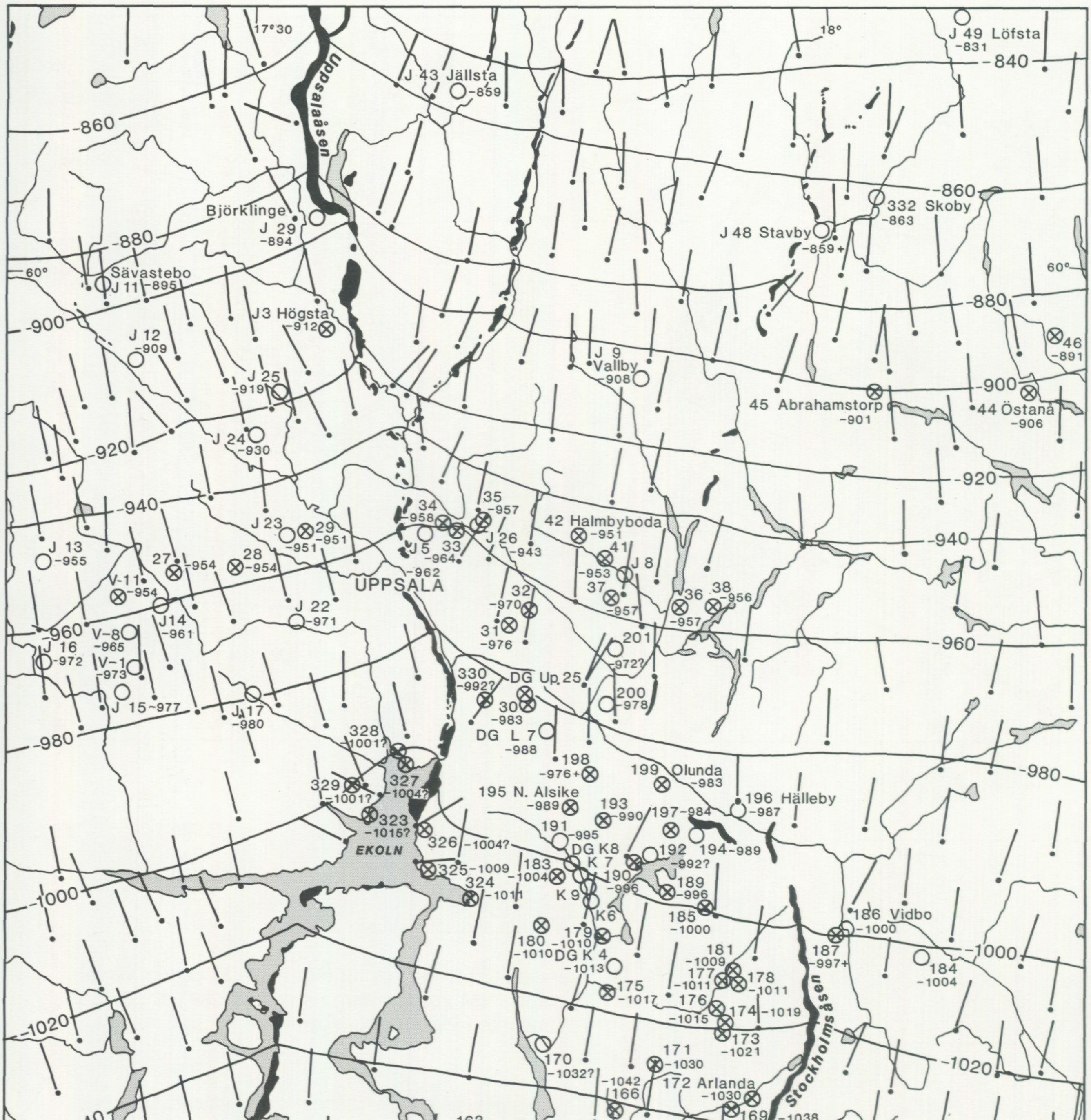
DG ○ -1147? Varve measuring site; graph not reproduced. DG, J etc, see Table 3. c; ? = uncertain dating. + = remaining proximal varves.

-1180 —— Ice recession line according to varve data and youngest striae.

-1191 - - - Broken line: uncertain position.

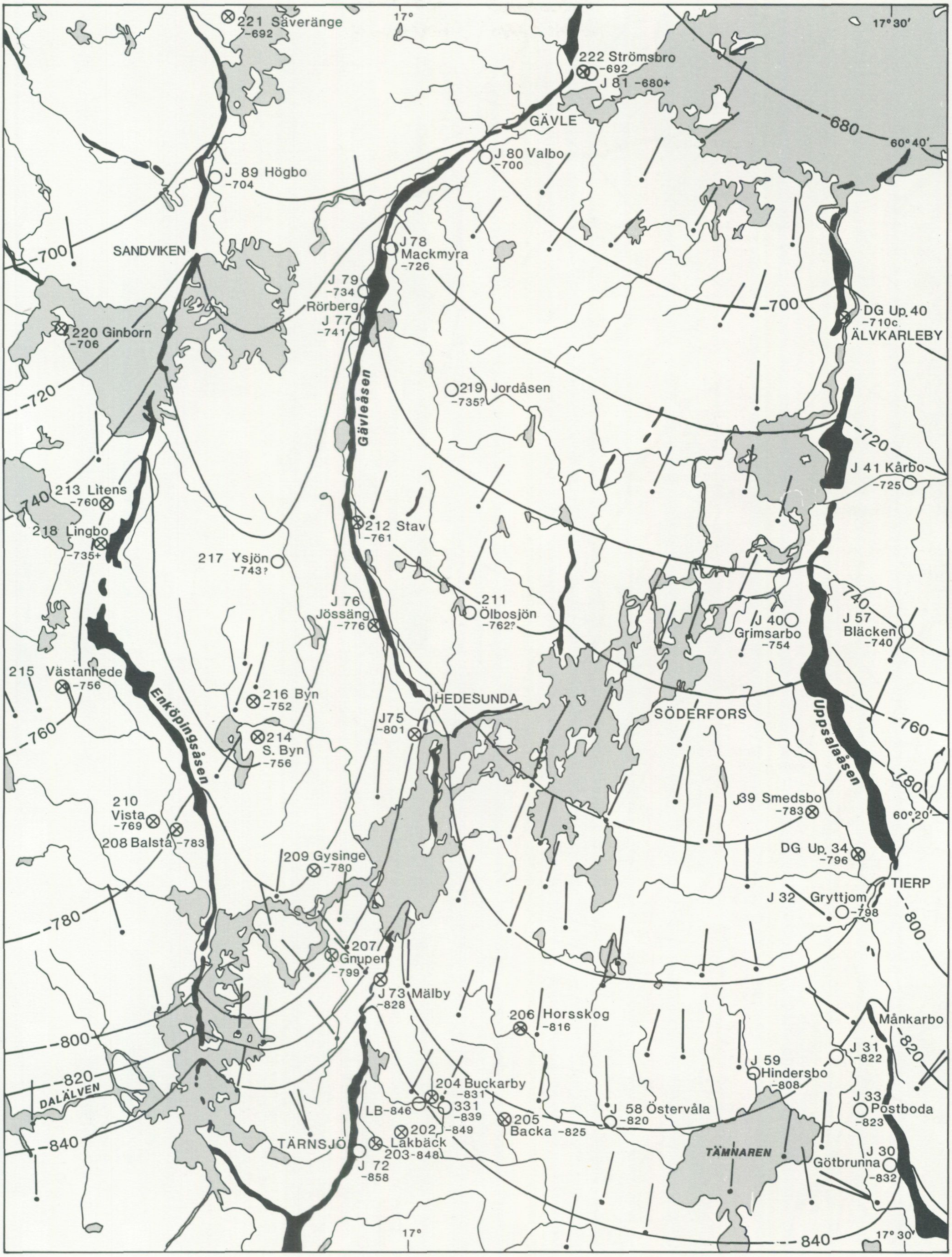
Eskers and most striae observations according to the geological maps.
Additional striae information from Karin Grånäs' (Pl. 2 and 3), Martin Sundh's (Pl. 4), and my observations.

Plate 2



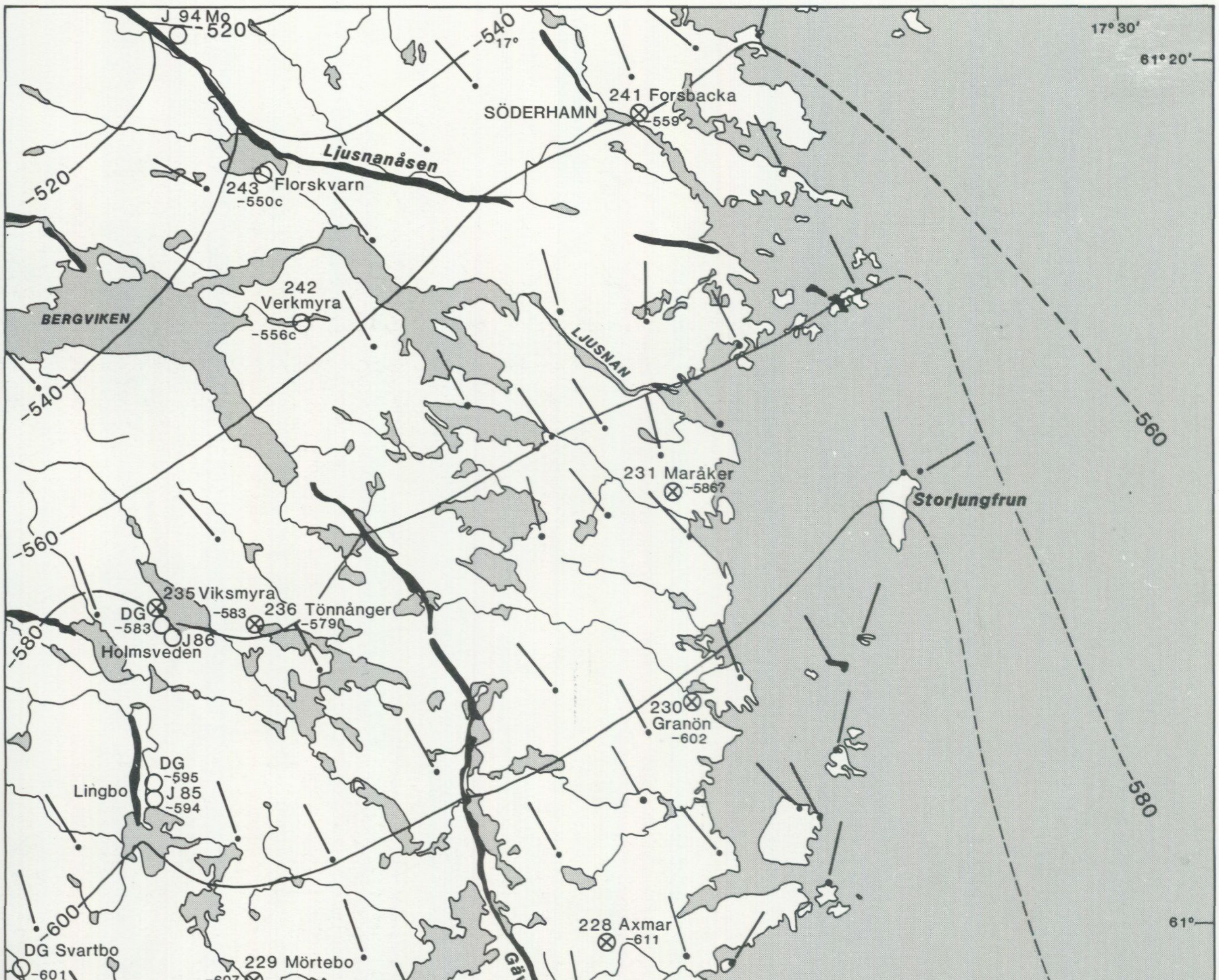
Scale 1:300 000. Legend: see Pl. 1.

Plate 3



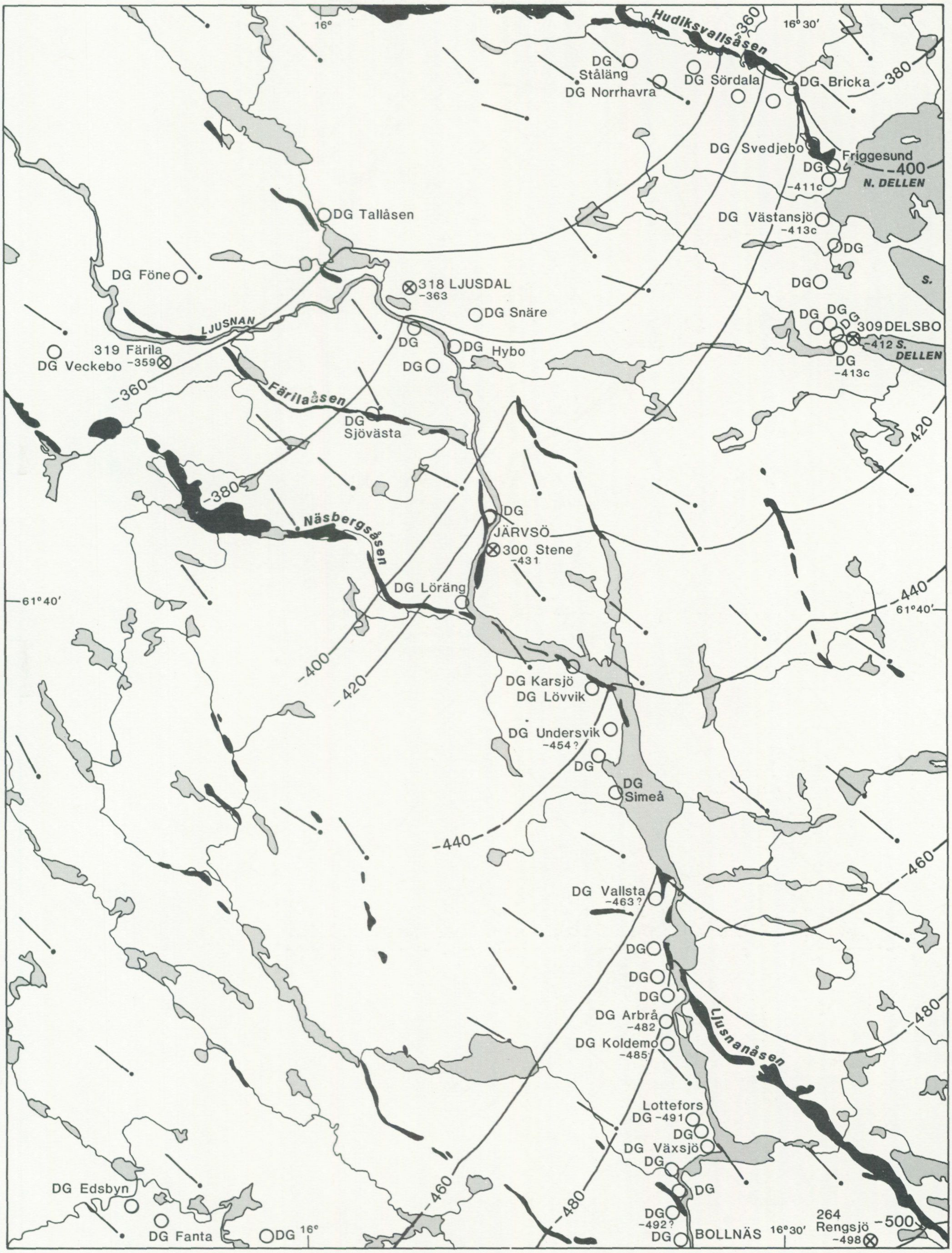
Scale 1:300 000. Legend: see Pl. 1

Plate 4



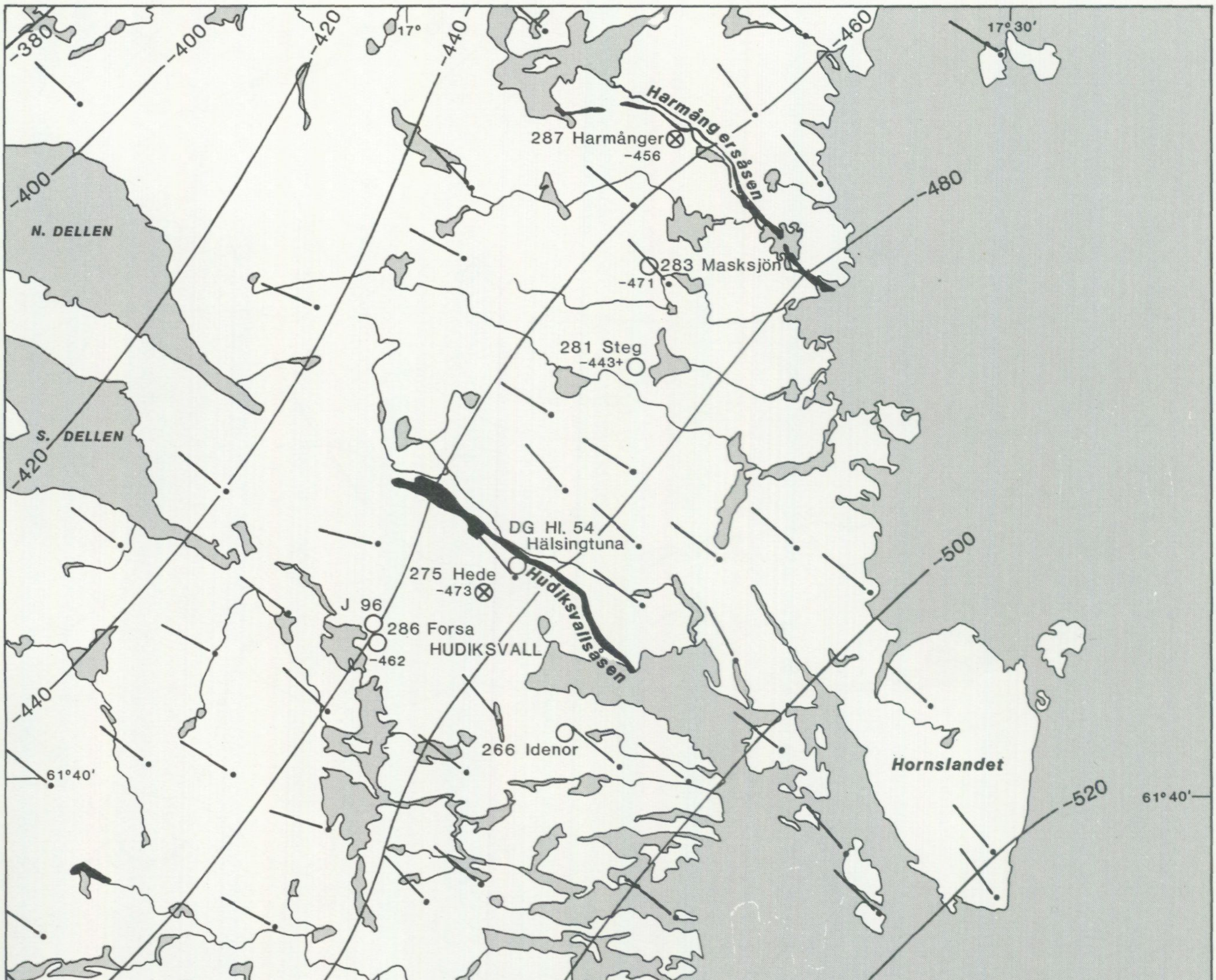
Scale 1:300 000. Legend: see Pl. 1.

Plate 5



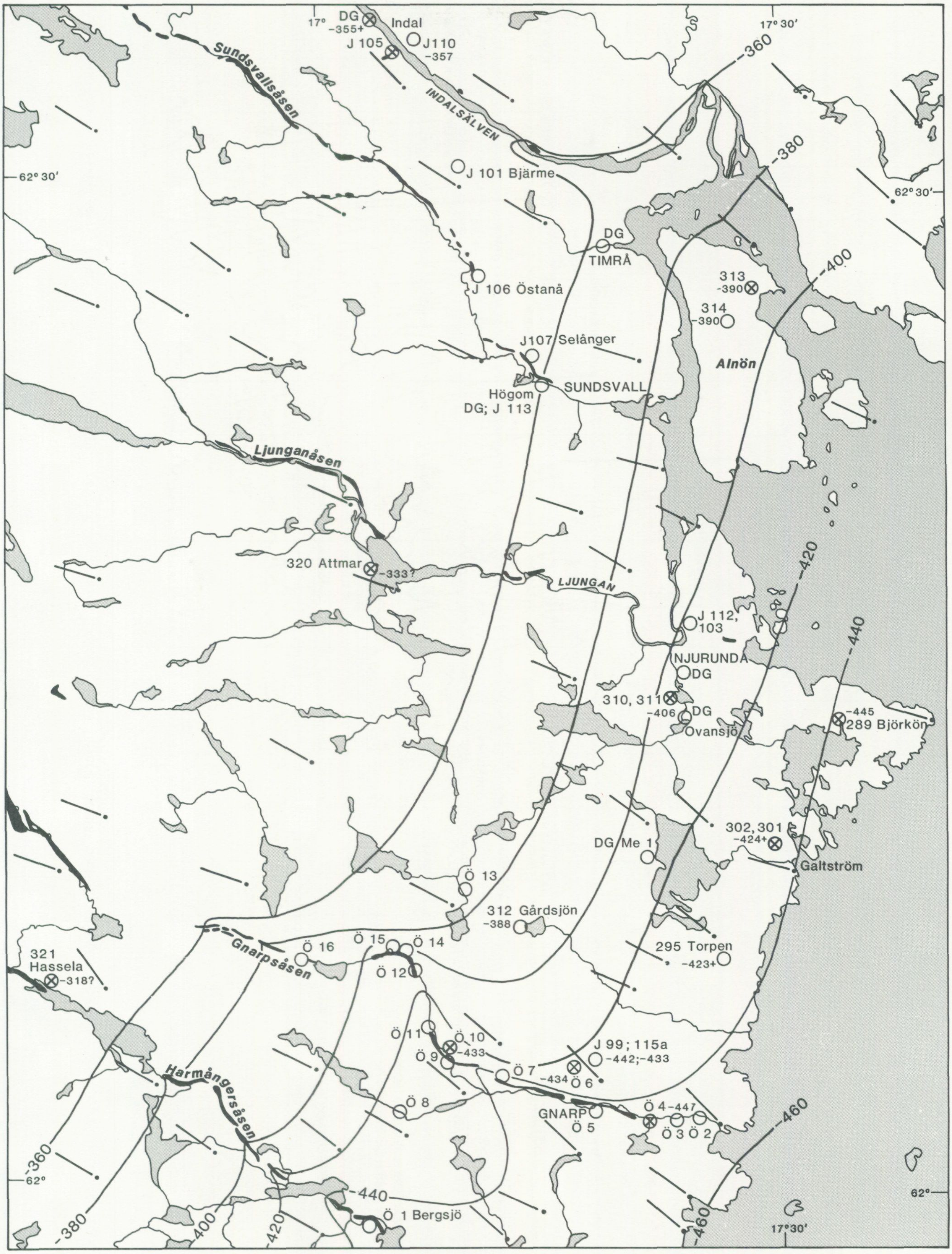
Scale 1:300 000. Legend: see Pl. 1.

Plate 6



Scale 1:300 000. Legend: see Pl. 1.

Plate 7



Scale 1: 300 000. Legend: see Pl. 1.

LEGEND, PLATE 8–20

Pl. 8–14, 19–20: 100 — 50 — 0

Pl. 15–18: 50 — 25 — 0

Varve thickness, mm

$\frac{1}{2}$ = 50% reduction,

$\frac{5}{1}$ = 500% magnification.

157, DG, J etc, see Pl. 1–7 and Table 3.

▹	Till bottom
+400	Remaining clay, mm
320	Varve thickness, mm
?	Uncertain varve
←	Indistinct varve limits
○▽△	Spot zone
s	Silt
----	Varves counted, not measured

Upper time scale: years before zero (±0 = 7288 B.C.; Cato 1987).

Lower time scale: years B.C. Upper time scale in Pl. 19–20 according to Järnefors 1963.

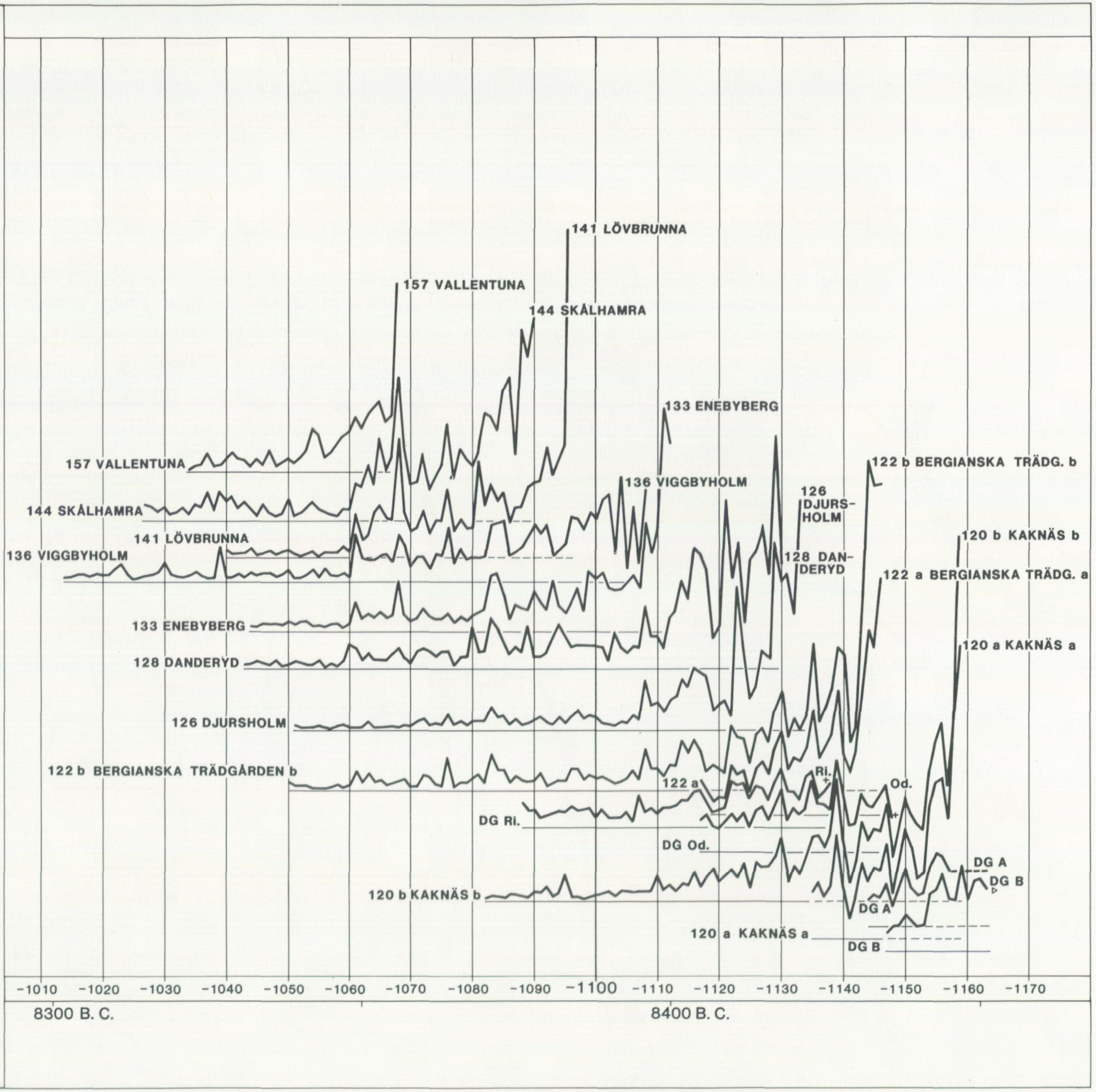
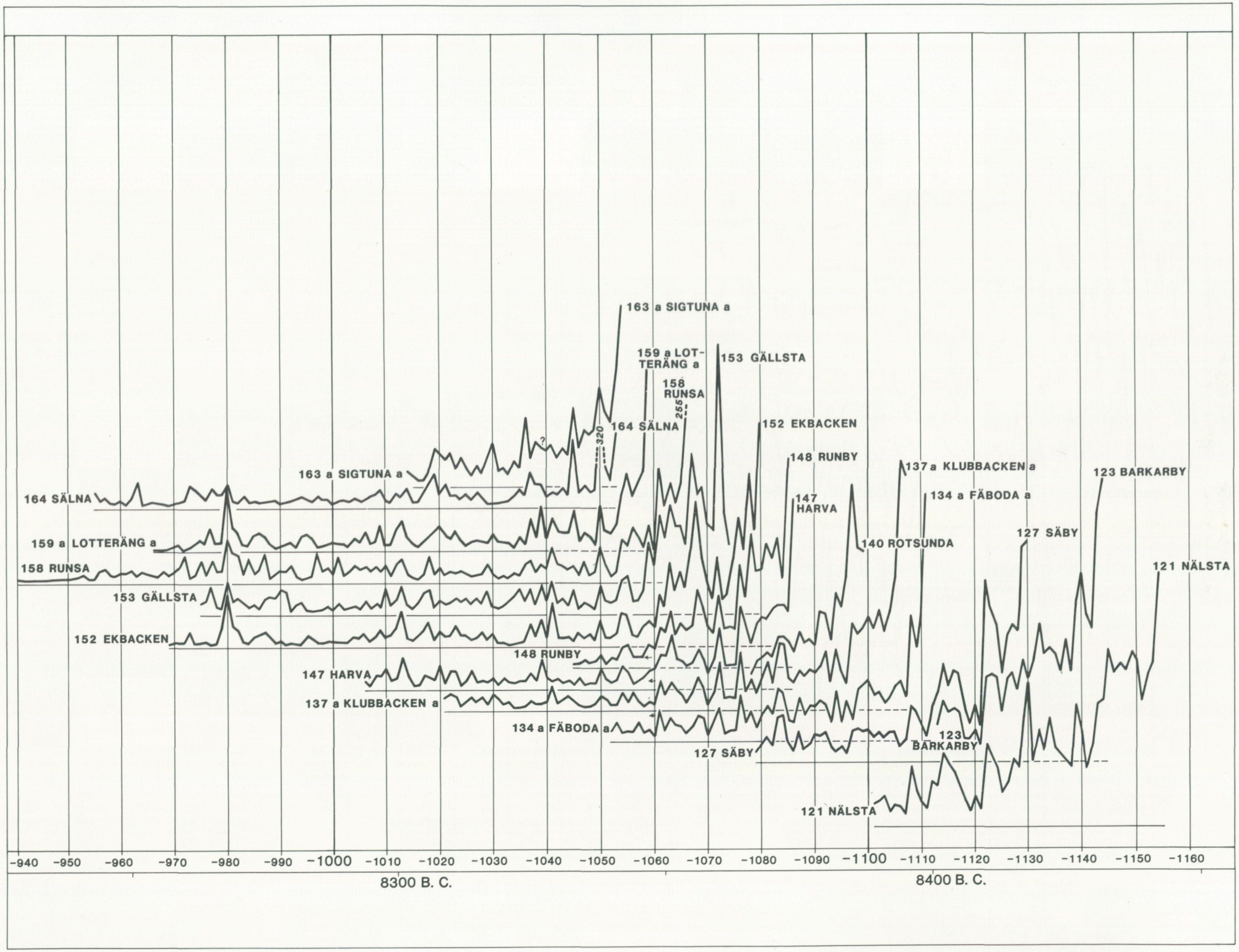
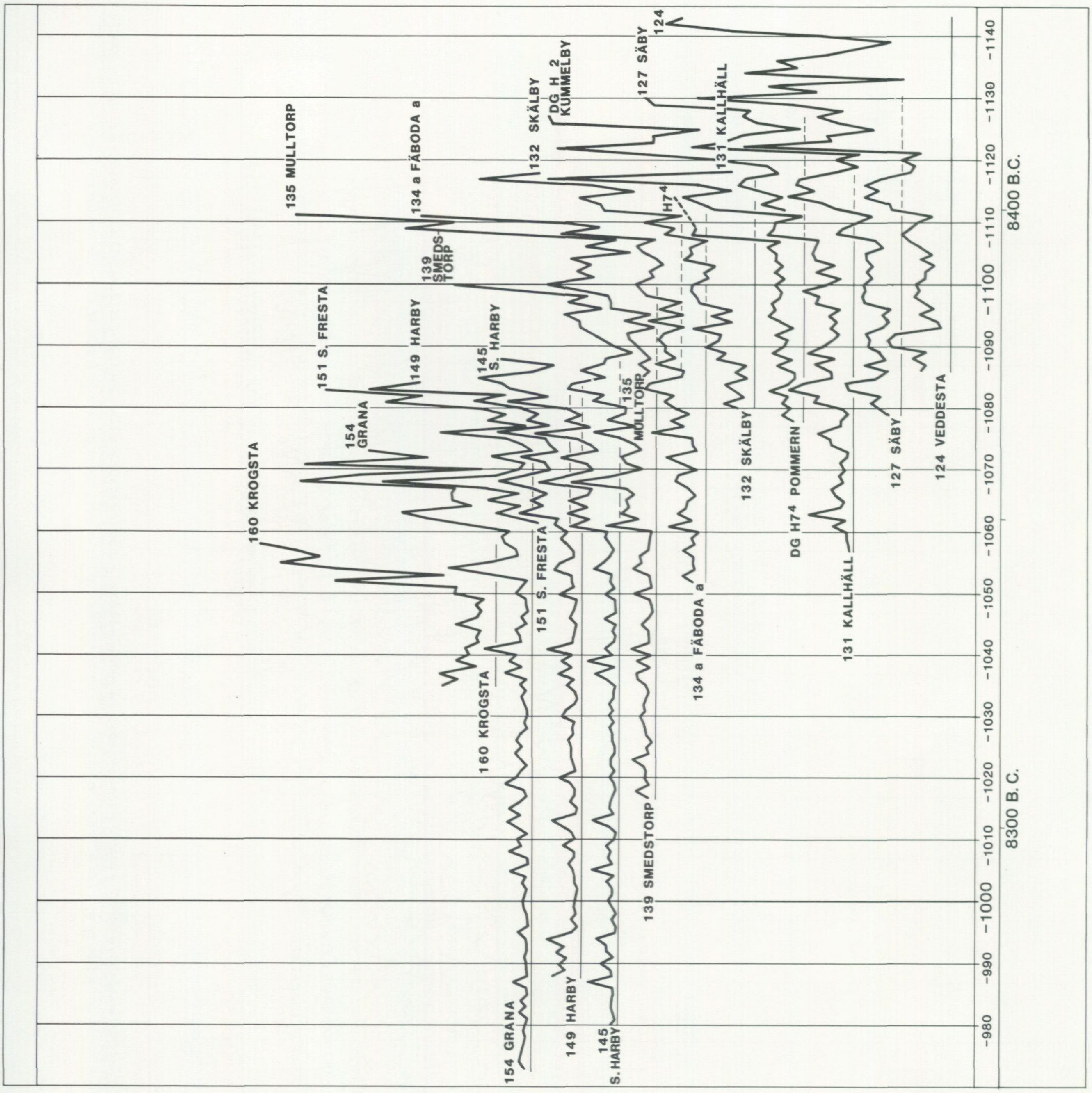


Plate 9



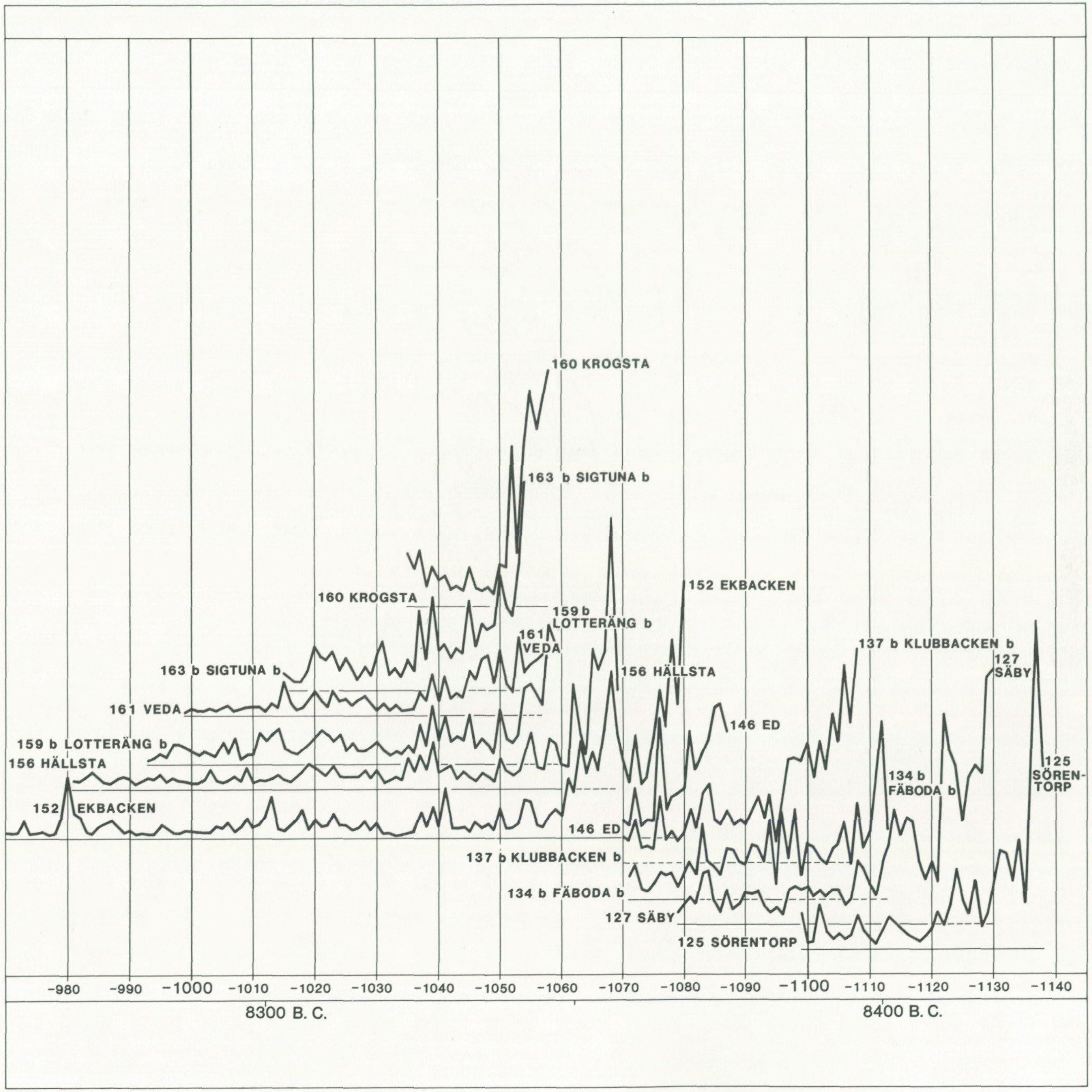
Legend: see Pl. 8.

Plate 10



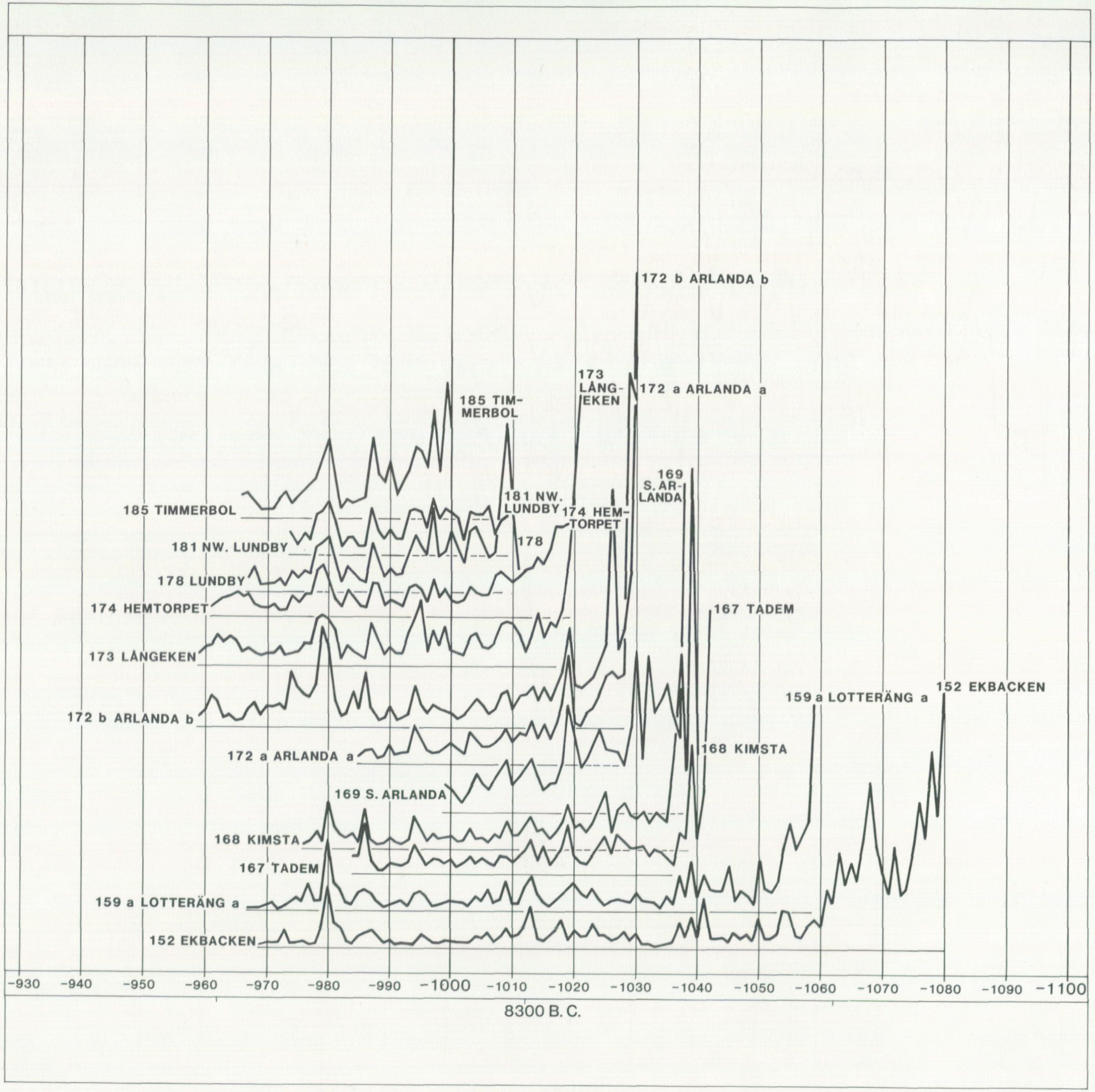
Legend: see Pl. 8.

Plate 11



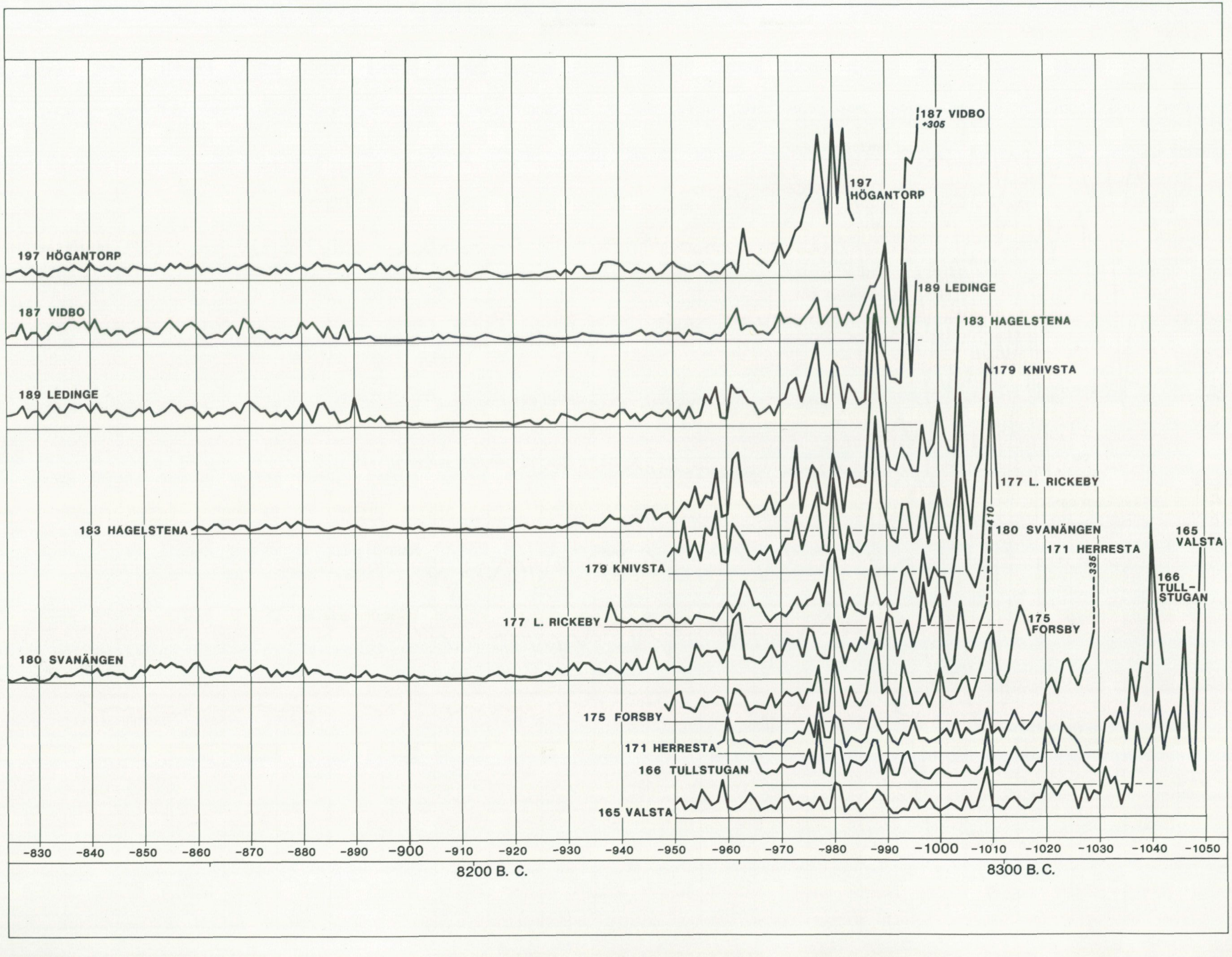
Legend: see Pl. 8.

Plate 12



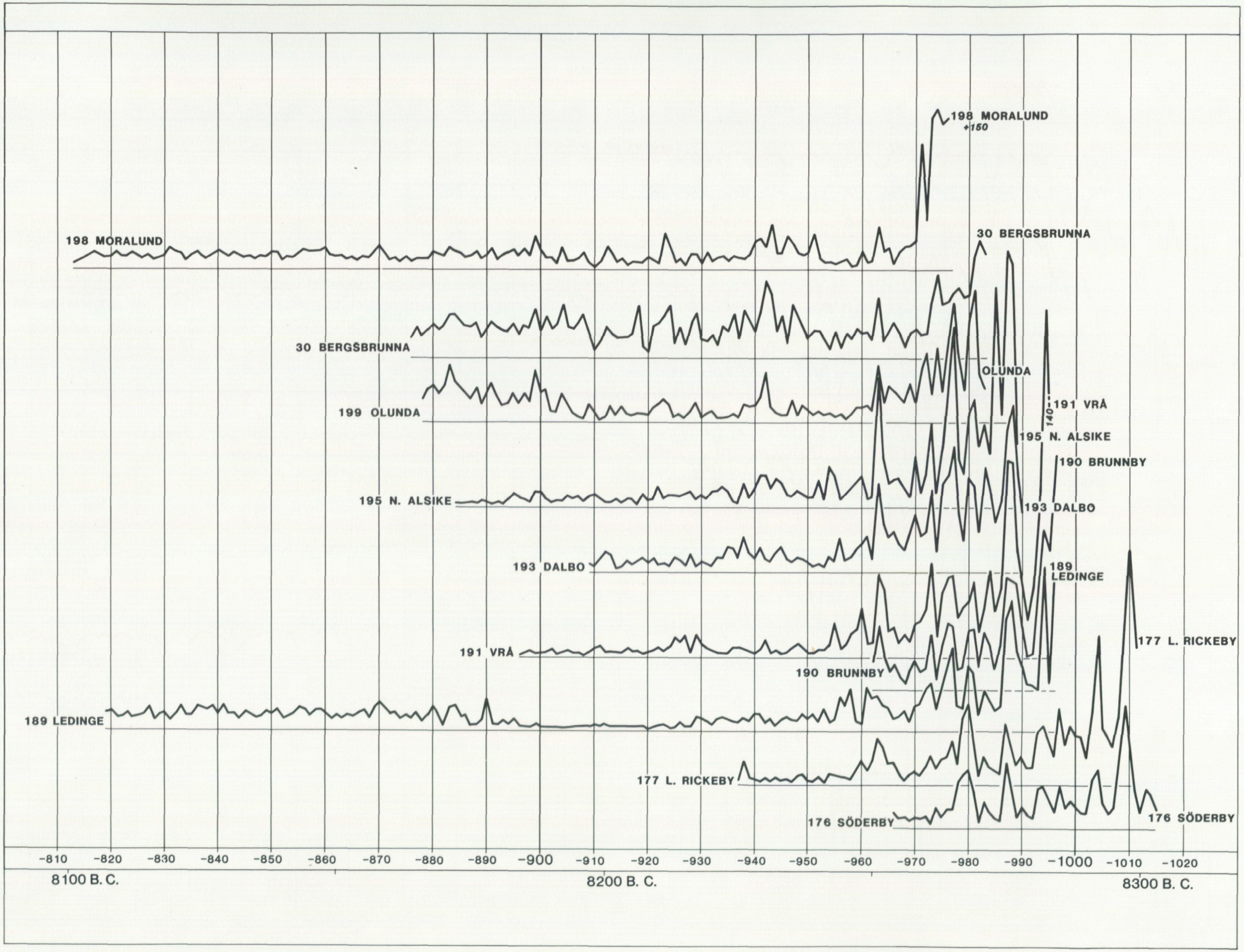
Legend: see Pl. 8.

Plate 13



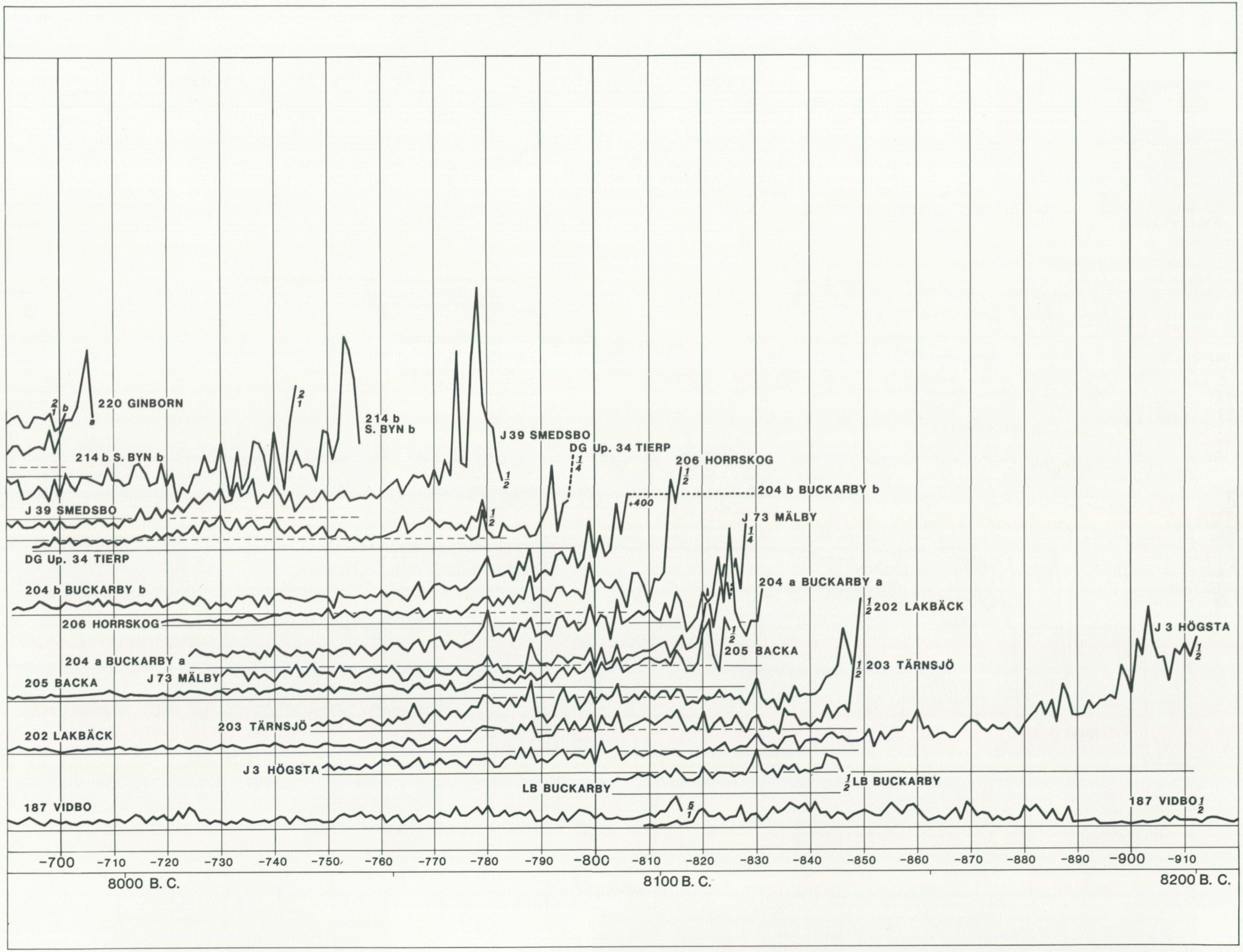
Legend: see Pl. 8.

Plate 14



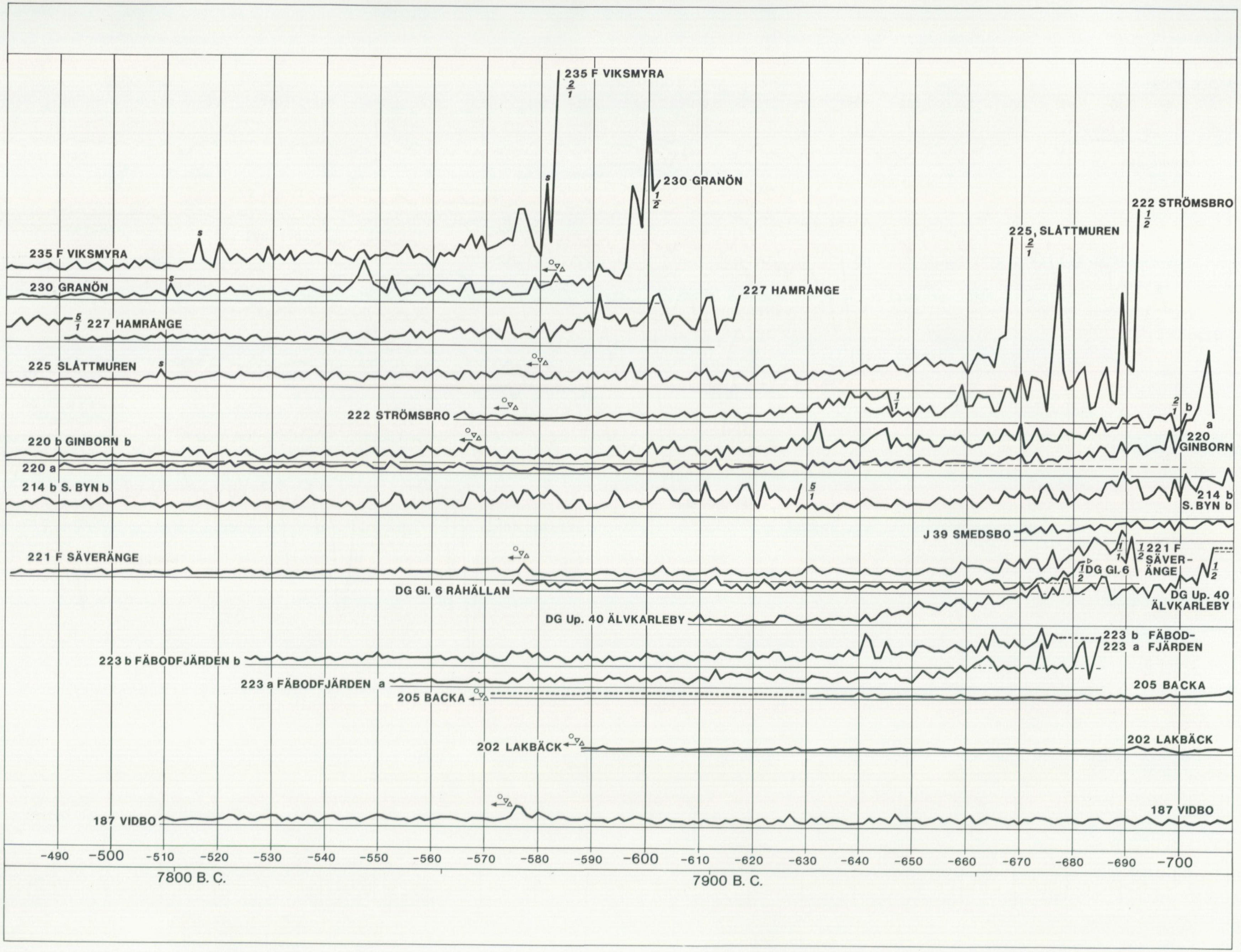
Legend: see Pl. 8.

Plate 15a



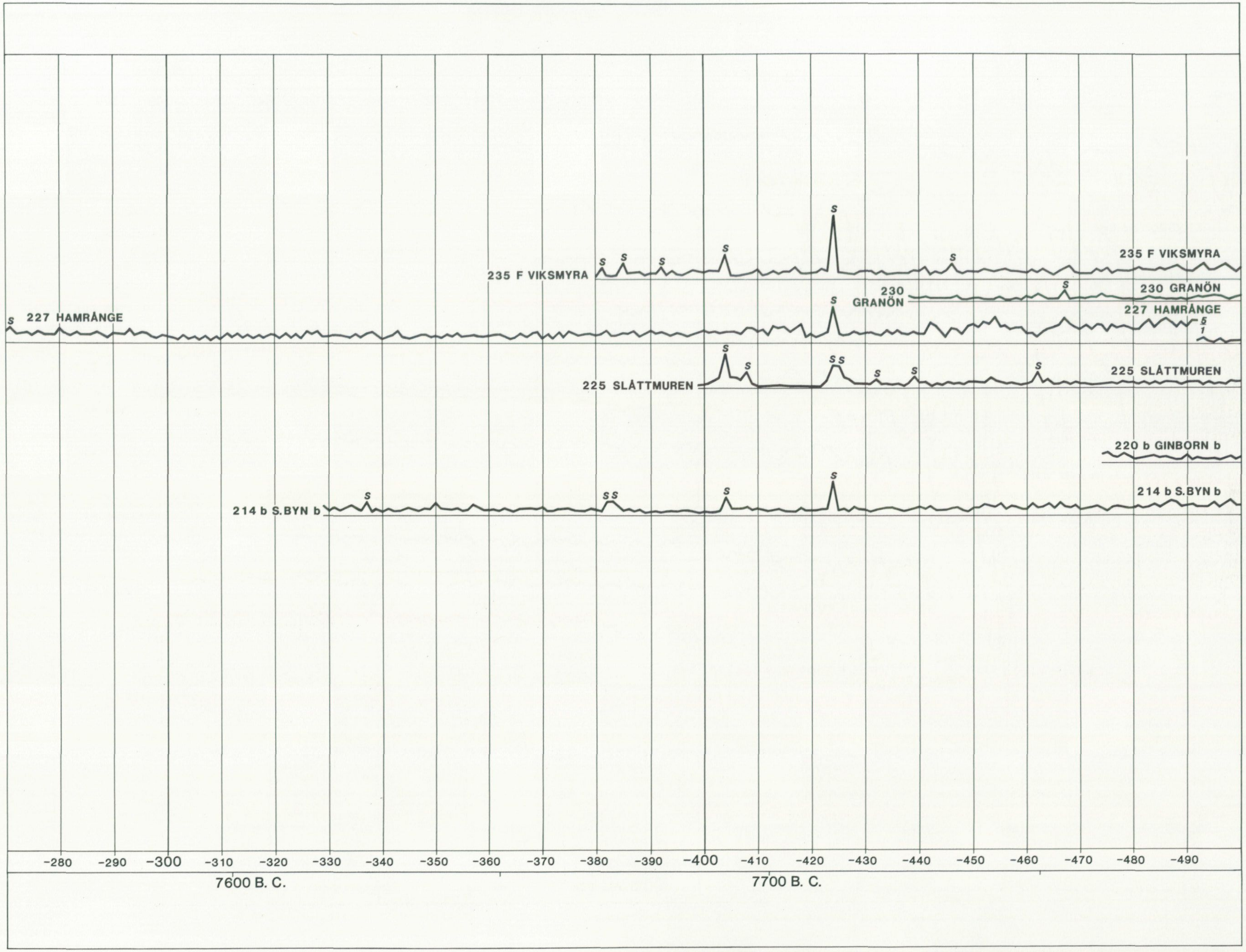
Legend: see Pl. 8.

Plate 15b



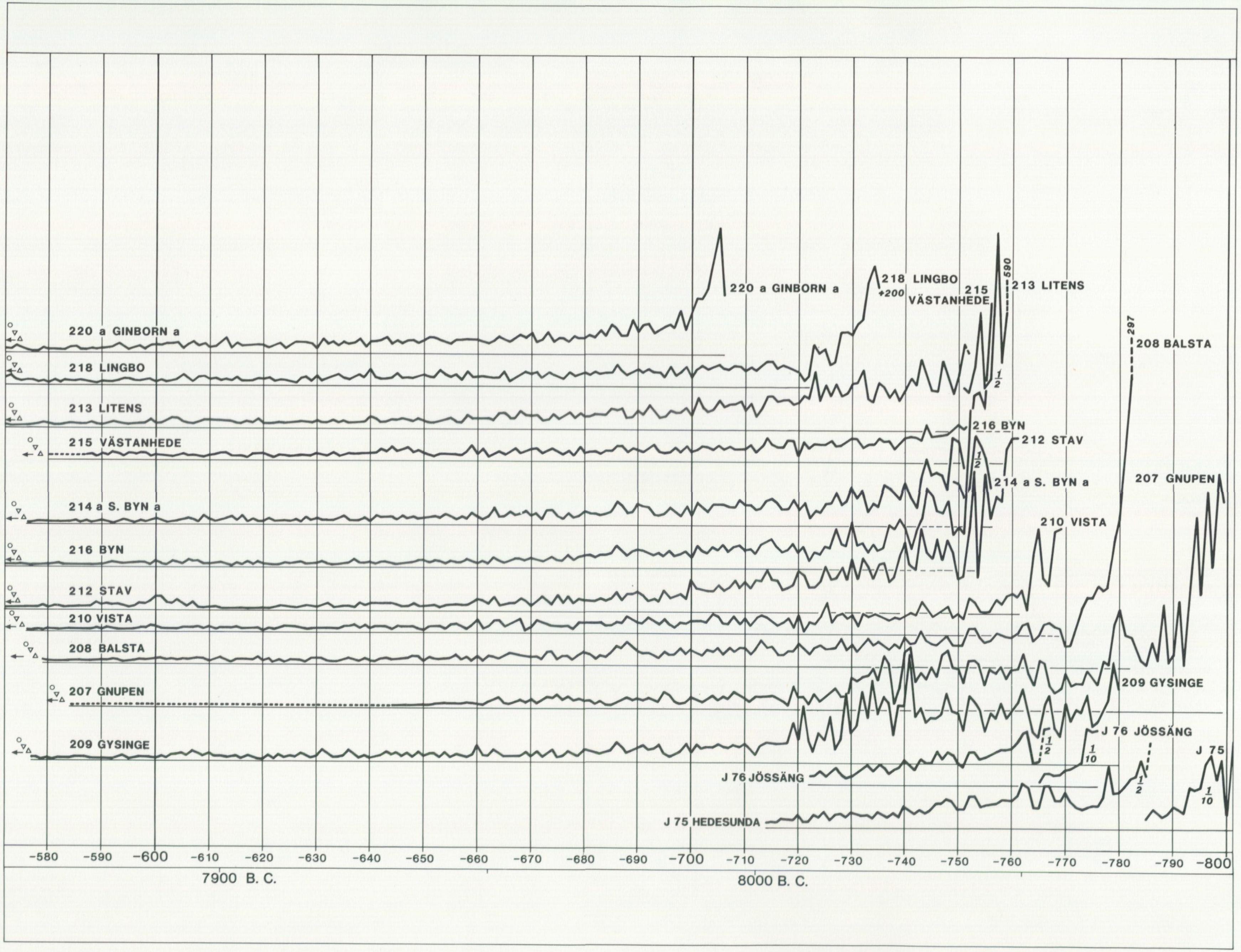
Legend: see Pl. 8.

Plate 15c



Legend: see Pl. 8.

Plate 16



Legend: see Pl. 8.

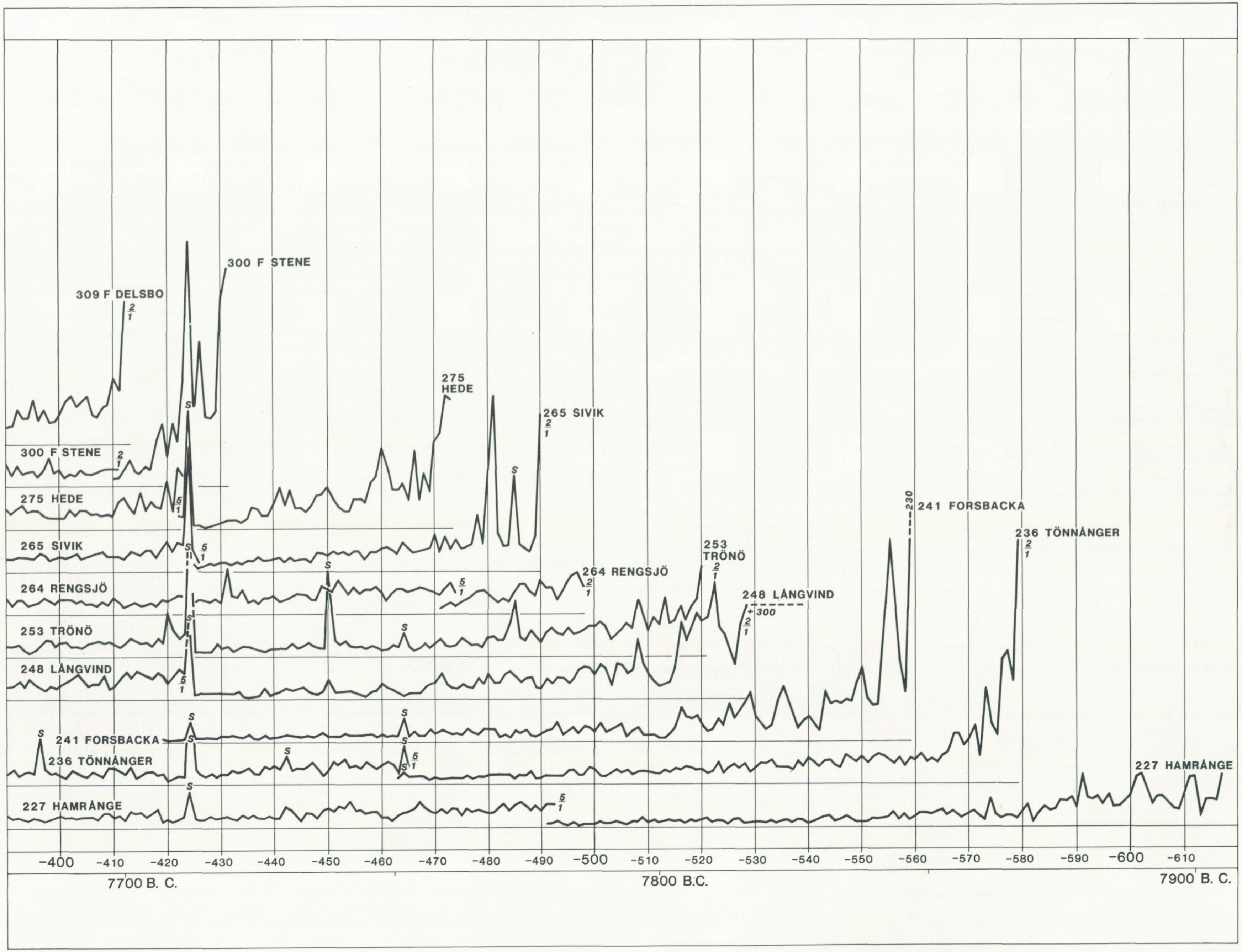
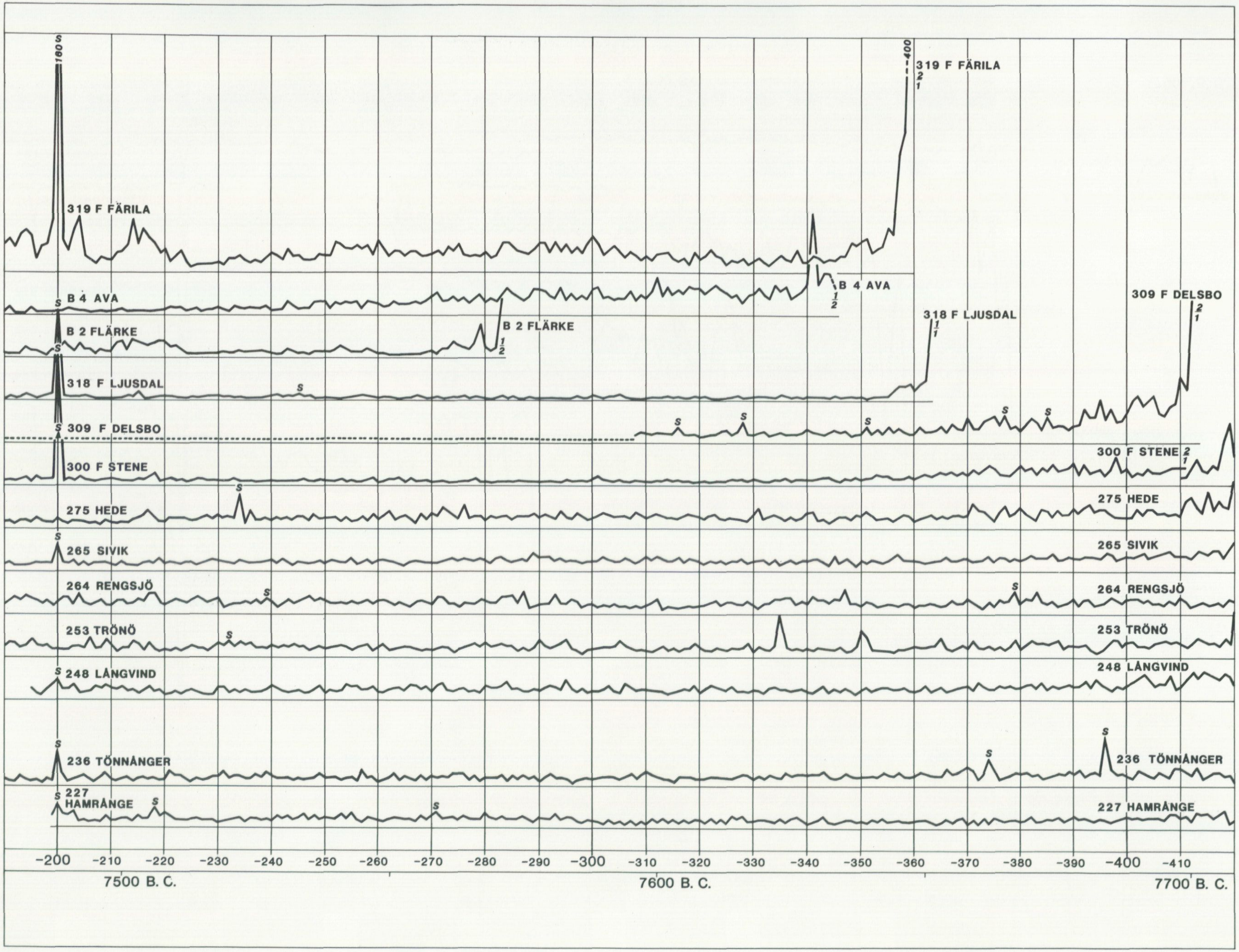


Plate 17a

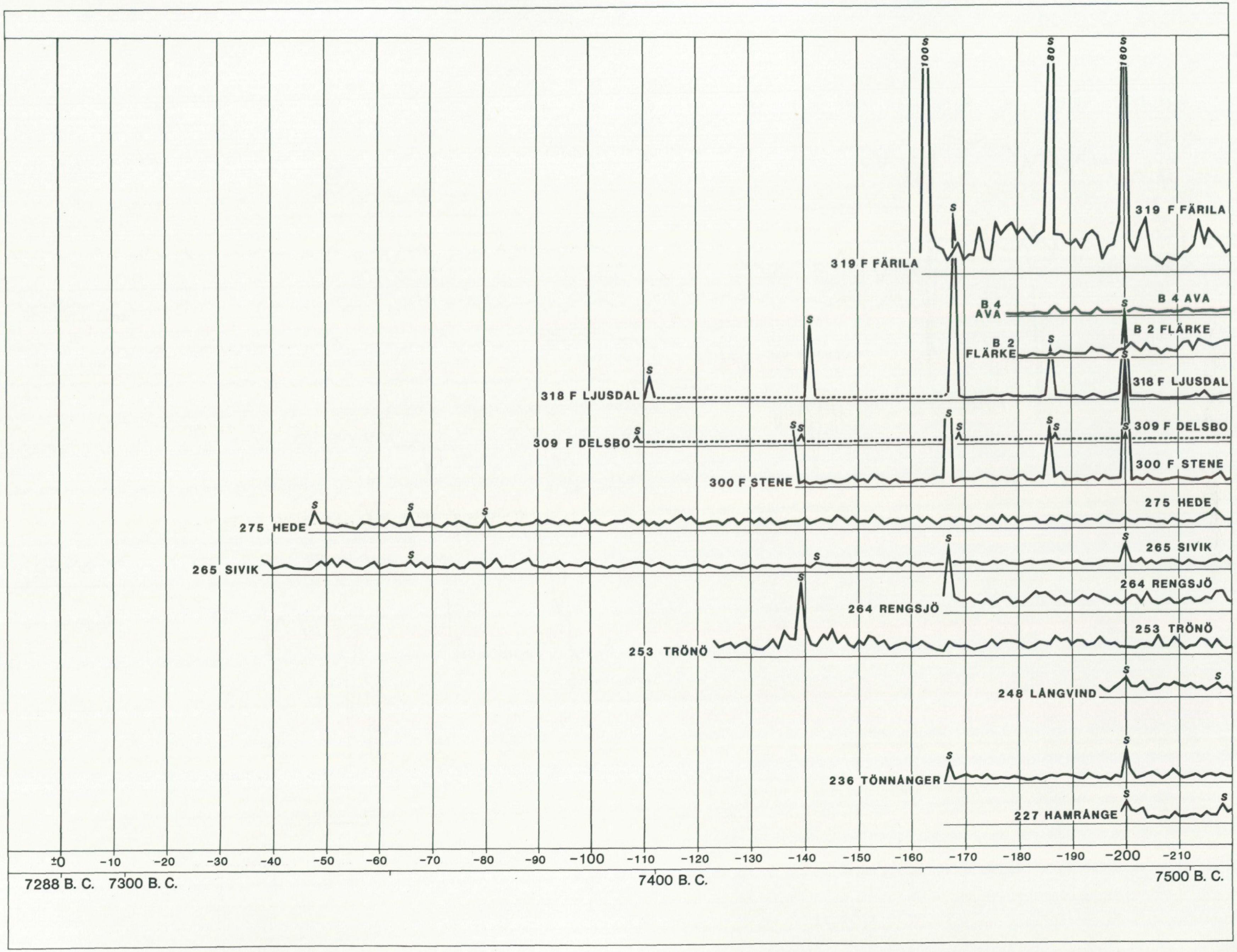
Legend: see Pl. 8.

Plate 17b



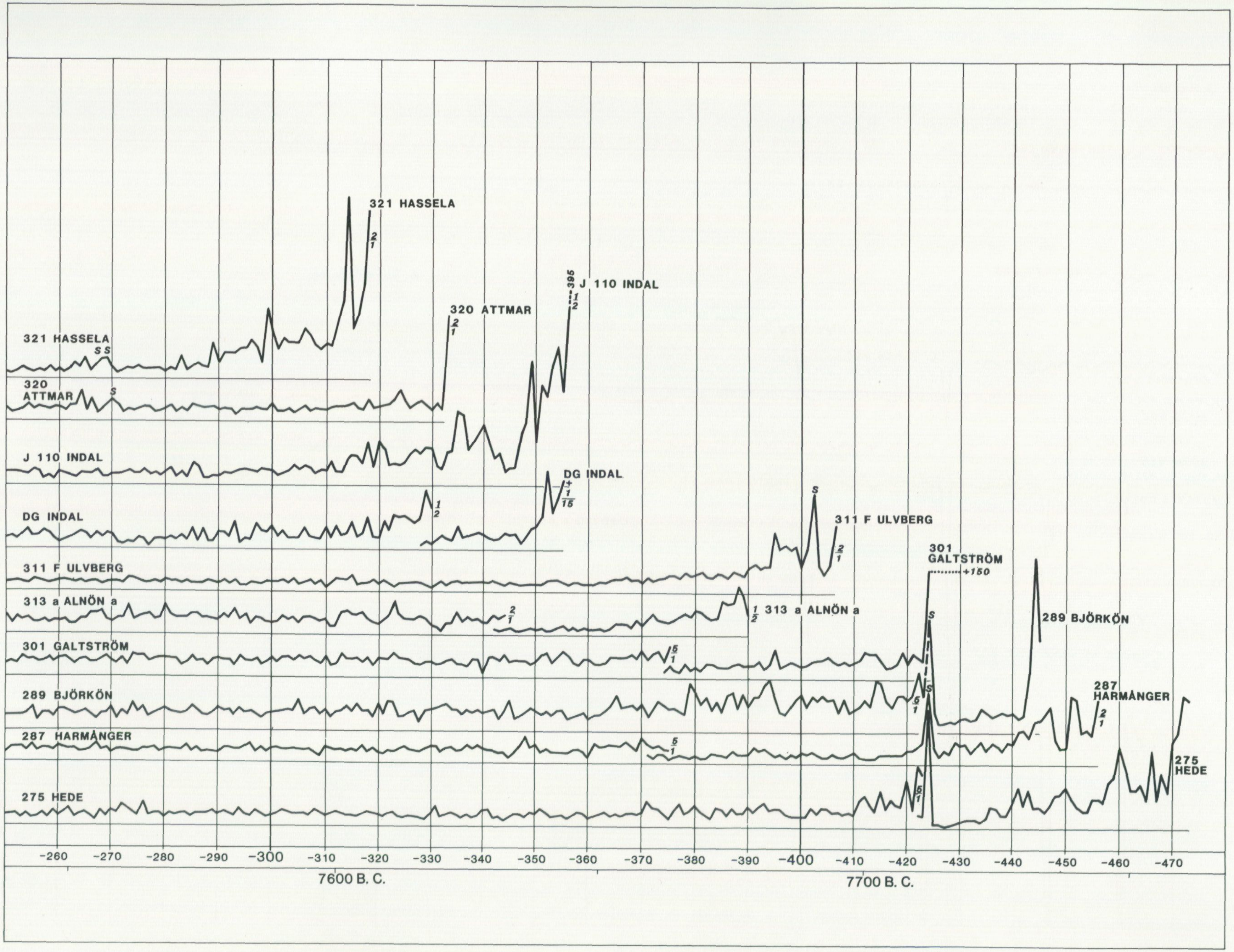
Legend: see Pl. 8.

Plate 17c



Legend: see Pl. 8.

Plate 18a



Legend: see Pl. 8.

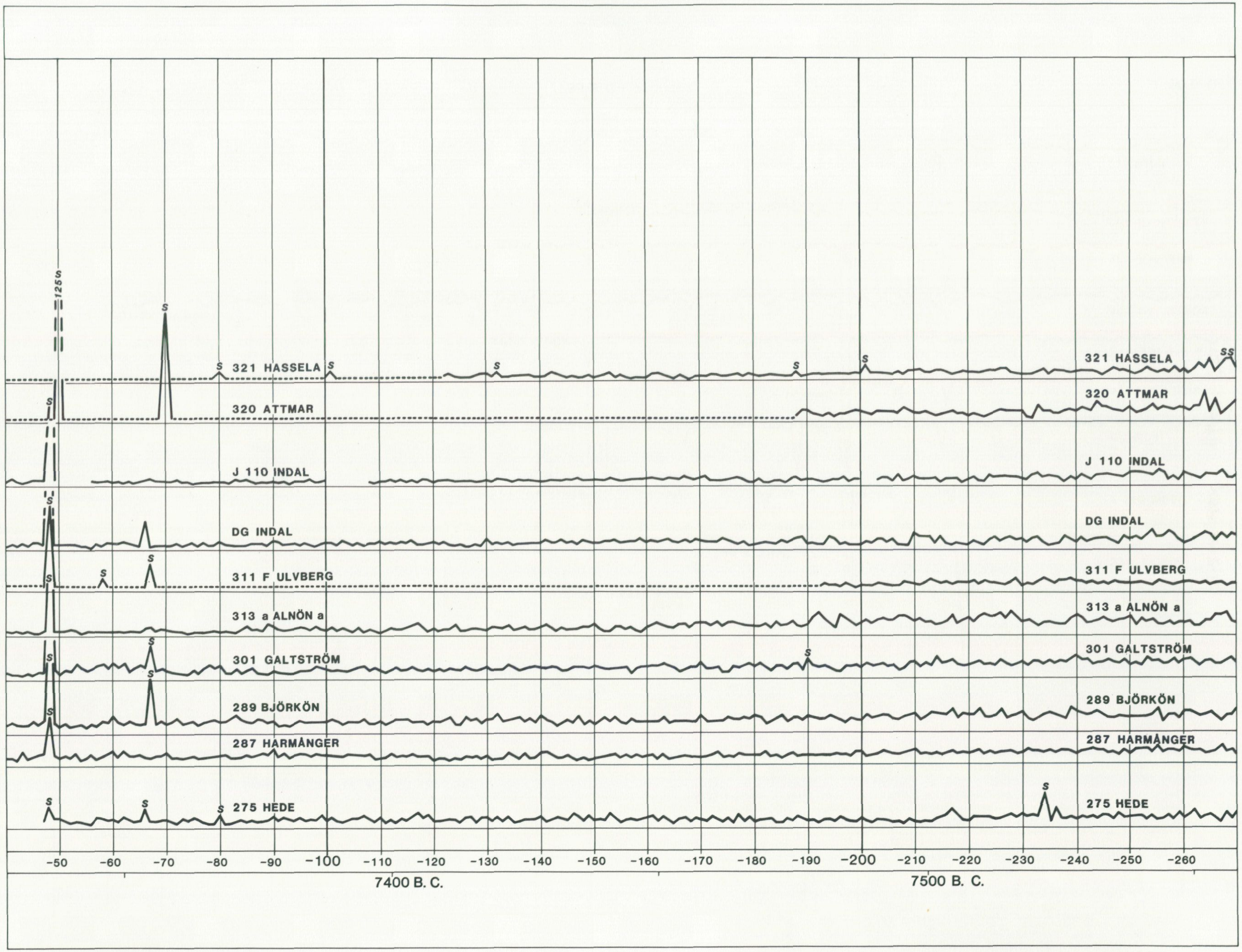
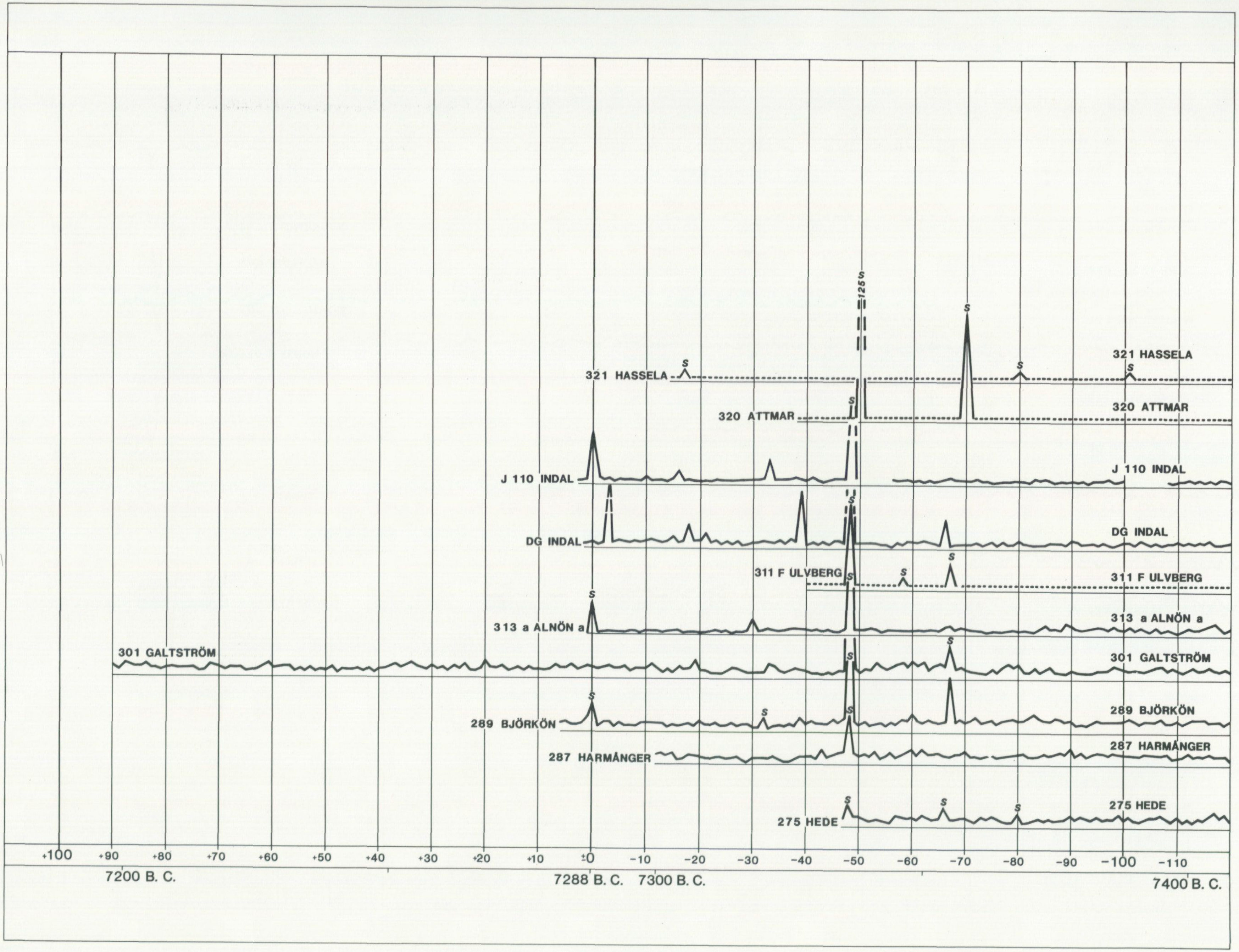


Plate 18b

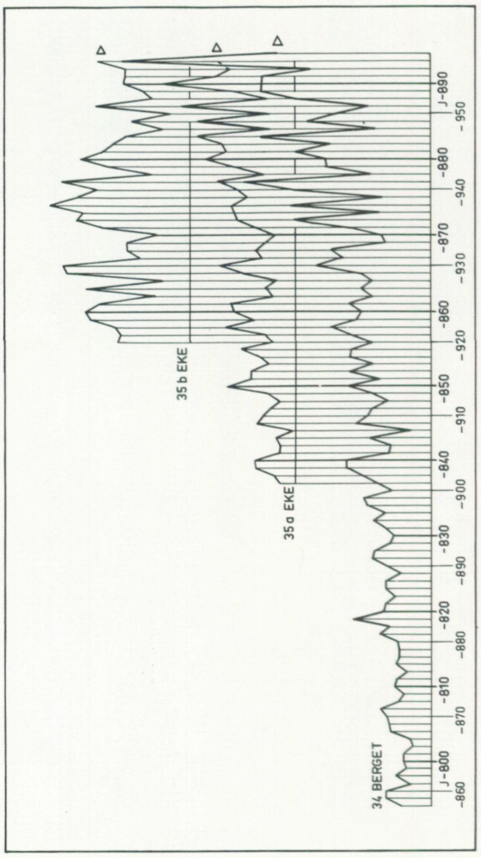
Legend: see Pl. 8.

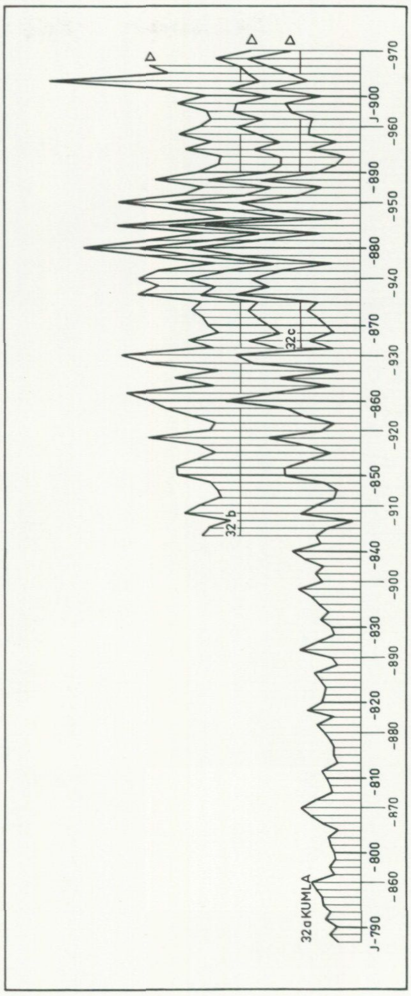
Plate 18c

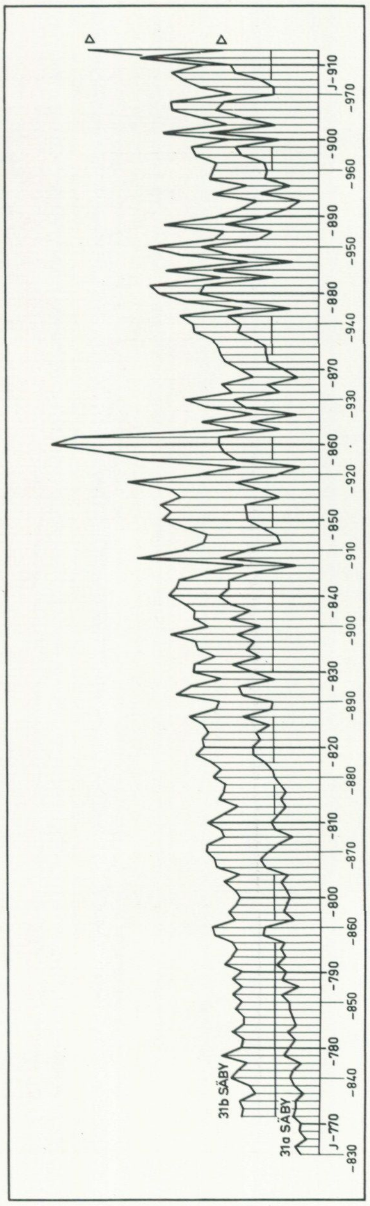


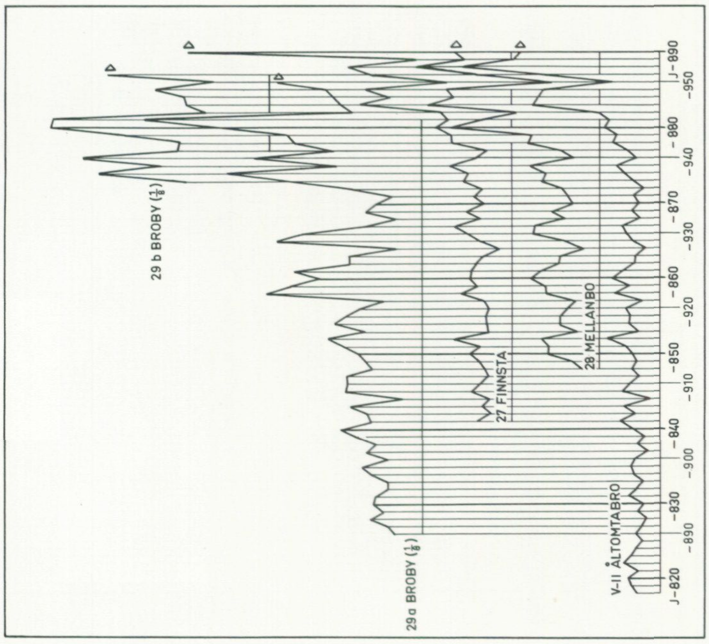
Legend: see Pl. 8.

Plate 19



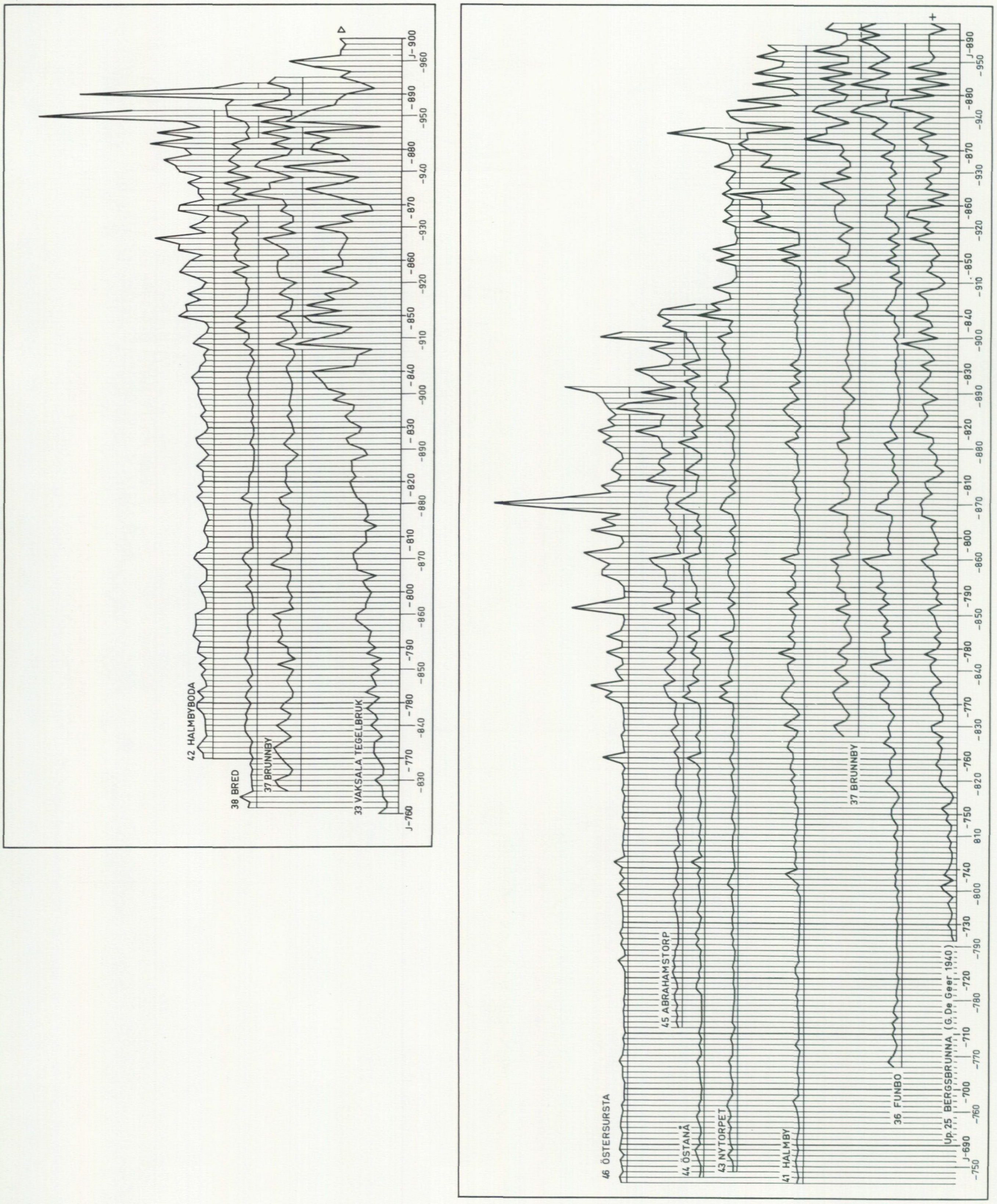






Legend: see Pl. 8.

Plate 20



Legend: see Pl. 8.

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S-162 89 STOCKHOLM
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Tryck: Offsetcenter AB, Uppsala 1989

ISBN 91-7158-465-X
ISSN 0348-1352