The Swedish Clay Varve Chronology

Interest in the Swedish clay varve chronology has increased over the last 20 years. There are two main reasons for this. The first is the possibility of obtaining a calibration for radiocarbon dates covering the last 13,000-14,000 years and the second general desire to better understand the history, climate, environment and drainage of large ice-dammed lakes.

The first clay varve chronological studies were made by Gerard De Geer more than 100 years ago. He relied, mainly, on natural exposures or excavations in his investigations (Fig. 1). De Geer assumed that it was possible to recognize annually deposited strata, or varves (Fig. 2), and that it should be possible to measure the varves at different localities and plot these measurements in a diagram which could be then be used for correlating between localities (Fig. 3).

Correlations within Sweden

De Geer presented his first attempt at a Swedish varve chronology at the XIth International Geological Congress in Stockholm in 1910 (De Geer, 1912). By 1940 he had achieved a detailed chronology for the recession of the ice sheet from Stockholm to the Indalsälven river which he published in his « Geochronologia Suecica Principles » (Fig. 4) (De Geer, 1940). The chronology was worked out from a thousand clay varve measurements which had been made by De Geer and his collaborators for a whole generation. « The Main Swedish Time Scale » had been known for some years by that time but few of the actual varve measurements had been published. The graphs printed in the « Geochronologica » covered 1400 glacial varves (younger than De Geer's 0-year) and 2000 postglacial varves.

By 1941 Caldenius had already pinpointed some weak points in De Geer's « Geochronologica ». Caldenius suggested a reconsideration of two of the correlations and thus made the first revision of the time scale. This first revision was followed by systematic improvements and revisions to the

Fig. 1. Varved clay at Lyckeby in eastern Blekinge, southeastern Sweden. The trowel is resting on sand at the bottom varve. From Ringberg, 1971.

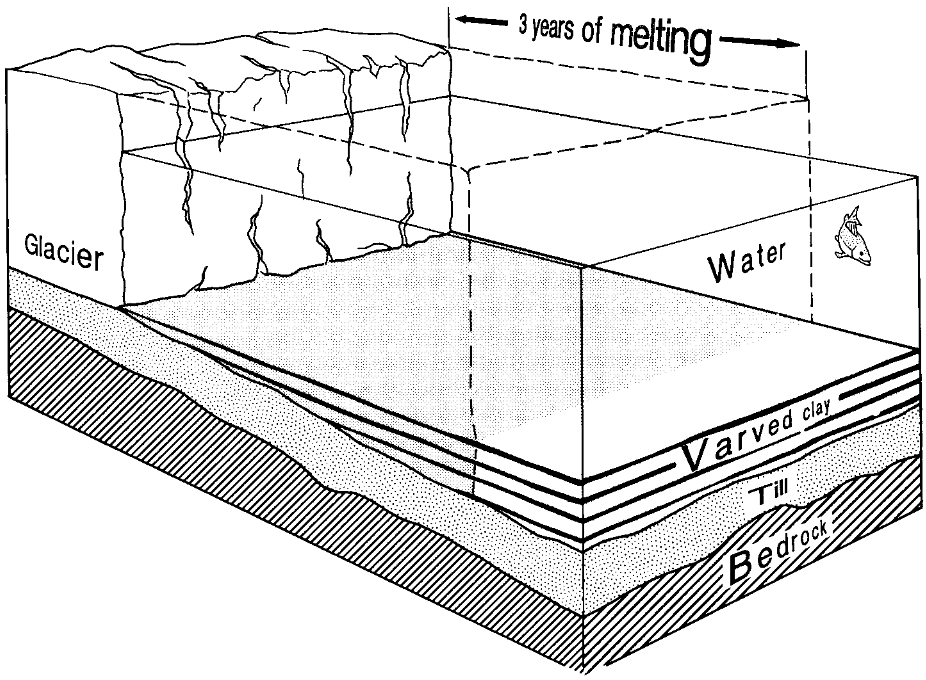

Fig. 2. Varved clay was deposited during the deglaciation when the ice melted in a lacustrine environment. A coarse-grained summer layer and a fine-grained (dark) winter layer were deposited during one year. Together they form one varve.

lateglacial part of the chronology in the 1940's, 1950's 1960's and 1970's (Fromm, 1945 ; Borell and Offerberg, 1955 ; Järnefors, 1963 ; Hörnsten, 1964 ; Bergström, 1968 ; Nilsson, 1968 ; Ringberg, 1971 and Rudmark, 1975). The most important problem, however, was not solved, namely a reliable connection between the postglacial varve chronology (Lidén, 1913, 1938) and the present.

In 1975 it was decided that the Swedish participation in the International Geological Correlation Programme (IGCP) should focus on the connection of the postglacial varve chronology with the present and on a new and total revision of the late-glacial time scale.

This weak connection between the postglacial time scale and the present, which was mainly based in shore-displacement data (Lidén, 1938), had been the subject of interest of several research workers (Werner, 1968 ; Fromm, 1970 ; Tauber, 1970). Between 1978 and 1983 twenty-five new sediment cores were taken in the Ångermanälven valley in an attempt to get a firm link between the Swedish timescale and the present. The cores were taken by foil coring on land and by piston and gravity coring on the sea bottom.

As a result of the measurements and correlations the youngest part of Lidén's (1938) postglacial varve chronology was extended by 365 years (Cato, 1985, 1987). Most of the diagrams of Lidén's time scale remain to be published (Lidén † and Cato, in prep.).

To the north of Stockholm, the late-glacial time-scale was based primarily on the systematic varve measurements made in 1905-1906 and on the revision made by Järnefors (1956, 1963). Järnefors' revision resulted in an independent, new varve chronology between Uppsala and Sundsvall.

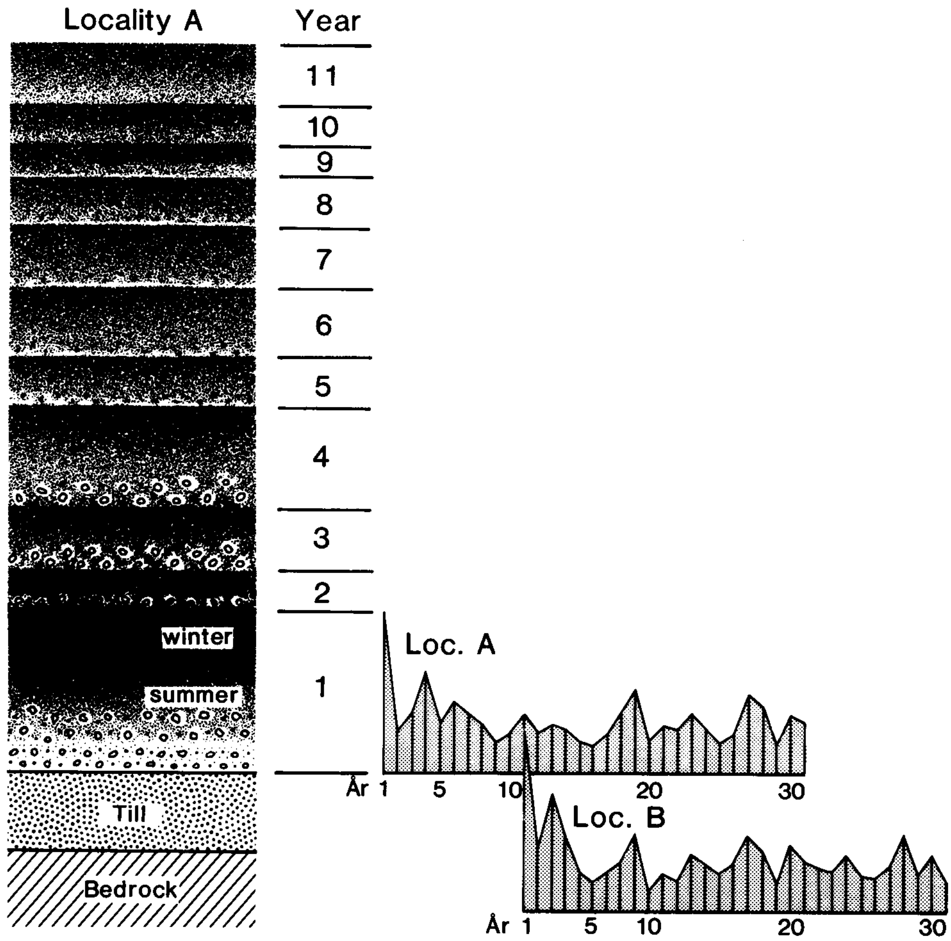

Fig. 3. Schematic section of varved clay showing 11 years of deposition. In certain years, years 1 and 4, for example, the varves are thicker. At each locality the thickness of the varves is measured and plotted against a time axis. The diagram for locality A shows the profile drawn from the section illustrated. When this profile is compared with the profile from locality B it is possible to see apparent similarities. If the varved clay at both localities can be followed to the underlying till it is possible to determine how many years it took for the ice to recede between these two localities (in this case 10 years).

Errors remained, however, (Lundqvist, 1975; Strömberg, 1985) and the chronology was especially weak in the ice recession area between Söderhamn and Sundsvall (cf. Lundqvist, 1975).

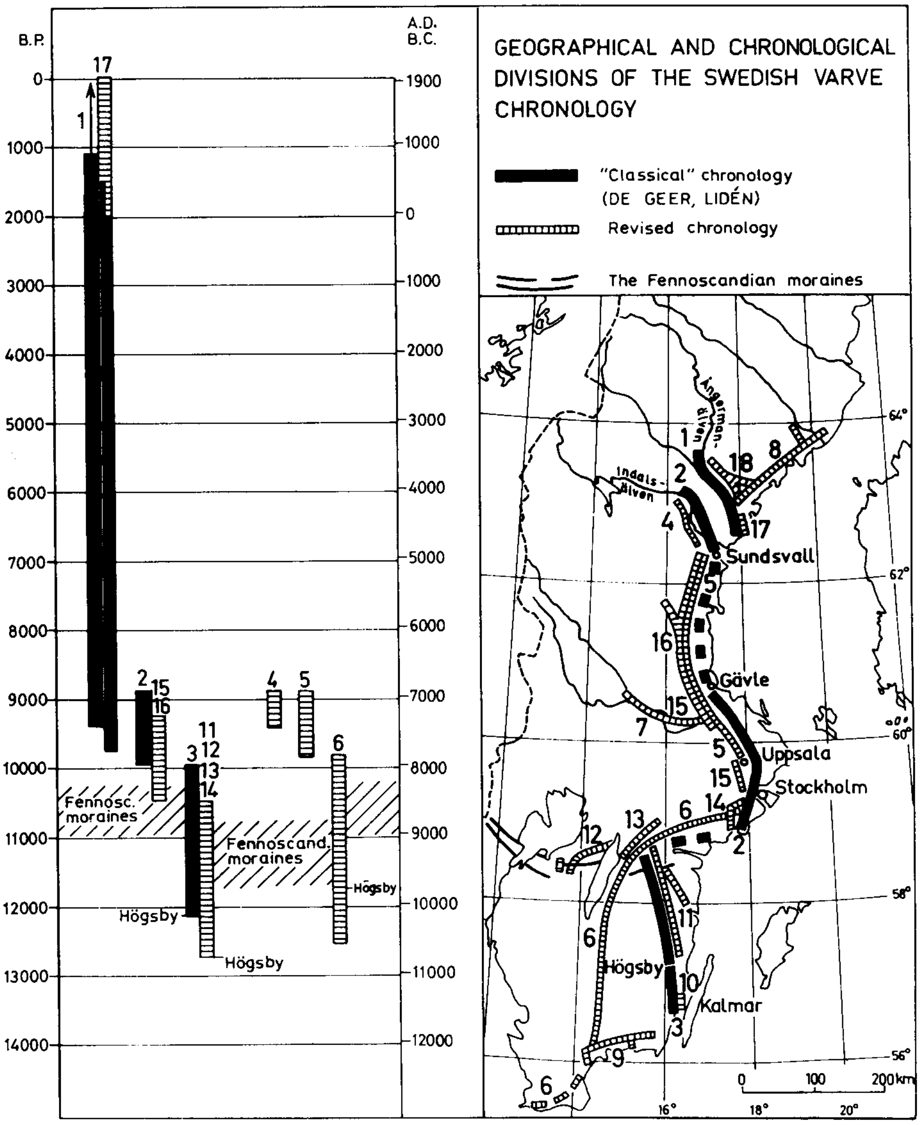

Fig. 4. The Swedish time scale (Strömberg, 1985, modified from Fromm, 1970). 1 = Lidén, 1913; 2 = De Geer, 1940; 3 = De Geer, unpublished; 4 = Borell and Offerberg, 1955; 5 = Järnefors, 1963; 6 = Nilsson, 1986; 7 = Fromm, 1964, 1991; 8 = Hörnsten, 1964, Bergström, 1968 and Andrén, 1990; 9 = Ringberg, 1991 and Ringberg and Rudmark, 1985; 10 = Rudmark, 1975; 11 = Kristiansson, 1986; 12 = Caldenius, 1944; 13 = Perhans, unpublished; 14 = Brunnberg, unpublished; 15 = Strömberg, 1989, 16 = Forsmark, unpublished; 17 = Cato, 1987; 18 = Fözö, 1980. Mainly from Strömberg (1989).

The 1975 revision resulted in an improved chronology for the deglaciation between Stockholm and Sundsvall. Varves were measured at more than 200 sites and 99 years were added to the chronology. The margin of error for the 1191 deglaciation years was estimated at 25 years. The margin of error for the entire period of 8479 varve years B.C. plus 1950 varve years A.D. was calculated at + 35/-205 years (Strömberg, 1989; cf. Cato, 1987).

No continuous late-glacial varve chronology existed to the south of Stockholm before the 1975 revision. Only a few of the original graphs of De Geer and his collaborators had been published, and Nilsson's (1968) new varve chronology had several weak points. Some of these have now been corrected and several original graphs of De Geer and his collaborators have been published (Kristiansson, 1981, 1982, 1986; Perhans, 1981; Ringberg and Rudmark, 1985; Ringberg, 1991). The revised chronologies for the ice recession in the Östergötland-Södermanland region have not yet been presented (western part, Perhans *in prep.*, eastern part, Brunnberg *in prep.*) and a strengthening of the correlations across the zone of the Fennoscandian moraines still remains to be done as does the filling of a gap in southeastern Sweden (Fig. 4).

Ringberg and Rudmark (1985) made an attempt to fill out this gap and also to extend the local varve chronology in Blekinge northeastwards to the Kalmar area in the province of Småland (Rudmark, 1975). This work resulted in two alternative correlations and continuing investigations in the area will show which of these is the more reliable. At present, the ice recession chronology there can be definitely dated to within a margin of 85 years. Another attempt was made to connect a varve series from Karlshamn (Ringberg, 1991) in Blekinge directly with varve series from southeastern Småland, north of the Kalmar area (Björck and Möller, 1987; Björck *et al.*, 1988). In cooperation with the present author the year +100 was preliminarily connected with the local year 2800 in Småland (Kristiansson, 1986). Future detailed investigations will show whether this preliminary long-distance correlation is reliable or not.

The Swedish Time Scale now covers 12,850 varve years. This reliable part of the time-scale comprises post- and late-glacial varve series from the Högsby area in the south to the Ångermanälven river area in the north (Fig. 4; Brunnberg, pers comm.).

Correlations with areas outside Sweden

Stay (1979) and Duphorn *et al.* (1979, 1981) made connections between varve series in northeastern Skåne and in the Bornholm basins in the Baltic southeast of Skåne. In these correlations Stay used the varve diagrams together with the colour boundary between grey and red clay described by

Antevs (1915). The varve diagrams at Bornholm and in northeastern Skåne show similarities, especially in their lower parts. The layer containing organic material described by Stay and dated to older than 39,500 years BP (Stay, 1979) is situated at the colour boundary. Stay also ^{14}C-dated what he assumed to be varve -100, just above the organic layer, and calculated an age of 28,000 B.P. The organic layer has not been found in Skåne but a similar stratigraphy was found in the Baltic in the Hanö bay east of Skåne (Björck *et al.*, 1990). Future investigations in the area between Blekinge and Bornholm will show whether the long distance correlations made by Stay are reliable or not.

A connection between the late glacial clay varve chronologies in Sweden and Finland has recently been made. The connection is based on correlations of varve measurements from east-central Sweden via the Åland islands to southeastern Finland and indicates that the Finnish 0 – varve (Sauramo, 1923) was deposited in 8693 B.C. The maximum margin of error is estimated at + 25/195 calendar years, without regard to possible errors in the Finnish timescale (Strömberg, 1990).

Palaeomagnetic correlations and relation to the Late Weichselian radiocarbon chronology.

Mörner (1975a, 1975b, 1976) made an attempt to extend the Fjärås line (The Gothenburg end moraine) from the west coast of Sweden to the Bredåkra delta in Blekinge, establishing a correlation on palaeomagnetic grounds. This was, however, criticized by Ringberg (1976).

Björck *et al.* (1987) have made a magneto-stratigraphic comparison between ^{14}C years and varve years for the Late Weichselian and have developed a ^{14}C dated magnetostratigraphy of absolute declination and inclination for southern Sweden between 12,500 and 10,000 years B.P. Statistical correlations between the two independently dated time-scales suggest that at 10,500 – 10,200 ^{14}C years B.P. the varve chronology exceeds the ^{14}C chronology by 500-600 varve years and that the difference between the chronologies increases steadily from 12,000 to 10,000 ^{14}C years B.P. If the correlations are correct, they imply that the rate of ^{14}C production increased steadily during the late Weichselian.

A recently started project on AMS datings of terrestrial macrofossils in the varved clay will possibly be the basis for a connection between the two time-scales between 10,000 and c. 13,000 varve years B.P. (Björck *et al.*, 1992). The first results of this project suggest that a ^{14}C chronology based on terrestrial organic remains is not consistent with the traditional Late Weichselian chronostratigraphy based on lake-sediment samples, and that « clay varve years » exceed 'terrestrial ^{14}C years' by c. 1100-1200 years at the beginning of The Younger Dryas Chronozone. B. Further back in time, the time-scales appear to converge. These results are compared with other recently published calibration studies (Wohlfarth *et al.*, 1993).

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