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ABSTRACT

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The field work for this investigation was carried out mainly in 1945 - 1949 by the present author as a part of G. Lundqvist's (1951) mapping of the Quaternary deposits in Dalarna (Dalecarlia). The "classical" method according to Gerard De Geer (1940) was used, with observations of the glacial varves and their substratum in open test pits. The results are geographically extended by the investigations of Kulling (1948) and Brunnberg (1974), and are now recalculated in the new, revised Swedish time-scale (Strömberg 1989) according to the correlation of the varves in Dalarna and Uppland, established by Järnefors (1963). The varve numbers used here correspond to absolute ages according to Cato (1987) in the following way:

600 = c. 9838 B.P.
700 = c. 9938 B.P.
800 = c. 10 038 B.P.

Deglaciation within the investigated area took place in a late-glacial archipelago or fiord-like bays with an average water depth of about 100 metres. The main conclusion from the varve chronology is, that deep calving bays in the ice front were developed at the mouths of the large subglacial melt-water streams. Fracturing of the ice front seems to have been most intensive there, but less pronounced between the streams even in deeper parts of the submerged valley. At some places dead-ice bodies were isolated from the sides of the calving bays and lingered for some tens of years. The average speed of the recession of the ice front was c. 300 m per year.

This reconstruction of an irregular ice front is supported by evidence from late-glacial supra-aquatic lateral erosion channels indicating ice-contacts, further by deviations of the glacial striae, and changes in the transport of glacial silt, during the proceeding deglaciation, as revealed by the varves.

1. Introduction

This investigation started in 1945 on the initiative of the late Professor G. Lundqvist as a project, included in the mapping of the quaternary deposits in the county of Kopparberg ("Kopparbergs län"). The mapping project was carried out at the Geological Survey of Sweden. The mapping area is practically identical with the historical province of Dalarna (Dalecarlia) in central Sweden, and this more familiar name is used in the text below. The area of the present study is restricted to the south-eastern part of the province, where varved late-glacial sediments were deposited in the former Baltic Sea. It was however necessary to extend the investigation into the adjacent province of Västmanland in order to obtain a reliable chronological connection between different regions within Dalarna (Fig. 1). The field work was carried out during the summers of 1945–1949. In the regions at Borlänge and south of Lake Runn it was performed in close cooperation with Kulling, who completed a similar investigation within the geological map sheet "Falun" (Kulling 1948). All notes and maps from the field work, including tabulations of all varve measurements, are preserved in the archives of the Geological Survey of Sweden under the index number E IV 2c, 269.

It remained to connect the chronology of the ice recession in Dalarna to the general varve chronology in eastern Sweden. This task was performed by Järnefors during his first revision of the Swedish varve time-scale (Järnefors 1963). Through the courtesy of Strömberg it has further been possible to adapt the chronology in Dalarna to the actual revised varve chronology for eastern central Sweden (Strömberg 1985, 1989) before the publication of his final report. The investigation is thus some decades old, but is now presented in a form that permits direct comparison with recent varve-chronological studies in Sweden. A local investigation in the Leksand area by Brunnberg (1974) is now also connected to the revised chronology.
The local chronology within Dalarna was completed already in 1950 and reported in the map description of Kopparbergs län (Lundqvist 1951) and in short preliminary notes (Fromm 1945, 1964, Järnefors & Fromm 1960). In these studies, however, varves were numbered in a local system or according to Gerard De Geer (1940) or Järnefors (1963).

This investigation in Dalarna demonstrates the usefulness of the varve method not only for purely chronological purposes, but also under favourable circumstances for investigation of geological and glaciological processes and events.

2. Field work and methods

The aim of this study of varve chronology was to determine the exact dating of ice recession in a great number of localities. Therefore it was essential to have reliable observations not only of sufficiently long varve series to enable the construction of a common time-scale, but also of the lowermost varves and their contact with the substratum (till or in some cases glaciofluvial gravel or bedrock) for the dating of the ice recession.

The field work was carried out according to the "classical" method as described by De Geer (1940). The varves were measured in open test pits, dug by hand at places where the substratum of the clayey or silty varved late-glacial sediments could be expected 1.5–2 m below the ground surface. In some cases excavations for building purposes etc. were available. The varves in the investigated area are in most cases very distinct (see further Chapter 6), and could be marked on paper strips in the manner of De Geer, and afterwards measured from the strips. In most cases it was possible to obtain a reliable dating already during the field work and thus compile the chronology and the picture of the ice recession successively.

Specimens were taken through the varve series in most localities for control and kept in 0.5 m long zinc boxes (De Geer 1940). In some cases with very thin varves or varves with indistinct colour differences between summer and winter layers, the measurements had to be made or at least checked on specimens in the laboratory with ideal moisture and better light conditions than in the pit.

The substratum below the varved sediments often has a rather uneven surface due to boulders. As seen from the descriptions of localities (Chapter 9) good observations of the bottom varves are often in this region possible only in open pits, where the contact between till and sediment can be followed for some distance. Another advantage of this method is, that the common small slidings and faults, which otherwise disturb the varve stratigraphy, can be avoided in the measurements. In fact, about every fourth trial digging for test pits had to be abandoned due to folded, disturbed or even obliterated varves in slidings. In this publication only at least partly successful observations are described. These features, together with the fact, that the silty bottom varves are often very hard and contain layers with pebbles and gravel grains, would make investigations of this kind difficult to carry out with the aid of boring and sampling devices only.

The varve numbers in the diagrams and in the text are here expressed in the revised Swedish time-scale according to Strömberg (1985, 1989). The varves are counted backwards from the zero year at Indalsälven (Döviken) with negative numbers. For the sake of brevity the minus signs are omitted here, except in Chapter 4, where different time-scales are compared. The particulars of this dating are discussed in the following two chapters. All varve diagrams are reproduced in the scale 1:2 for the varve thicknesses, if not otherwise stated.

3. The starting point for the investigation

When the systematic work for this investigation began in 1945, Gerard De Geer's (1940) description of the Finiglacial part of his Swedish time-scale had been published. De Geer presented the following localities from the area of investigation (cf. op. cit. pp. 253–254):

Index no.	Locality	Commented here in Ch. 9 under locality no.
Dalarna:		
Da 1 - 2	Avesta, river bank	20 B
Da 3	Krylbo, Fors	15
Da 4	Smedjebacken, Kvarnsnäs	89
Da 5	Hedemora, Bältarbo	See below
Da 6	Gustafs, river bank	60
Da 11	Hälgnäs, brick-yard	73
Västmanland:		
Vsl 8	Norberg, Livsdalen	76
Vsl 9	Västanfors, bank-house	79

It very soon became clear that De Geer's long series Da 1–2, Da 3, Da 5 and Da 6 offered a firm chronological backbone for new datings along the Dalälven valley from Avesta to Borlänge. As a consequence, De Geer's varve numbers were used as a local time-scale during the the field work in spite of doubts, that the diagrams from Dalarna might not be correctly connected with the main Swedish time-scale, in this part of Sweden based on De Geer's localities in central and northern Uppland. Kulling (1948) also quotes De Geer's datings in his investigation of the ice recession in the Falun area, where the chronology was supported by the remaining localities (Da 7–10) from De Geer's publication.

The new results do not agree with some specific parts of De Geer's varve diagrams. The oldest c. 40 varves of Da 1–2 Avesta differ completely from the new observations. In Da 4 Smedjebacken only the oldest varves are similar to those of new localities in the vicinity, but with changed dating. The varve diagram from Da 11 Hälgnäs differs considerably from new measurements in the same brickyard. The short, geographically isolated varve series Vsl 8 Norberg and Vsl 9 Västanfors are according to comparison with new localities in the close vicinity correctly measured, but erroneously dated. The particulars are discussed in Chapter 9.

De Geer's publications are sometimes inconsistent. For example he states explicitly (1938) that no bottom varve was found in Da 5 Hedemora, but in his table of localities (1940, p. 253) the same oldest measured varve is noted as bottom varve, which then would be considerably too young according to the new observations.

Of more general interest is that De Geer has inserted two extra years, appearing as gaps in his diagrams between the years corresponding to 655–656 and 620–621 respectively in the new time-scale. These extra years do not appear in any of the new varve measurements, covering the actual span of time, nor in the original measurement of Da 6 Gustafs, published by Caldenius (1926). Kulling (1948) reports the same findings. These extra years should probably be regarded as "telecorrections" sensu De Geer (1940, p. 35) in order to obtain better agreement with varve diagrams from other regions outside Dalarna.

After these remarks it is only fair to emphasize that most of De Geer's varve measurements and local datings within the Dalälven valley are confirmed by the numerous new observations, which consist of independent varve measurements carried out by different persons. The new measurements form by themselves a coherent and controlled local time- scale in the region Avesta – Hedemora – Borlänge – Falun, identical with that of De Geer, with the exception only of the two gaps and the oldest varves from Avesta, already mentioned.

Fig. 1. Orientation map, showing varve localities with index numbers, and place-names used in the text.

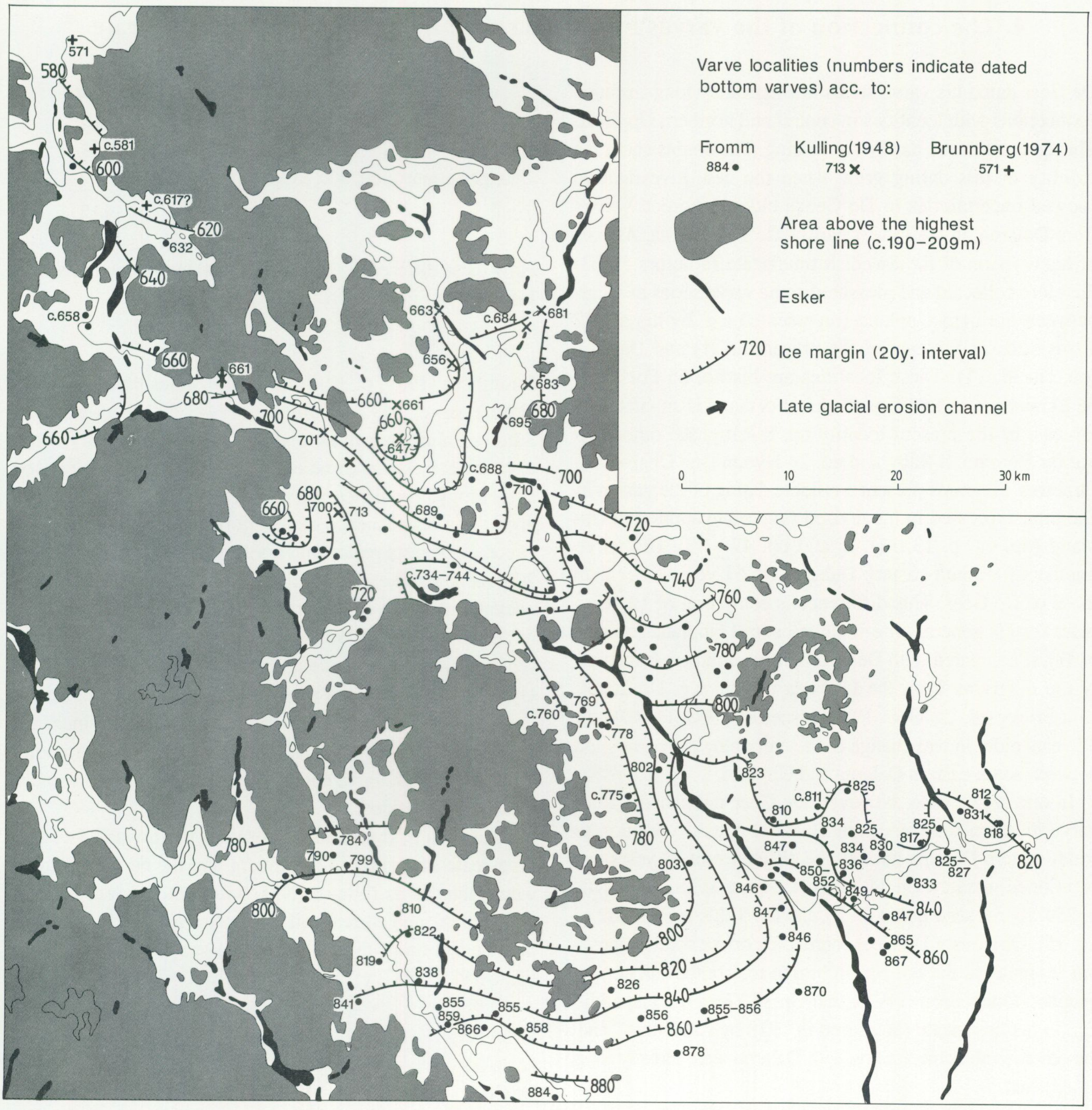

Fig. 2. General map of the ice recession, expressed in time-scale years, and the extension of the late-glacial Baltic Sea. For details of the varve datings in the central parts of the map see the Special Maps 1 and 2 (cf. Fig. 1), in Fig. 4 and 5 respectively.

4. The connection of the varves in Dalarna with the main Swedish time-scale

De Geer dated his varve series in Dalarna by long-distance connections with localities in central and northern Uppland. The agreements are hardly convincing. The doubts about the validity of this dating grew when the new investigation showed uncertainties in De Geer's oldest recorded varves from Dalarna, in the lowest part of Da 1–2 Avesta. As part of his revision of the Swedish time-scale Järnefors (1963) therefore collected and measured some varve series as a link between northern Uppland (represented e.g. by his no. 72 Tärnsjö, c. 22 km east of the present no. 1) and Dalarna (op. cit. Pl. 11). These localities are his no. 65 Forsänge, 66 Skinnarbo, and 67 Grytnäs k:a. Forsänge is situated c. 6 km east of the present locality no. 8 Råby, the other two not far from no. 8 Råby and no. 24 Hyttan (see Chapter 9). Järnefors' diagrams present a reliable dating of the varves in Dalarna, expressed in his revised time-scale applied in Uppland (op. cit. p. 13, Fig. 2, and pp. 47 - 48). His varve numbers for south-eastern Dalarna are 51 years older than those of De Geer. This difference is composed of 19 years older for his general time-scale in central Uppland (op. cit. p. 39), if compared with De Geer's varve numbers (especially the diagrams from the Uppsala region, e.g. Up 26 St. Erik brickyard, De Geer 1940, Järnefors 1963, Pl. 10) and 32 years older in real change of the chronological correlation between south-eastern Dalarna and Uppland.

In one single case, however, De Geer published a long varve diagram from northern Uppland dated in relation to south-eastern Dalarna without the difference of 32 years just mentioned, namely Up 34 Tierp (De Geer 1938, and 1940, p. 254, reproduced in his Pl. 77 and the Table p. 301-302 as Up 35). Obviously De Geer found the correct solution here, but his material did not permit him to realize the full consequences. One reason may be that Up 34 Tierp is a late addition to his time-scale (measured in 1938 by Caldenius), and the other invalid correlations with Dalarna were already long established.

Strömberg (1985, 1989) has stated that Järnefors' varve datings in central and northern Uppland are reliable, but that all should be changed to 64 years earlier, if counted from the zero year at Indalsälven. The varves in south-eastern Dalarna thus should have varve numbers in total 115 years older than according to De Geer (1940) as follows:

	Years
Addition to the time-scale, acc. to Järnefors	19
" " " " " " Strömberg	64
Changed connection, acc. to Järnefors	32
Total	115

How these differences appear in actual varve diagrams is illustrated in Fig. 3.

Strömberg (1989, p. 30) furthermore states, that De Geer's (1940) varve -549 in Kulling's (1948) diagrams from the Säter - Falun area is now shown by a preliminary long-distance correlation to be equivalent to -664 in the revised chronology. The difference is exactly the 115 years derived above as a consequence of Järnefors' (1963) correlation between the Avesta region and north-western Uppland, almost 200 varve years earlier. Kulling's diagrams are firmly connected with those of the present study by several localities in common, e.g. no. 60 Gustafs and 70 Barkargärde. Consequently, not only is the correlation between Dalarna and Uppland confirmed, but a complete agreement is also demonstrated between the time-scales in the two provinces for the approximate period from -850 to -650 (revised chronology), although the varve datings were achieved by quite independent correlations.

Examples of the relations between the revised Swedish time-scale according to Strömberg and the earlier versions would thus be as follows (N.B. within the present investigation area), and correspond to absolute ages, deduced from the connection of the Swedish time-scale with the present (Cato 1985, 1987, cf. Fromm 1985):

Strömberg	-600	-700	-800
Järnefors	-536	-636	-736
De Geer	-483	-585	-685
Absolute age:			
Years B.C.	c. 7888	c. 7988	c. 8088
Years B.P.	c. 9838	c. 9938	c.10038

The difference in De Geer's equivalent to Strömberg's -600 is due to the two gaps in the diagrams as discussed above.

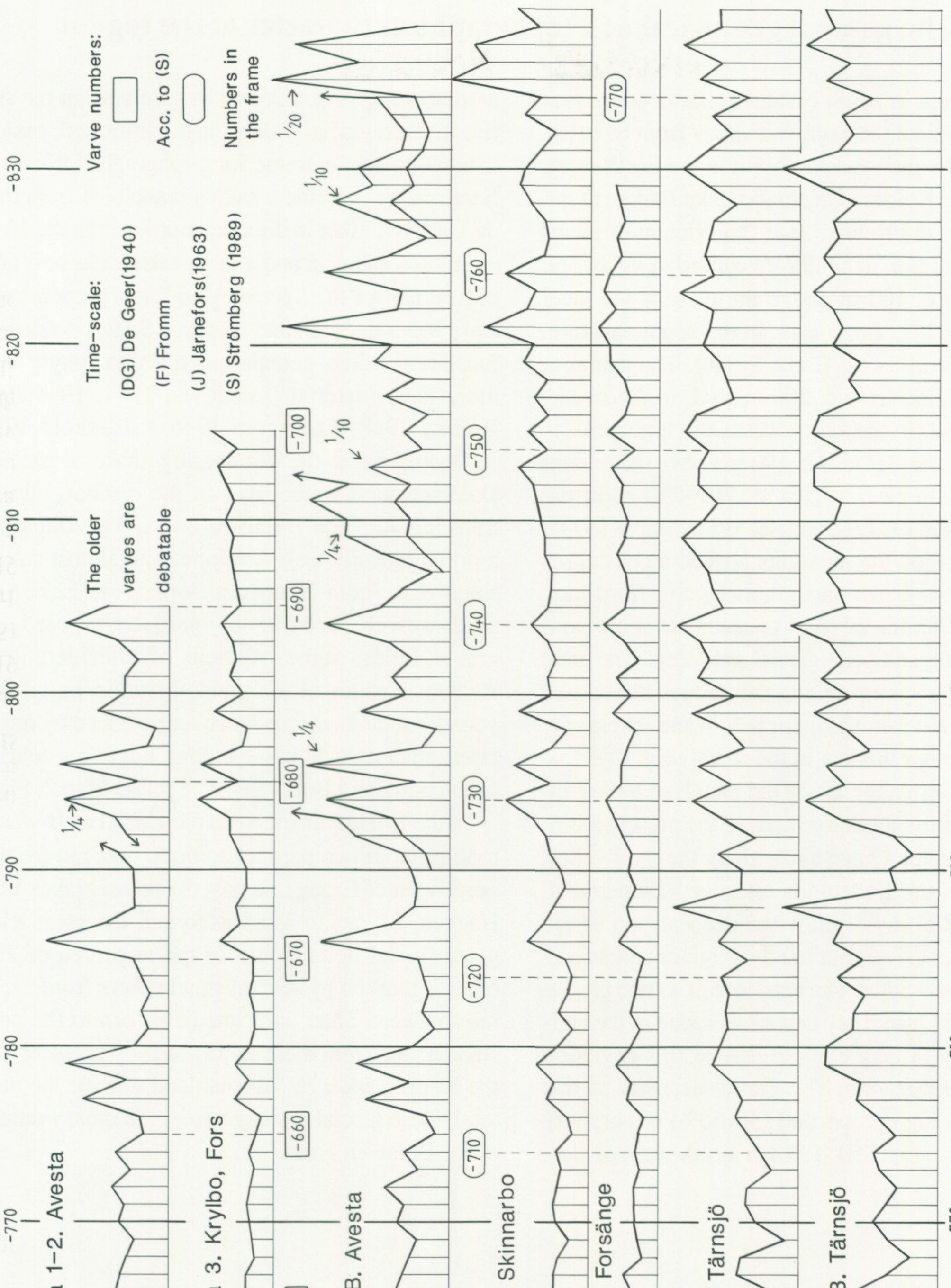

Fig. 3. Diagrams to illustrate Järnefors' (1963) connection of the varves in north-eastern Uppland and Dalarna, and the relation between the time-scales used by G. De Geer (1940) and Järnefors in Dalarna with the new, revised Swedish time-scale according to Strömberg (1989). Explanations see Fig. 8.

5. The general geological and topographical character of the region

The investigation area in south-eastern Dalarna comprises parts of two river basins: the Dalälven valley from the eastern border of the province to lake Siljan in the north-west, and the upper part of Kolbäcksån around Lake Barken at the southern border of the province (see the orientation maps Fig. 1 and 2). This region is a hilly Precambrian landscape with Kolbäcksån in c. 100 m above the present sea level (a.s.l.) and Dalälven in c. 60 m a.s.l. in the south-east to c. 160 m a.s.l. in the north-west (Lake Siljan). The summits of the highest hills rise from c. 200 m a.s.l. in the south-east to c. 400 m a.s.l. in the north-west. The highest late-glacial shore-line of the Baltic is c. 190 m above the present sea level in the south-eastern part, c. 209–210 m in the north-west (cf. Ingmar 1931, Lundqvist 1951, Brante 1974). During the ice recession the area thus formed a coastal region with islands and bays, partly narrow and fiord-like, partly more open. The lower parts of the valleys are now covered by Baltic late- and post- glacial sediments. The great subglacial melt-water streams along the valleys discharged into c. 100 m deep water in the main part of the investigated area, somewhat more shallow in the north-west.

The main glacial drainage along the Dalälven valley included large parts of the discharge area of the present River Dalälven and resulted in a huge esker along the river valley as a continuation of the Badelunda esker in Västmanland. This esker does not always follow the deepest part of the valley with the present river, but has a straighter course e.g. between Hedemora and Säter. The existence of a deep preglacial valley below the Quaternary deposits, eroded in the bedrock (Thorslund 1981) may explain part of this deviation from the present topography. The gravel deposits of this esker contain a very high proportion (30–60%) of porphyry from the Älvdalen region, 50–100 km north-west of the map area Fig. 1 and 2, much more than in the surrounding till. The preglacial valley, just mentioned, may have contributed to this extreme long-range glaciofluvial transport. Some rather prominent eskers branch off from the Badelunda-Dalälven esker in direction northwards: the Möklinta esker in the south-east and a large esker at Lake Viggen (in the central part of the Special Map Fig. 4), continuing through Lake Runn to Falun and also past Svärdsjö north-east of Falun. These eskers contain much less porphyry boulders and more local material (Lundqvist 1941, 1946, 1951, 1953, Kulling 1948, Sandegren 1946, Lilliesköld 1990). These facts emphasize the dominating share of the Badelunda-Dalälven melt-water river in the discharge and sediment transport into the Dalälven basin. The Dalälven esker is morphologically well developed and almost coherent in the south-east. From Säter past Borlänge to Lake Siljan in the north-west the esker is only partially exposed as ridges or gravel fields, some of them of considerable size, e.g. Ålsheden south of Leksand. Missing parts, covered by younger sediments, can however be traced by remaining features, such as oval kettles along the esker course, e.g. between Säter and Borlänge (cf. Special Map 2, Fig. 5).

In the Kolströmmen basin the glacial melt-water drainage took place in two parallel courses. One ran from the region north-west of Grangärde past the present lakes Vässman and Haggen, further to Malingsbo and the great Riddarhyttan glaciofluvial delta (south of the map area of Fig. 1). The other is marked by several small eskers from the higher terrain between Säter and Smedjebacken to the present Lake Barken, and from there southwards by an esker, which joins the Köping esker in Västmanland outside the map area. In total, these glacial drainage areas are more limited than that of the Dalälven basin.

6. Description of the varves

The general appearance of the varves in Dalarna is that they are very distinct and mostly rather thin. There is a clear difference between the summer and winter layers of the varves. The winter layers are sharply separated from the following summer layers and mostly from the preceding ones also. Close to the main eskers the thickness of the bottom varves may be as much as 0.5–1 m or even more, the main part ofthe varve consisting of fine sand (e.g. localities no. 20 B, 60 and 72). Generally, however, also in the upper part of the varve series just mentioned, the thickness varies between about 30 and 3 mm, thus under favourable conditions allowing more than 100 varves to be measured in a test pit, 1.5–2 m deep, Often, however the number of measurable varves is considerably lower due to weathering near the surface and other disturbances.

Varves of the same age are thinner in a higher topographical position (compare no. 38 with no. 32 and 39 in the close vicinity, Special Map 1 Fig. 4 and the diagrams Fig. 10 and 13). The silt transport and the sedimentation was obviously concentrated to the deeper parts of the valley. Abrupt changes of the average varve thicknesses or in the composition and appearence of the varves at the same locality may be caused by alterations of the silt transport due to the proceeding recession of the ice margin. Some cases are discussed in Chapter 8.3.

The varves of the region are characterized by clear differences in grain size between the winter and summer layers, as shown from the table below, compiled from analyses according to Kulling (1948). The samples were taken in two adjacent localities near Borlänge, c. 4 km south-south-west of no. 70 Barkargärde and c. 6 km north of no. 62 Nyby.

TABLE 1. Grain size.

W = winter layer
S = summer layer

Varve number	Thickness mm	Grain fractions per cent				
		Sand	Silt			Clay
		(size mm)	Coarse	Medium	Fine	
		>0.06	0.06–0.02	0.02–0.006	0.006–0.002	<0.002
673 W	100	1	41	31	6	21
S		1	46	35	6	12
636 W	35	1	1	23	43	32
S		2	15	54	15	14
572-577 W	10	3	9	16	38	34
S		6	5	35	29	25

The composition of the sediments is thus more silty, in comparison with the pronouncedly clayey varves in the Uppsala region, the younger varves described by Hörner (1948), and older varves without clear difference in grain size between winter and summer layers by Arrhenius (1947). In contrast to the Uppsala clay the varves in Dalarna have a very low carbonate content (see below).

The bottom varves in particular may contain distinct, thin layers of sand, sometimes horizons or lenses of pebbles or even of diamicton from icebergs as a consequence of the calving activity of the ice margin. In some cases (e.g. the localities no. 53, 55 and 74) the bottom varves are wavy with variable thickness due to ripple structures. At other localities even the thick bottom varves have parallel stratification (e.g. no. 20 B).

In the greater part of the investigated area the colour of the varves is light brownish or almost white in the summer layers and dark, almost black in the winter layers in the superficial part of the sediment. Below the groundwater level the sediment is blueish grey.

In some parts of the investigated area, however, the colour difference between the summer and winter layers is less pronounced. The identification of the varves must then rely more on the difference in grain size. In such cases it may be difficult to distinguish the varves if the sediment is either too wet, or too dry. In the latter case a subordinate stratification often appears so strongly that it can be confused with the true winter layers. This type of varve occurs in the inner, narrower parts of the former sedimentation basins, namely south and south-west of Borlänge and along Dalälven in the Gagnef – Leksand area, and also in the younger varves in the Smedjebacken area (younger than varve 791, Chapter 9, localities no. 81–89). If varves of this type are measured under proper conditions (cf. Chapter 2) they show the same good correlations as the more distinct varves. The cause of these differences in varve facies may be the proportions and the stratification of the outflowing glacial melt-water and the water of the open Baltic basin.

G. Arrhenius (1947) has demonstrated, that the content of

TABLE 2. Organic content.

Explanations: W = winter layer
S = summer layer
Two values for each sample:
First = [C] · 10^4
Second = [N] · 10^5
E.g. 7–11 means: [C] = 7 · 10^{-4}
[N] = 11 · 10^{-5}
Analyses: G. Arrhenius (1951)

Locality		Varve number 566–567	587–588	669–670	765–766	785–786	815–816	832–833
74. Leksamd	W	9–22						
	S	8–14						
72. Gråda	W	77–13	22–20					
	S	84–13	11–11					
73. Hälgnäs	W		7–15					
	S		4–10					
71. Gimsbärke	W		15–14					
	S		12–13					
70. Barkargärde	W	9–17	9–18	14–21				
	S	8–16	6–10	10–19				
63. Vallsta	W	10–13	8–15	11–15				
	S	12–17	8–11	12–16				
58. Tåå	W	8–16	8–15					
	S	7–13	4–7					
35. Åsen	W			10–20				
	S			12–18				
56. St. Skedvi	W			7–15				
	S			11–16				
51. Arkhyttan	W			13–29				
	S			8–17				
39. Nordansjö	W				16–19			
	S				16–15			
32. Ivarshyttan	W			37–43	14–18			
	S			11–21	13–16			
42. Västerby Nygård	W				24–32			
	S				9–9			
27. Dräcke	W				9–19			
	S				1–5			
26. Garphyttan	W				17–21			
	S				7–8			
24. Hyttan	W				21–32		14–29	10–30
	S				9–14		10–14	4–12

Table 2, cont.

Locality		Varve number						
		566–567	587–588	669–670	765–766	785–786	815–816	832–833
23. Jularbo	W				14–30		17–32	
	S				7–13		5–7	
11. Folkärna	W				14–33			
	S				6–10			
2. Rosse	W				19–34		14–31	
	S				11–20		3–8	
20B. Avesta	W							17–28
	S							4–8
17. Dalsberga	W						18–39	10–25
	S						4–9	5–8
76. Livsdal	W					20–30	19–27	17–28
	S					10–15	5–12	5–12
79. Västanfors	W					17–34		
	S					11–17		
80. Semla	W					11–31	13–27	11–23
	S					5–12	7–18	6–13
84. Sörbo	W					7–14	15–30	13–26
	S					6–11	7–15	5–11
89. Saxhammar	W				7–7	7–11		
	S				7–9	2–5		

dark organic matter can be the main cause of colour differences within the varves. Therefore, I submitted a number of selected samples of synchronous varves to Arrhenius (1951), who then used them for a statistical investigation of the relation between the carbon and nitrogen content. These analyses are presented separately by locality and age in Table 2 (the samples always consist of two varves for a sufficient quantity of analysed matter). Arrhenius also determined the carbonate content in the samples. The amount of $CaCO_3$ is only 0.0–0.6 per cent, with the higher values in the north-western part of the investigated area, next to the Palaeozoic limestones in the Siljan region. There is no significant difference between summer and winter layers.

The localities in Table 2 are quoted in geographical order from Leksand in the north-west downstream along Dalälven to the south-east, and from there westwards to Fagersta – Smedjebacken (cf. Fig. 1).

From the table it is evident that a clear difference in the content of organic matter also exists within the main part of the investigated area, where distinct dark winter layers appear. The organic content is higher in the winter layers. In the parts with more evenly coloured varves the content of organic matter is often almost the same in the summer and winter layers. Of special interest is, that in the localities no. 84 Sörbo and 89 Saxhammar this difference between varves with dark winter layers older than 791 and light varves younger than 791 appears also in the analyses. Further southwards, where all varves have dark winter layers (localities no. 76, 79, 80) the normal contents appear again. The very high content of carbon in no. 72 Gråda may depend on redeposited pre-Quaternary carbon, although the possibility of contamination may not be excluded.

7. The chronological correlations within Dalarna

For practical reasons the varve diagrams are presented here in two groups, the main time-scale (Fig. 13–16) of long coherent diagrams, forming the chronological framework for the whole region, and additional localities (Fig. 8–12), mostly short varve series, dating the ice recession at the remaining investigated sites. Where space permits, some short series are inserted in the main time-scale. The additional localities Fig. 8–12, all in the region Avesta – Hedemora – Borlänge are when possible presented in connected groups. All of these are very similar to the main time-scale. The varve numbers given for each diagram or group of diagrams are thus relatively easy to check with the diagrams of the main time-scale (Fig. 13–15).

There is a strong visual correlation between all varve diagrams from the whole Dalälven basin, from the eastern end of the province to Lake Siljan. Both thickness maxima and minima and the general shape and the proportions of the thickness curves coincide. Distal thin varves show the same variations as thick proximal varves, more or less proportionally smoothed out. The characteristic groups of thick varves, separated by a fixed number of thinner varves, could often be identified in the test pits already before the measuring. Within the Dalälven basin correlations are thus possible also at long distances, several tens of kilometres. This conclusion is verified by the great number of intervening localities in this study. The uniform general appearance of the varve thickness variations may be ascribed to two factors: the Dalälven basin is a well defined sedimentation area, on both sides limited by higher, partly supramarine terrain, and the Badelunda - Dalälven melt-water river is the dominating source of the material in the varved sediments (Chapter 5). Thus thickness variations of the varves are determined by the conditions in one single melt-water drainage system. This general pattern of the varve diagrams continues eastwards at least across the Möklinta esker at By (localities no. 1, 2, and 18).

Sometimes a few of the lower varves show local variations, but in other cases there is an almost complete agreement with the general pattern also in the oldest varves. The localities no. 44, 45 and 46 west of Hedemora present a good example of the latter (Fig. 11).

The varves in the Kolbäcksån basin around Lake Barken are generally very thin and lack the sharp, characteristic thickness variations of those in the Dalälven area. Therefore it was necessary to establish the chronological correlation stepwise by the aid of a number of intervening localities (no. 75–80). In this way the dating of the ice recession around the present Lake Barken is firmly connected with the development at Dalälven. As described under the localities no. 76 and 79 (Chapter 9), earlier attempts to make direct datings of isolated measurements can now be shown to be erroneous. In the localities around the northern end of Lake Barken (no. 90–96) it may be possible to trace some similarities of the varve diagrams with those from the Dalälven basin according to the given stepwise correlation. But these agreements are hardly so consistent and obvious that they would permit a safe direct chronological connection between the two sedimentation basins, in spite of the relatively short distance (ca. 30 km: compare the diagrams no. 90–96 with no. 16 Häggebäcken in Fig. 16). The probable explanation is that the Barken basin as already described has its melt-water and sediment sources from more restricted, local discharge areas, with partially different conditions than in the vast drainage basin along the upper course of Dalälven.

Comments on the single varve diagrams and the reliability of the bottom varve observations are given in Chapter 9.

8. The progress of deglaciation

8.1 General results from the varve datings

Two main conclusions can be drawn from the datings of the bottom varves in the investigated area:

The ice margin in the late-glacial subaquatic area retreated towards the north-northwest with an average rate of c. 300 m per year without interruptions, and the ice margin was very irregular and formed deep calving bays around the mouths of the principal melt-water rivers, now marked by the great eskers, the Badelunda – Dalälven esker and its branches, the Möklinta esker and the esker in direction Falun and Svärdsjö. It is difficult to determine exact positions of the mouths of the melt-water rivers, because rapid sedimentation of varves more than 1 m thick close to the mouths make bottom varves difficult to follow. The general directions of the ice margins are, however, established by localities such as no. 17, 19, 20A, 24 and 7, all with bottom varve 846 or 847 (Fig. 1–2). The main reason for the formation of these deep bays in the retreating ice margin must be fractures around the great melt-water river mouths resulting in extensive calving of ice-bergs. In some cases it is obvious that the melt-water rivers, rather than the greatest depth of the present river valleys, cause the most intensive calving. The calving bays thus followed the courses of the great eskers also when these deviate from the deepest part of the present valley, e.g. between Hedemora and Säter. Where the Badelunda – Dalälven esker branches in that region, the calving bay also was divided into one bay following the main esker in direction Säter – Borlänge, the other through the present Lake Runn along the Falun and Svärdsjö eskers (see Special Map 1, Fig. 4, and Fig. 2). Between those two calving bays an ice tongue was left during several decades at St. Skedvi (Fig. 4) in the deepest part of the present valley along the River Dalälven (see further Chapter 8.3). Only in the lower, south-eastern part of the investigated area at Lake Åsgarn and locality no. 15 there is reason to believe, that a topographic depression has caused an increased calving by itself. As already mentioned, the depth of the late-glacial Baltic in the main part of the area was only about 100 metres.

When the pronounced calving bay which followed the Badelunda – Dalälven esker entered the narrow river valley north-west of the wide plain around Borlänge and Lake Runn, remnants of the ice on both sides of the calving bay were cut off from the main ice body by the higher terrain in the north and north-west. East of the calving bay this development is attested only by one of Kulling's (1948) localities, Ornäs, with bottom varve corresponding to 647, but in the south-western corner of the Borlänge plain several varve localities show the gradual disappearence of an ice remnant close to the valley side (Special Map 2, Fig. 5). The last ice body in this region lingered in a higher edge of the plain, protected by low till and bedrock hills (cf. the 175 m contour of Fig. 5). It is remarkable that this site became finally free from ice in the year 655, some three years later than locality no. 72 Gråda in the narrow Dalälven valley about 25 km further to the north-west. Very probably a similar development occurred elsewhere on a smaller scale, but cannot be revealed by the present grid of observations. A possible case is suggested under locality no. 44 Laggarbo (Chapter 9).

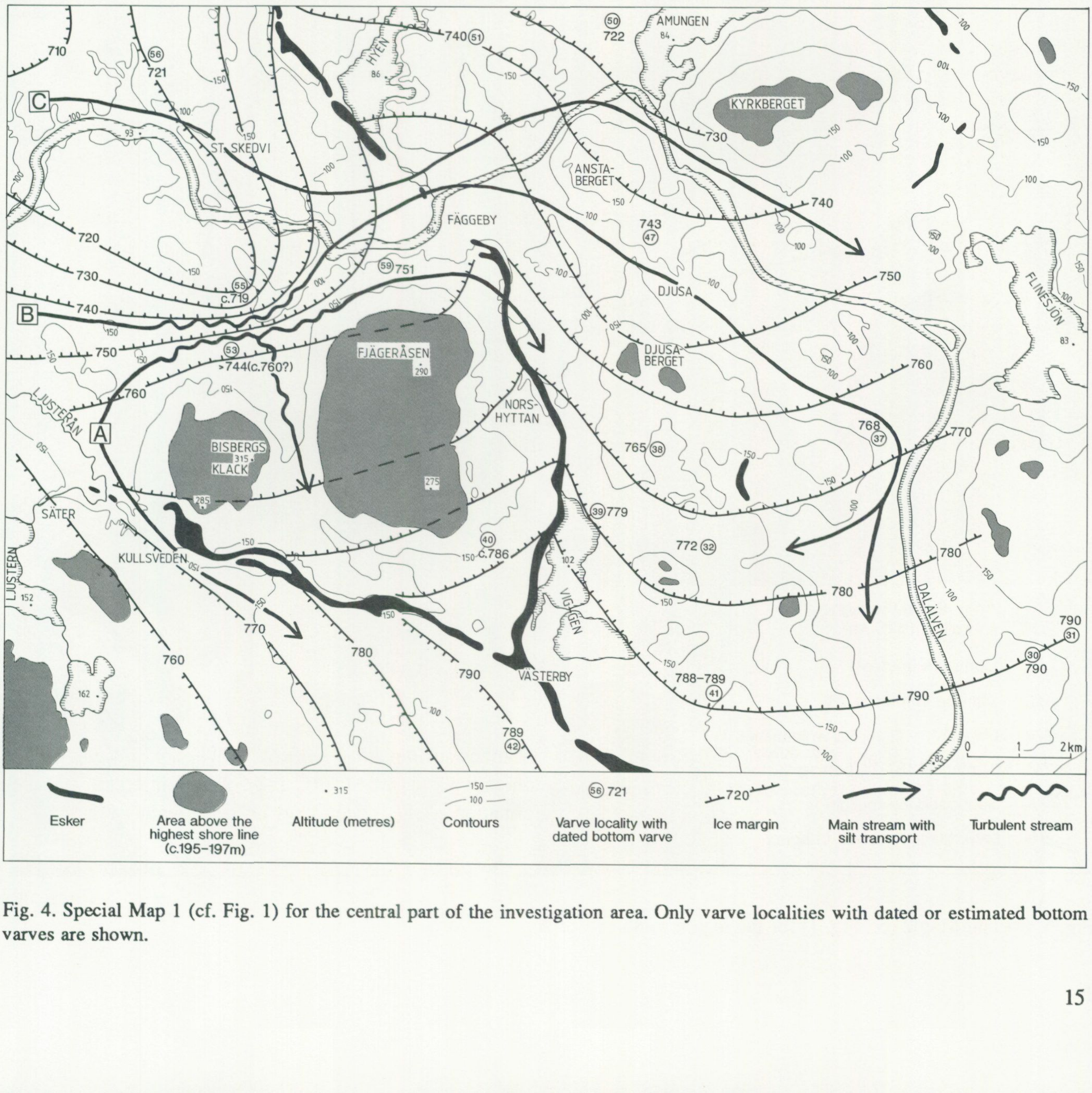

Fig. 4. Special Map 1 (cf. Fig. 1) for the central part of the investigation area. Only varve localities with dated or estimated bottom varves are shown.

Some decades ago a hypothetic oscillation of the ice margin just east of the investigated area, the "Gävle oscillation", was much debated. This oscillation was supposed to reach into the easternmost corner of Dalarna at By (Sandegren 1946). The varved clay in this region is said to be generally disturbed by the readvancing ice (op. cit. pp. 67–69). However the localities no. 1, 2, and 18 with undisturbed varves and safe connections are situated within the area in question. The varves around By thus do not differ from varves in other parts of southern Dalarna. The diagrams show a normal recession of the ice margin with a calving bay at the Möklinta esker. This experience is in good agreement with the opinion of Lundqvist (1951, p.53 ff.) and the results of Järnefors (1963) and Strömberg (1985, 1989) further eastwards.

The ice margins are plotted on the maps only in the late-glacial subaquatic parts of the region, where the varve chronology is applicable and the calving of icebergs possible. Hints of the mode of deglaciation in the supraaquatic parts can be deduced from the supporting evidence discussed below.

8.2 Supporting evidence

Apart from the varve chronology information on the positions of the ice margins is given by traces of contact between the ice sheet and supraaquatic slopes, especially erosion channels from lateral melt-water and the drainage of ice-dammed lakes. Some observations of this kind have been made within the investigated area.

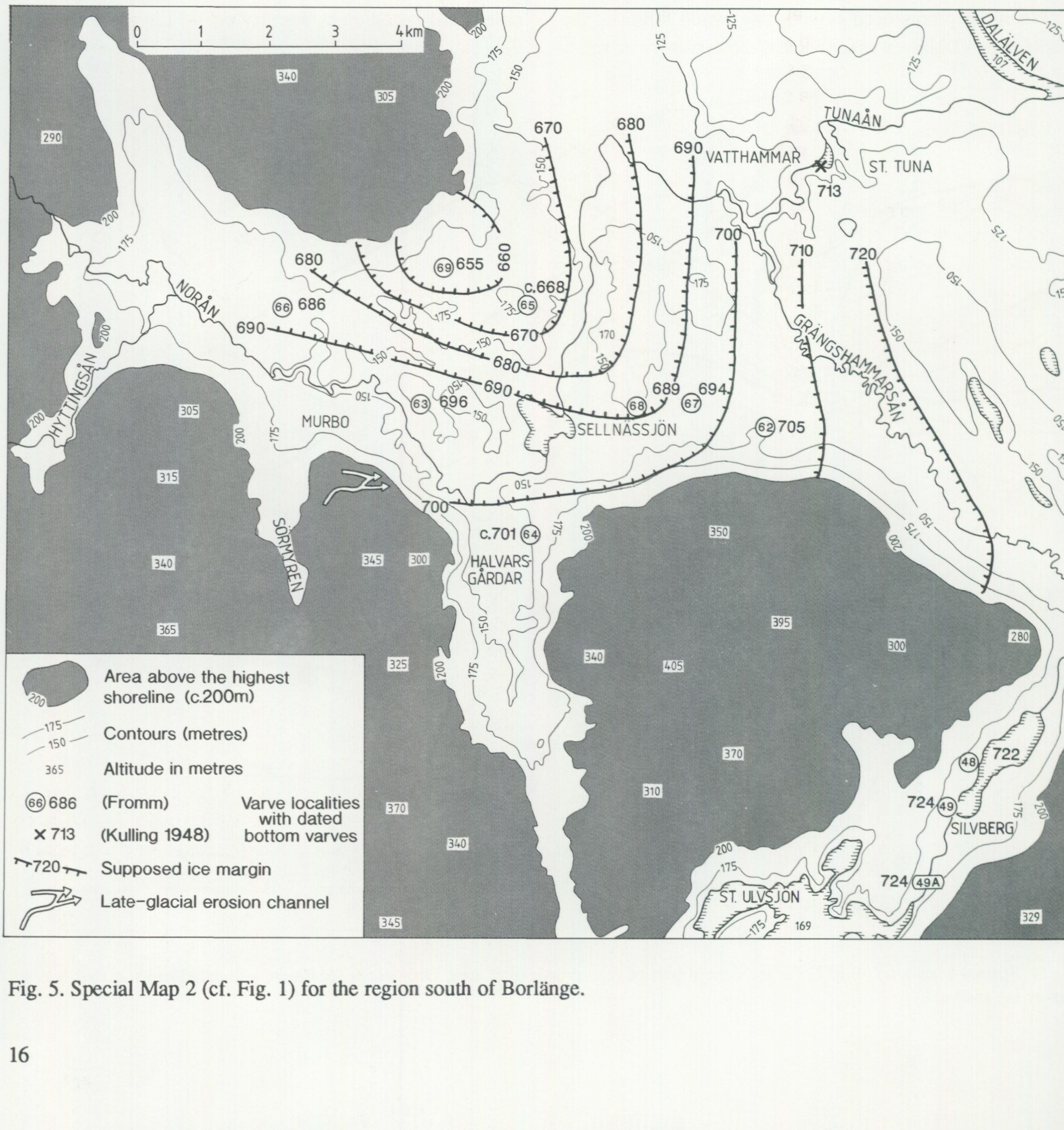

Fig. 5. Special Map 2 (cf. Fig. 1) for the region south of Borlänge.

In the valley at Persbo, north of lake Hillen, c. 10 km north-west of Smedjebacken the eastern slope is dissected by a series of lateral erosion channels ("Persbo-däljorna", Lundqvist 1937, p. 100) down to the highest shore line. They show, that an ice tongue from the north filled the valley down to the subaquatic depression around the present Lake Hillen, when slopes and summits on both sides were already free from ice. The principle that the supraaquatic ice margins were strongly influenced by the topography (cf. G. Lundqvist, passim) implies that many summits and higher slopes adjacent to the calving subaquatic ice margins described above may have been free from ice at an early stage. West of Säter the Badelunda - Dalälven esker is situated close to the southern valley slope ("Gustafs-fältet"). The sedimentation continued up to delta plains at 185–195 m a.s.l., close to the highest shore line. In such a case it is probable, that the calving bay in the Dalälven valley was one-sided with an ice-free slope on the southern side. In line with such conditions the adjacent Silvberg valley (Fig. 5) was rapidly deglaciated only 10–20 years later (localities no. 48, 49, 49 A). Further westwards (Fig. 5), according to the varve measurements, an ice margin existed during the years 700–690 in a direction mainly east–west, which closed the northern outlets of some valleys south of the Borlänge plain. The valley south of Halvarsgårdar (Fig. 5) has a free outlet southwards below the highest shore-line to the Barken basin with a threshold between Järsjön and Myrgåsen (Fig. 1–2) in c. 195 m a.s.l. The Silvberg valley, which joins the Halvarsgårdar valley at St. Ulvsjön, became free from ice before the year 720 as described above, and probably offered an outlet of melt-water also from the area south of Halvarsgårdar. Thus it seems plausible that the water level was not dammed in the Halvarsgårdar valley. The only possibility for a limited damming of short duration would be a remaining isolated icebody in the basin of the present Lake St. Ulvsjön. But there are no clear traces of damming and drainage either in the north at Halvarsgårdar or in the south at St. Ulvsjön.

The two valleys from Murbo to Sörmyren and along Hyttingsån (Fig. 5) have no outlets southwards below the highest shore-line. Ice dammed lakes have been supposed there (Ingmar 1931, Lundqvist 1953). This interpretation is supported by the ice margins, constructed from the varve measurements. The drainage of the ice-dammed lake at Sörmyren probably formed the erosion channels at Murbo (cf. Lundqvist 1951, p. 63) at the ice contact in the years around 700. In c. 690 at the latest both lakes must have been drained down to the level of the Baltic. Possibly the stratigraphy at the varve locality no. 64 Halvarsgårdar reflects drainage events (see Chapter 9).

In the valley of River Västerdalälven further north there is evidence for damming and drainage on a larger scale (Ingmar 1931). South of Björka a deep drainage channel or rather canyon, "Trolldalen", was the outlet of an ice-dammed lake along the River Västerdalälven down to the level of the highest shore-line c. 195–200 m a.s.l. A coherent damming ice margin must have crossed the Västerdalälven valley in the main direction east–west simultaneously with the rapid deglaciation of the main Dalälven valley. Possibly the final drainage took place approximately in the year 660.

At Heby (Brändan) west of Gagnef erosion channels down to the highest shore line (Lundqvist 1951) presuppose an ice contact along the south-western valley side. The shape and dating of this ice margin in relation to the varve locality no. 72 Gråda remain uncertain on the basis of the present observations alone.

In southern Sweden changing directions of the iceflow on both sides of deep calving bays are registered at many places by glacial striae. Observations of this kind from southern Dalarna exist, but they are not common, partly due the difficulty of obtaining good observations of striae on outcrops of coarse granites. Kulling (1948, pp. 60–62) describes some younger striae mainly on the shore of Lake Runn and interprets them as young adaptions of the ice movements to the topography, but they fit well with ice movements towards the calving bays.

At Grevbo, 0.3 km north of the varve locality no. 67 I noted in 1948 older striae from the north-north-west (337°) and younger from the west (263°), with some traces of intermediate directions. The older striae are best preserved on rock surfaces sloping towards the east, The younger striae are common on rock surfaces sloping towards the west and are partly missing on surfaces exposed towards the east. This observation was made without knowledge of Lundqvist's later description of the same locality (1953, p. 49, no. 2). He had found other localities with striae from an easterly direction and interpreted the younger striae as coming from the east (60°–70°). If my observation is correct, the younger striae at Grevbo could represent the ice movement towards an ice front on the south-western side of the calving bay, corresponding to the years c. 710–720.

Further southwards it would be difficult to identify young deviations of the striae north of the calving bay along the Badelunda - Dalälven esker. They would almost coincide with the normal direction approximately from the north. On the southern side there is at least one observation of striae, strongly influenced by the calving bay, namely at the "Dead Falls" in Avesta, c. 1 km south-east of the varve locality no. 20 B Avesta (Jan De Geer 1973, p. 22). In two places on the extensive bedrock outcrops younger striae from the south-west (227°–231°) are found together with older, "normal" striae from the north (346°–348°), and some intermediate directions. The younger striae are approximately perpendicular to the ice front of the year c. 860 on the south-western side of the calving bay.

There are no end moraines (De Geer-moraines) in the investigated area in contrast to their presence at several eskers in southern Sweden with calving bays registered both by striae and the moraines.

8.3 Deglaciation and silt transport

With a pronounced hilly topography and a dissected ice front the conditions of silt transport from the mouths of the melt-water rivers could change considerably during deglaciation. Consequences of such a development are found in the varved sediments as alterations in the average thickness and the composition of the varves. Such cases may have only local consequences, e.g. at the localities no. 26 and 73 (Chapter 9), but two situations have a more regional significance.

The difference between lower varves with thick winter layers and upper light, silty varves in the Barken basin at Smedjebacken, with the transition between the two varve types in the year 791, has already been described in Chapter 6. The map of the ice recession (Fig. 2) gives a plausible explanation. Before 791 drainage into the Barken basin was limited to the small melt-water rivers indicated by the local eskers north and north-east of the present lake. The main melt-water drainage from the Vässman area and north of Grangärde (for the place-names, see Fig.1) continued towards Malingsbo south-east of Lake Haggen through a valley with a threshold approximately in level with the highest shore-line. Later, about the year 791, the passage from the present Lake Haggen to the Barken basin at Smedjebacken became open. The melt-water and its sediment load then mainly flowed into the Barken area, with a clear difference in the sediment as consequence in northern part but with only a slight change in the south (cf. locality no. 80, Chapter 9).

The complicated development between Hedemora and Säter with two diverging calving bays is reflected also in the sedimentation processes (Special Map 1, Fig. 4 and the varve diagrams Fig. 6). The sediment transport, which followed the bottom streams, can be divided into three stages:

A. (older than the year 744). At first the melt-water and suspended sediment from the main Dalälven stream had only one outlet through the shallow passage at Kullsveden (threshold c. 165 m a.s.l., 25–30 m below the highest shoreline). Soon afterwards a new and deeper passage was opened between the ice front in the north and the northern slope of Bispbergs Klack. This mountain (max. altitude 315 m a.s.l.) probably became a nunatak at the end of the deglaciation, and this fact may have contributed to the rapid retreat of the ice front until about the year 760. Further eastwards the melt-water had a broad shallow outlet between the mountains Bispbergs Klack and Fjägeråsen (threshold c. 160 m a.s.l.) and a deeper one through the broad valley at Norshyttan (threshold c. 105 m a.s.l.), where the silt transport received a further contribution from the northern esker at Fäggeby. The ice front impeded silt transport north of Djusaberget until some years after 750. Consequently, at varve locality no. 37 (and to some extent also at no. 32) the varves older than 744 are thinner than the following younger varves due to the restricted silt transport in this direction before that year.

Most of the discharge from the Dalälven melt-water river probably ran through the narrow, but rather deep passage north of Bispbergs Klack. Here the bottom current was so strong that on average rather thick varves were deposited as stream ripples during the melting season. The depth of the water at varve locality no. 53 (c. 120 m a.s.l.) was c. 75 m. The rapidly variable thicknesses of the wavy ripple varves even within an ordinary test pit make connections by thickness variations impossible (Fig. 6). It is obvious that such a strong current on the side of the valley could only develop if the wide main furrow of the present valley was barred by remaining ice. At locality no. 59 (c. 105 m a.s.l.) rather thick, but regular varves were deposited in a wider and more open body of water.

B. (the years 744–712). The main water and silt stream north of Bispbergs Klack continued. The ice front north of the mountain retreated only slowly, and as late as in the years 719 - 712 thick ripple varves were deposited in locality no. 55 (c. 105 m a.s.l.), and the ripple sedimentation in no. 53 continued. In the east the silt transport found a new way to the deepest part of the Dalälven valley through the broad and deep passage at Djusa (threshold c. 95 m a.s.l) and later along the present river course between Anstaberget and Kyrkberget. Varves younger than 744 are therefore thicker than the older varves in no. 37 (and no. 32). Thick but regular varves are deposited at no. 47 during stage B and continue at no. 59, indicating that the main silt transport passed these localities as described.

C. (after the year 712). The sedimentation of thick ripple varves in no. 53 and 55 ceased, and was replaced by the deposition of regular, much thinner varves, which show a close accordance with the general pattern of thickness variations. The main valley furrow along the present river must have become free from ice rather rapidly about the year 712, probably through a sudden and intensive calving process. The silt transport eastwards could then proceed through the broad and deep valley without obstacles.

The reconstruction of an ice tongue protruding into the main furrow of the Dalälven valley at St. Skedvi on the basis only of dated bottom varves in the localities no. 53, 55, 56, and 59 may seem daring. However, the existence of stream ripples in no. 53 and 55, but not in synchronous varves at other places gives a strong support for this interpretation of the varve datings.

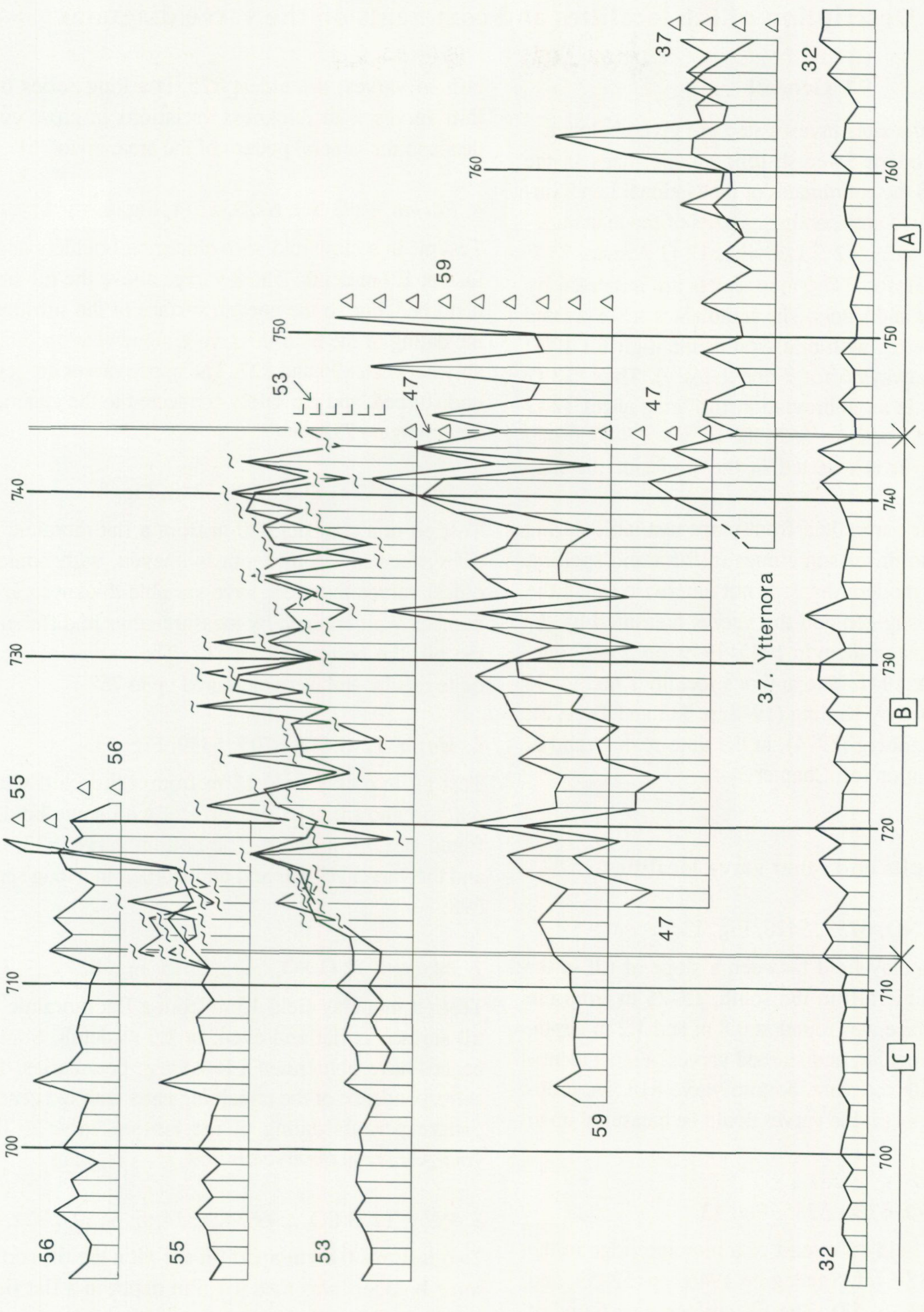

Fig. 6. Varve diagrams from localities within Special Map 1 (Fig. 4) to illustrate the different courses of silt transport and sedimentation. Explanations see Fig. 8.

9. Description of the localities and comments on the varve diagrams

9.1 General

The locations of the sites investigated are given below according to the modern Swedish topographic maps in the scale 1:50 000 and the coordinates of the National Land Survey. The investigated area comprises parts of the map quadrangles 11 G Västerås, 12 F Ludvika, 12 G Avesta, 13 F Falun, and 13 G Hofors. The map sheets are indicated by their index number and letters. The coordinates are expressed in hundreds of metres with omission of the digit for 1000 km (in this area always 6 for x and 1 for y). Thus "12 G NO, 6753, 5420" is an abbreviation for "map sheet 12 G Avesta NO, coordinates x = 6675300 m, y = 1542000 m". The coordinate grid is inserted in the frame of the map Fig. 1.

The place-names are taken from maps available during the field work and differ sometimes in form and spelling from those of the modern maps. If not otherwise stated the localities are investigated and the varves measured by the present author, most of them in 1945–1949, no. 21–22 during mapping work 1941. The author's localities no. 34–36 have been published by Kulling (1948, p. 118 and Tavla 2), no. 72–74 by Brunnberg (1974), in the time-scales valid at the time of publication (cf. Chapter 3–4).

9.2 Test pits and other varve localities

1. Staksbo. 12 G NO, 6753, 5420, Fig. 13.

Two test pits in a clay field between a slope of till in the north and a morainic hill in the south, 15–25 m from the latter. The till surface was found at 0.8 m and 1.2 m depth, respectively, and regular, undisturbed varves, almost identical in the pits, with the same bottom varve 818, were observed. In the deeper pit the varves could be measured up to 743 (Fig. 7).

2. Rosse. 12 G NO, 6764, 5385, Fig. 13.

Test pit in a clay field 15 m east of a moraine ridge in the direction NNW–SSE (cf. Sandegren 1946, pp. 52–53, and G. Lundqvist 1951, p. 53). The till surface was found at 1.75 m depth below regular, undisturbed varves with the bottom varve certain at 831. Varves were measured up to 713 (Fig. 7).

3. Juvik. 12 G SO, 6748, 5367, Fig. 8.

Test pit in a clay field 20 m from a slope of till with large boulders. The till surface was found at c. 1.5 m depth with two ca 50 mm thick, sandy bottom varves, probably influenced by the nearby Möklinta esker. Above these two bottom varves, the oldest 825, is a long series of regular thin varves with thickness variations in close correspondence to the general pattern of the area, up to 761.

4. Färjan. 12 G SO, 6729, 5374, Fig. 8.

Test pit in a clay field with emerging boulders and till surface at 1.0 m depth. The 8 varves above the till are slightly disturbed, due to the uneven surface of the substratum, and the dating of the bottom varve is somewhat uncertain, probably between 825 and 827. The upper varves are regular and undisturbed, and are safely connected to the general pattern, the youngest 792.

5. Spisbo. 12 G SO, 6738, 5348, Fig. 8.

Test pit in a clay field 20 m from a flat morainic hill. The till surface in 1.6 m depth is uneven, with boulders. The oldest varves therefore have variable thicknesses, but their number is ascertained by measurements in different parts of the pit, the bottom varve 817. The varves above 811 are quite regular and were measured up to 767.

6. Mesta. 12 G SO, 6705, 5339, Fig. 13.

Test pit in a clay field 15 m from a little hill with a rock outcrop and till. The till surface, with some boulders was found at 1.75 m depth. The bottom varve, 833, is certain and the varves regular and undisturbed in a long series up to 698.

7. Bäsinge. 12 G SO, 6672, 5315, Fig. 8.

Test pit in a clay field 15 m from a flat morainic hill. The till surface is flat and even, in 1.5 m depth. Some disturbances have obliterated a few varve boundaries. The close correspondence of the remaining parts with the general varve pattern permits dating of the bottom varve to 847. The youngest varve observed is 769.

8. Råby. 12 G SO, a: 6634, 5314; b: 6639, 5321, Fig. 8.

Two test pits 0.8 km apart. In the pit a the till surface with some boulders was met at 1.5 m depth in a flat field 10 m from emerging till. The upper varves are weathered and indistinct. The lower varves are distinct, but with layers and lenses of sand and diamicton in 867–862. With aid of the b profile a probable dating is obtained, 867 for the bottom varve and 852 for the youngest varve measured.

Pit b is situated in a clay field 50 m from a flat morainic hill. A long series of distinct varves were measured with the bottom varve safely dated to 865. There are lenses and layers of sand and diamicton in the varves 865–863, and the youngest varve is 815. The sand and diamicton layers are

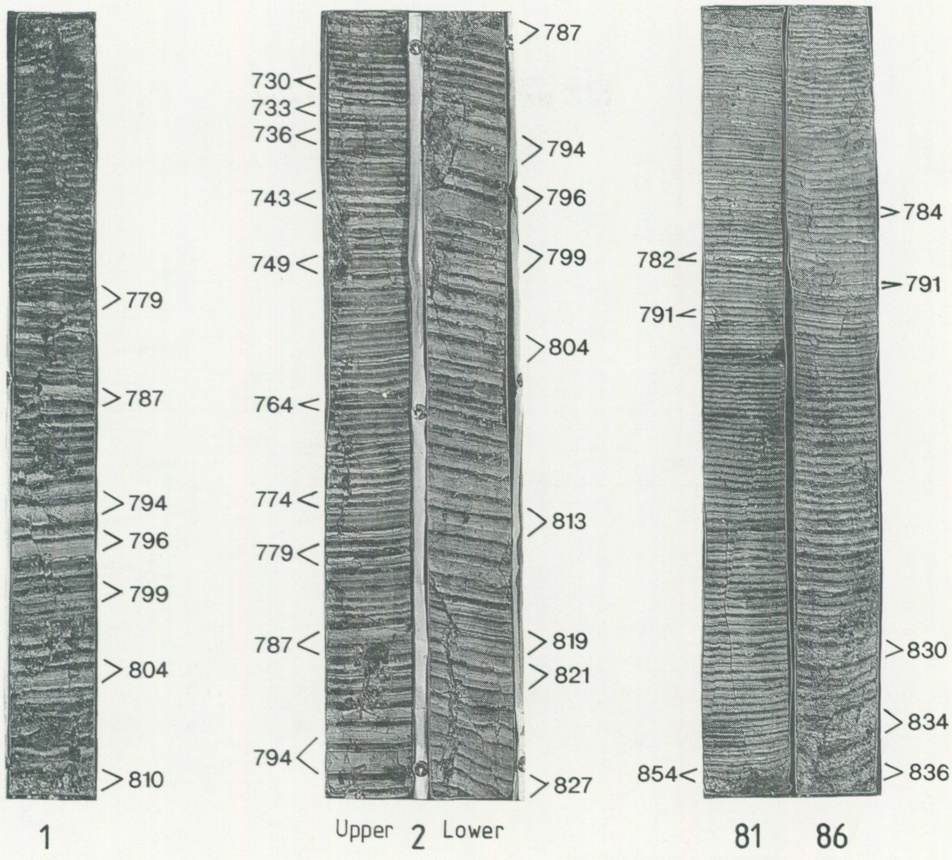

Fig. 7. Specimens from varve localities. The length of the zinc boxes is 0.5 m. From the left: No. 1 and 2 with regular varves, east of By. No. 81 and 86 with change of the varve type in the year 791, from the Smedjebacken area. Some characteristic varves are dated according to the diagrams Fig. 13 and 16. Photo Carl Larsson, SGU

probably traces of the calving activity of the ice front (cf. Chapter 6).

Järnefors' (1963) locality no. 66 Skinnarbo is situated c. 0.5 km to the NNW from pit b. His long diagram shows an excellent agreement with the measurements in this study (the Skinnarbo diagram is partly reproduced in Fig. 3). The oldest varve corresponds to year 854. His boring probably did not reach the true bottom varves.

9. Illmyra. 12 G SO, 6646, 5302, Fig. 8.

Test pit in a clay field 20 m from the exposed till showed a series of distinct, regular varves, 851–808. Sliding disturbances occur below these varves, and no dating of the bottom varve was possible. The oldest varve, 851, thus gives a rather self-evident minimum age of the ice recession, in comparison with the locality no. 8.

10. Folkärna södra. 12 G SO, 6681, 5289, Fig. 9.

Test pit in a clay field 25 m from a flat till slope. The till surface, with a few boulders, was found at 1.9–2.0 m depth. A series of varves, mostly regular but with some limited deformations due to small slidings, could be reconstructed by comparison of all sides of the test pit, 849–813. The bottom varve 849 contains layers of fine sand and diamicton, and should possibly be divided into two varves. In that case the dating should be 850.

11. Folkärna. 12 G SO, 6708, 5279, Fig. 9.

Test pit in a clay field 20 m from an outcrop of Precambrian metabasite. A regular series of varves, with the bottom varve concordantly upon the till surface with some boulders, was measured, 836–736. Around 790 two varves are missing according to the connection with all other varve localities in the vicinity with this part represented. No traces of the missing varves could be found in the test pit, but the great number of varve series, confirming this part of the local sedimentation leads to the conclusion that these two varves have disappeared through sliding or possibly erosion during the deposition. The dating of the bottom varve, 836, was confirmed in another test pit 25 m from the pit mentioned, by 17 almost identical varves.

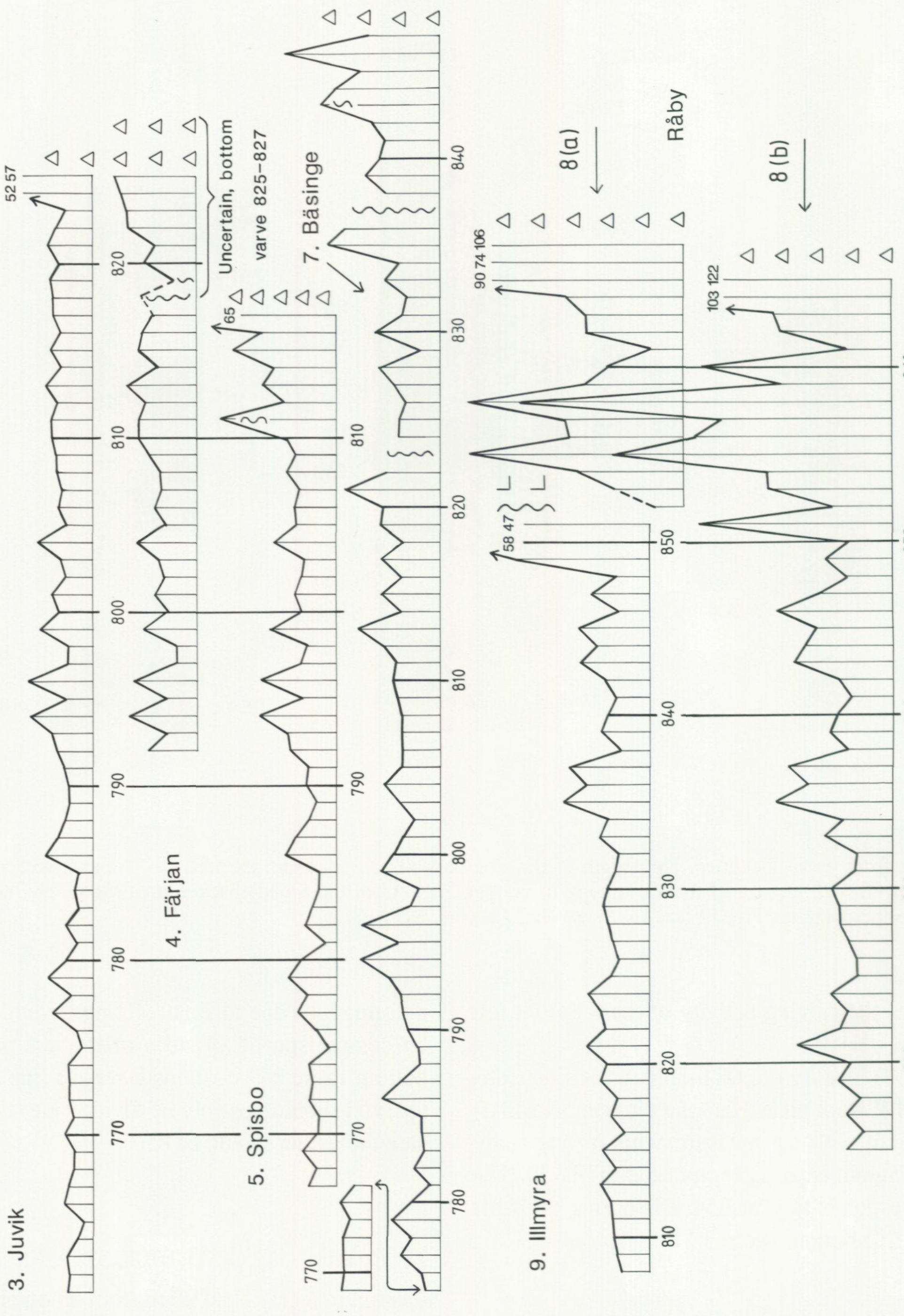

Fig. 8. Varve diagrams from the additional localities east of Avesta. The curves show the varve thicknesses in the scale 1/2, unless otherwise stated. Numbers instead of thickness curve indicate the true varve thickness in mm. For further explanations see Fig. 13.

12. Backa-Mesta. 12 G SO, 6725, 5312, Fig. 9.

Test pit in a clay field, 25 m from a flat till slope. The till surface was met at 1.5 m depth, flat and with few boulders. A series of distinct, regular varves was measured, 830–791, with a reliable observation of the bottom varve 830.

13. Backa. 12 G SO, 6723, 5297, Fig. 9.

Test pit in a clay field, 25 m from till, rich in boulders. The till surface with boulders was met at 1.5 m depth. The lowermost varves are bent around the boulders, but at two different places between boulders the same number of varves was counted and the bottom varve dated to 834. Above the

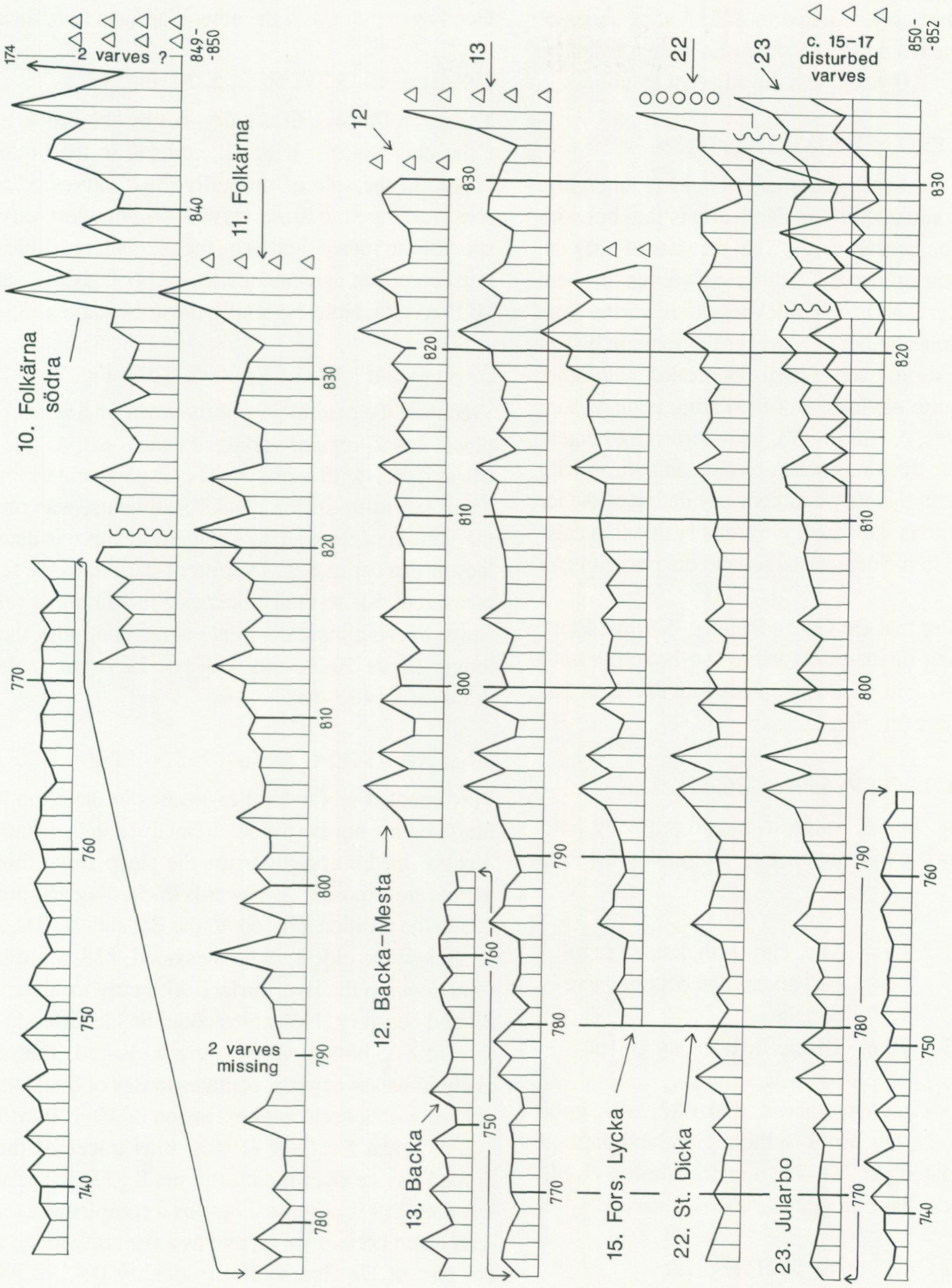

Fig. 9. Additional localities no. 10 - 23 (Avesta region). For explanations see Fig. 8 and 13.

top of the boulders the varves are regular and were measured up to 741 with good connection with the other varve series in the area.

14. L. Dicka. 12 G SO, 6745, 5285, Fig. 13.

Test pit in a slightly sloping clay field, 25 m from a flat morainic hill. The till surface at 2.0 m depth was even, and the completely undisturbed bottom varve, only a thin silt layer and the winter clay, is dated to 825. A long series of regular, distinct varves up to 725 shows an almost complete agreement through 100 years with the adjacent localities.

15. Fors, Lycka. 12 G NO, 6783, 5279, Fig. 9.

Test pit in a clay field with some large boulders emerging. The till surface is situated in 1 m depth and is flat, but with some boulders, The bottom varve, 825, consists of only the winter clay directly on the till. The lower varves are bent around the boulders, and their thickness thus varies from point to point. Their number is however the same in different sides of the test pit, even if their connection with other localities is not quite obvious. But the dating is made sure by the upper varves, c. 800 to 780, with perfect agreement of the characteristic thickness variations in comparison with other varve series. In this way a rather early dating of the ice recession at this site is indicated, presumably due to a calving bay developed in the depression around the present Lake Åsgarn.

It is worth noting that De Geer's locality "Krylbo, Fors" (Da 3) has a dating of its oldest varve (no bottom varve) corresponding to 815, in good agreement with the other diagrams presented here (cf. Fig. 3).

16. Häggebäcken. 12 G SV, 6598, 5236, Fig. 13.

Specimens in zinc boxes, taken in a gravel pit by Sten Florin in 1940 during the mapping of the geological map sheet Avesta.

Stratigraphy:	0– 2.95 m	Silty clay with distinct regular varves. The bottom varve certain
	2.95–3.70 m	Glaciofluvial stony gravel

A long series of regular varves, 870–682, with good agreement with the other series in the region, and the bottom varve safety dated. At 781–782 a minor sliding, visible in the box specimen, has obliterated these two varves.

17. Dalsberga. 12 G SV, 6649, 5221, Fig. 13.

Two test pits in a clay field, one close to exposed till, down to the till surface, the other further outwards in the clay field with the younger varves. The connection of the varves between the pits could be established visually already in the field. The bottom varve is 846, the youngest varve measured 796. With the exception of the uppermost weathered six varves there is good agreement with the other localities.

18. Storbyn. 12 G NO, 6775, 5410, Fig. 13.

Test pit in a clay field with the till surface at 1.5 m depth, with some boulders, and a reliable observation of the bottom varve, 821, and distinct, undisturbed varves up to 765. Good agreement with the other diagrams from the region.

19. Åfsta. 12 G SV, 6672, 5220, Fig. 13.

Trench in the side of a gully, cut by the brook Lerbäcken ("the clay brook") with till exposed in the bottom of the brook. In the side of the gully thick varves of coarse silt were measured, bottom varve 847, youngest varve 821. In spite of the rather short sequence (26 varves), there is an almost complete agreement with no. 17 Dalsberga and 20 A–20 B Avesta. Note especially the thick varves 835–837.

20 A. Avesta . 12 G SV, 6695, 5202, Fig. 13.

Trench in the central part of the town of Avesta for sewage pipes. Thick, regular varves of coarse silt. At one place the till surface, with some rather large boulders protruding about 0.5 m up in the glacial sediments, was observed in the bottom of the trench. The bottom varve is dated to 846, the uppermost to 825. In spite of the relatively few varves measured, due to their thickness, the dating is reliable because of the almost complete agreement with the adjacent longer series 20 B, and with no. 19 Åfsta, including the thick varves 835–837.

20 B. Avesta. 12 G SV, 6702, 5210, Fig. 13.

Test trenches and natural exposures in the 25 m high river bluffs on the northern side of Dalälven in the central part of Avesta. In the upper part of the steep slope thinner silty varves are exposed, downwards thickening and more sandy, due to the position adjacent to the Badelunda - Dalälven esker. Below the oldest varve measured, 838, there is c. 12 m sand down to the river surface with only local exposures of till and bed-rock. No varves could be identified in the sand, therefore no bottom varves were measured. The sand, especially in its lower parts, contains lenses of boulders and diamicton with a horizontal extension of 10–100 m. These are "rafts" sensu De Geer (1940), thus traces of the calving around the ice river mouth (cf. no. 8 Råby). The varve series, 838–758 is presented here as a complement to no. 20 A with dated bottom varve, and as a firm link to the main, upper part of De Geer's (1940) locality Da 1–2 Avesta (cf. Fig. 3). In De Geer's diagram, however, the varves older than a dating corresponding to 805–810 deviate completely from my own measurements and all the other diagrams presented here. Perhaps there have been difficulties to combine the outcrops of thick varves in the lower part of the river bluff.

21. N. St. Dicka. 12 G NO, 6772, 5253, Fig. 13.

Gravel pit in a local glaciofluvial deposit. On the top above sand and gravel, there is a layer of silty clay with regular thin varves, dated 807–759. Below the varve 807 there is

0.2 m sand with broken remnants of 4 silty varves, and gravel. The dating of the bottom varve therefore has an uncertainty of some years, c. 811.

22. St. Dicka. 12 G SO, 6748, 5256, Fig. 9.

Gravel pit in a local glaciofluvial deposit. A layer of silty clay is conformally deposited upon the gravel, with thin, regular varves 834–767, thus a safe dating of the bottom varve 834.

23. Jularbo. 12 G SO, 6717, 5257, Fig. 9.

Three test pits in a clay field with large boulders and till at 2.0 m depth. The upper varves are regular and easily dated from the youngest 736 down to c. 820–825. Below that level there are deformations and variations of thickness of the varves due to the very uneven till surface with boulders. In spite of several attempts only a tentative counting with dating of the bottom varve was obtained, c. 850 to 852.

24. Hyttan. 12 G SV. 6735, 5228, Fig. 13.

Test pit in a clay field close to a slope with till rich in large boulders. Due to the protruding boulders there are some deformations in the lowest varves, but undisturbed concordant bottom varves were found in a low level on a flat, even boulder surface, the oldest dated 847. The long series of regular distinct varves continues upwards to 731.

Järnefors' (1963) locality no. 67 Grytnäs k:a is situated c. 1.5 km south of the present no. 24 Hyttan. The long diagram has a very good correlation with no. 24 and other localities. Järnefors' oldest varve corresponds to 840. Clearly the boring has not reached the bottom varves.

25. Knutsbo. 12 G NV, 6758, 5212, Fig. 13.

The upper, thin varves were measured in a ditch and the lower ones in a test pit more close to a morainic hill, with a good observation of the bottom varve 810. The upper varves in the pit show a close agreement with the varves in the ditch, where the youngest varve measured is 671, in all 140 varves.

26. Garphyttan. 12 G NV, 6795, 5180, Fig. 13.

Test pit in a clay field, close to a morainic hill. The till surface with boulders was found in 2.0 m depth, with a reliable observation of rather thick bottom varves. The rapid sedimentation is explained by an adjacent local esker. The varves thin out rapidly upwards, but become thicker again after the year 805. Then the silt transport from the north through the valley, in which no. 26 is situated, is supposed to be opened by the ice recession, and the sedimentation rate increased. The varves could be measured up to the year 697.

27. Dräcke. 12 G NV, 6779, 5078, Fig. 13.

Test pit in a clay field. Thin, regular varves down to the bottom varves, resting on till with boulders. Due to the uneven surface of the till, the dating of the lowest varve may be somewhat uncertain, probably 775, possibly 1 - 3 years older. The youngest varve measured is 684.

28. Nås. 12 G NV, 6801, 5105, Fig. 10.

Two test pits in a clay field, one with a good observation of undisturbed bottom varves on an even till surface, the other with younger varves. The distance between the two pits was 25 m, and the varves show a close agreement. A series from the oldest varve, 802, to 767 could be combined in this way.

29. Trollbo. 12 G NV, 6880, 5164, Fig. 10.

This profile was measured in 1939 by B. Waern during mapping work in an excavation down to the till for a house foundation. The varves 746–677 are dated by their close agreement with the adjacent varve series, but with 5 varves, 725–721, missing, probably due to a sliding. The oldest varve measured, 746, probably does not represent the true bottom varve. The dating 746 seems to be far too young, if compared e.g. with 790 for both localities no. 30 and 31. A sliding or erosion may have destroyed older varves, and Waern's notations on the measuring strip may suggest some disturbance, perhaps comparable with the cases observed at locality no. 43 or 57 (see below).

30. Borsbo. 12 G NV, 6893, 5160, Fig. 10.

In an almost 3 m deep test pit down to a flat till surface regular bottom varves were found between large boulders protruding 1 m up in the clay. The oldest varve is 790, the same year as in the adjacent no. 31, and the youngest dated varve is 741.

31. Höjen. 12 G NV, 6897, 5168, Fig. 10.

Test pit in an slightly sloping clay field, some 20 m from a flat morainic ridge, rich in boulders. The till surface was found in 1.5 m depth, rather even and without larger boulders at the actual site. By comparison of the different walls of the test pit a series of about 50 varves could be combined, the oldest varve (790) with the same dating as in no. 30 and the youngest 740. It may be noted that the bottom varve 790 is rather thin in no. 31 in comparison with no. 30. This fact can be interpreted as an ice recession at no. 31 in a later part of the same year as in no. 30.

32. Ivarshyttan. 12 G NV, 6914, 5097, Fig. 6 and 13.

Test pit in clay field, 10 m from a till slope with moderate number of surface boulders. In the test pit the till surface

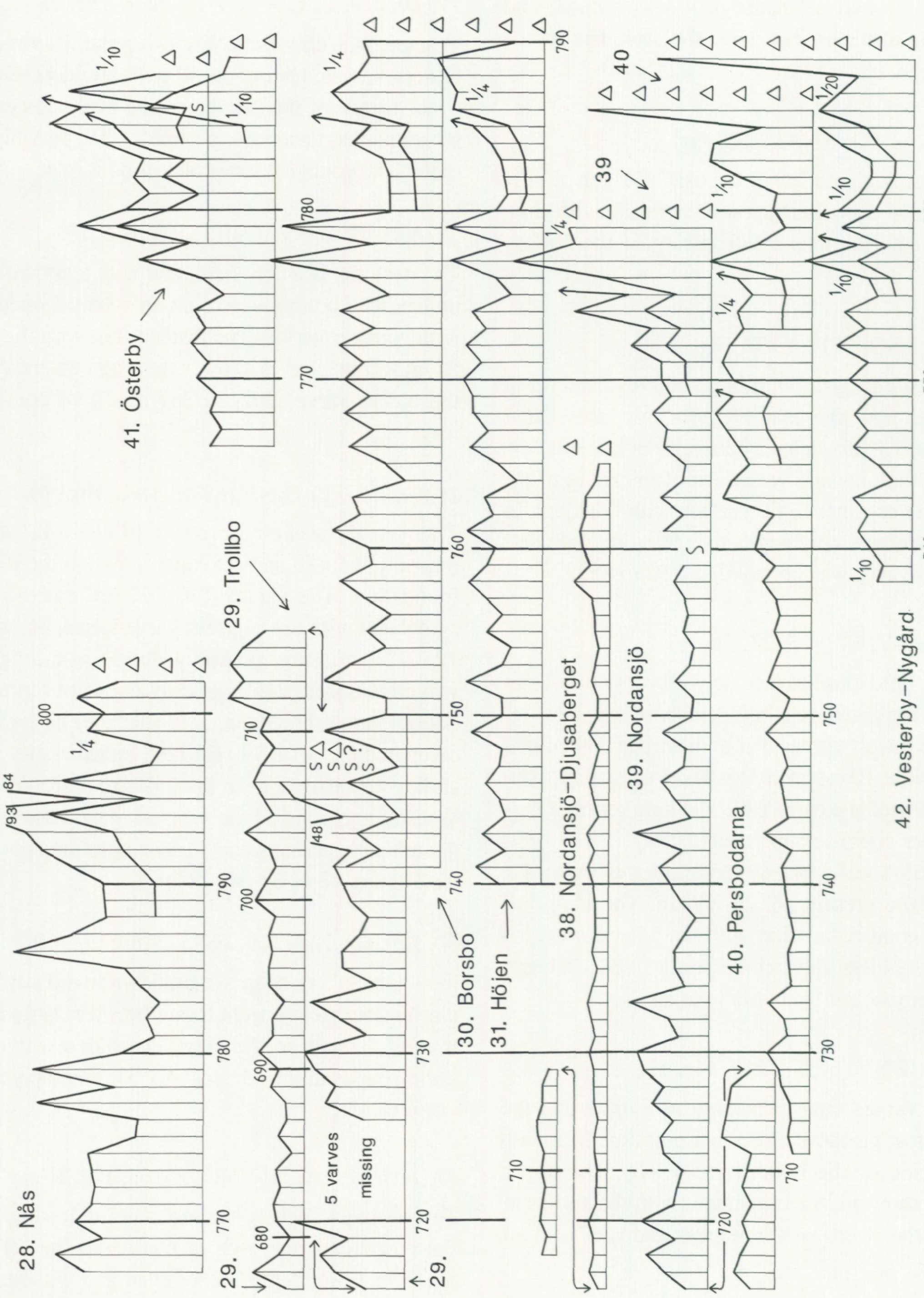

Fig. 10. Additional localities no. 28–42 (Hedemora region). No. 37 Ytternora is reproduced in Fig. 6 only. For explanations see Fig. 8 and 13.

was even and only slightly sloping, at 1.8 m depth, and the varves including the bottom varves concordant, regular and distinct. By measurements in different walls of the pit more than 100 varves were combined from 772 to 661.

33. Olofsfors. 12 G SV, 6716, 5133, Fig. 13.

Test pit in a clay field down to the till surface, which was rather even with only few boulders. The varves are regular and distinct from the bottom, 803, up to the youngest, 741.

Two of the lower varves, 797 and 794, are thicker, due to layers of sand and pebbles, but have constant thickness and conform fully with the other varves. The agreement with other varve series is best in the upper part, but there is no reason to doubt the dating of the bottom varve.

34. Rankhyttan. 13 F SO, 7065, 4964, Fig. 14.

Test pit in a flat clay field, 20 m from a morainic hill. Almost horizontal, flat till surface with only few boulders below the clay with conform, regular and distinct varves from the bottom, 710, up to the youngest varve measured, 590.

35. Åsen. 13 F SO, 7072, 4931, Fig. 14.

Test pit in a clay field close to till with rock outcrops. The till surface in 1.5 m depth was rather uneven, with boulders. The bottom varves were therefore somewhat disturbed, but a measurement between boulders gave estimated dating for the lowest varve, 688, with an uncertainity of only some single year. The younger varves are quite regular and distinct up to 618. There are no traces of the missing varve according to the time scale of De Geer (1940) between 656 and 655.

36. Milsbo. 13 F SO, 7034, 4899, Fig. 14.

Test pit in a clay field close to a flat morainic hill. The till surface with boulders was found at 1.5 m depth, but the varves are regular, the oldest almost only the winter clay directly upon the till, dated 689, and the youngest measured 621. The supposed varve between 656 and 655 (De Geer 1940) is absent also in this measurement.

37. Ytternora. 12 G NV, 6934, 5130, Fig. 6.

Two test pits in a clay field close to till rather rich in surface boulders. In both pits the till surface was found at about 1.5 m depth. In spite of the uneven till surface with boulders, causing disturbances and thickness variations of the bottom varves, the number of varves and thus the datings of the oldest varve, 768, is identical in the two observations. The younger varves, up to 737, are quite regular and almost identical in the two pits, permitting a safe dating. The youngest varves (from 744) are thicker than those below. An explanation is discussed in Chapter 8.3.

38. Nordansjö-Djusaberget. 12 G NV, 6932, 5087, Fig. 10.

Test pit in a clay field between mountains (about 145 m a.s.l.). The till surface is situated at 1.5 m depth, rather even, with regular but thin varves due to the shallow water during the sedimentation of the varved sediment (c. 50 m depth compared with c. 90–100 m in the valley plains). The thickness variations are thus much smaller than at localities in the valleys, but permit a safe dating with bottom varve 765 and the youngest varve measured 705.

39. Nordansjö. 12 G NV, 6920, 5076, Fig. 10.

Test pit in a clay field near a morainic hill, rich in boulders. The varves are regular, resting on a rather even till surface, with the bottom varve dated 779, the youngest measured 703. The varve 760 is almost destroyed by a horizontal sliding and represented only by a double winter clay layer on the top of varve 761.

40. Persbodarna. 12 G NV, 6915, 5056, Fig. 10.

Test pit in a clay field close to a till slope with varves sloping out from the emerging till. The uppermost 40 varves are regular, clayey - silty, with good agreement with other series. The lower varves are thicker and consist mainly of fine sand in the summer layers. Slidings have partly obliterated the winter clay layer in some of the lower varve limits. The dating of the bottom varve, 786, therefore may be uncertain by a few years. The upper varves, up to 744, are firmly dated in the time scale.

41. Österby. 12 G NV, 6885, 5099, Fig. 10.

Four test pits in a clay field. In two of them, 20 m and 100 m from the adjacent till slope, varve series could be measured down to an even, flat till surface at about 1.5 m depth. Good agreement between the pits and with other series shows, that the western pit (close to the till slope) has a bottom varve, 788, one year yonger than the eastern pit (100 m from the till), 789. The youngest varve dated is 766.

42. Vesterby-Nygård. 12 G NV, 6874, 5058, Fig. 10.

Four test pits in a field of silty sediments 35–150 m from a slope with exposed till. In the pit closest to the till slope, the surface of the till was found at 2.7 m depth, and the lowest thick 10 varves, including the bottom varve, could be observed. By addition of the measurements in the other pits, a series of younger but rather thick varves could be combined in almost complete agreement between the different pits. The bottom varve is dated 789, the youngest 758.

43. Vesterby p. 150. 12 G NV, 6876, 5055, Fig. 11.

Three test pits within 15 m distance. In all of them there is an upper series of regular, thin varves, dated 732 – c. 675. Below varve 732 there are traces of sliding and two considerably thicker silty varves (each c. 100 mm), in two pits resting on the till, in the third upon folded, disturbed varves. The two thick varves therefore cannot be regarded as true bottom varves. Disturbances through sliding and possibly erosion may be the explanation. An ice recession only a few years older than the oldest dated varve 732 is further hardly compatible with the dating of locality no. 42 only 0.4 km away.

44. Laggarbo. 12 G NV, 6843, 5055 and 5053, Fig. 11.

One test pit (a) in a silty field 20–30 m from the slope of exposed till on the eastern side of a valley in the direction N–S, and a trench (b) at the brook in the centre of the valley, 200 m west of the test pit (a). At both sites regular silty varves were found with some small disturbances by faults, which, however, could be avoided in the measurements. The till surface in both pits was flat or slightly sloping without larger boulders, and covered by regular, well ascertained bottom varves. The varve diagrams, 778–764 (a) and 771–740 (b) show a very good connection with the general pattern of thickness variations. In spite of these good observations there is a difference in the dating of the deglaciation at these adjacent sites of 7 years. The explanation may be that an ice remnant was left in the protected valley around no. 44 for some years after the rapid deglaciation of the main lowland area at Hedemora, and that the two observations are situated just at the border of this isolated ice body (cf. Chapter 8.1).

45. Jälkarby. 12 G NV, 6856, 5032, Fig. 11.

Test pit on a plain field, 20 m from a morainic hill, rich in boulders, with a series of regular varves. The upper varves are thinner and clayey, the lower ones thicker and silty. The bottom varves rest without disturbances on a flat surface of gravelly till at 2 m depth between larger boulders. The bottom varve is dated 769, and the youngest 728.

46. Vikmanshyttan. 12 G NV, 6859, 5014, Fig. 11.

Excavation through the late-glacial sediments with upper thin clay varves and lower silty varves, 10–40 mm thick, resting on a sloping till surface with boulders. Due to the uneven substratum there is some uncertainty in the lowermost 5 varves. The best estimation gives the dating 760 for the bottom varve. From 755 to the youngest varve 691 there is no doubt about the measurement or its connection with the main time scale.

47. Bengtsbo. 12 G NV, 6973, 5086, Fig. 6 and 14.

Test pit with the till surface at 1.5 m depth with some rather large boulders, and c. 30 thick silty varves, with regular bottom varves between the boulders. In spite of the few varves a very good connection with the main pattern is obtained (cf. especially no. 52 Landsbro), corresponding to a dating of the bottom varve to 743 and the youngest varve to 715.

48. Silvberg norra. 12 F NO, 6946, 4834, Fig. 11.

Test pit in a silty field with the till surface at 1.2 m depth and distinct, undisturbed varves. A comparison with the adjacent series no. 49 and 49 A gives a dating from 722 (bottom varve) to 712.

49. Silvberg. 12 F NO, 6940, 4831, Fig. 11 and 14.

Test pit in an silty field with the till surface at 1.2 m depth. 16 varves could be measured, the uppermost three weathered, the remaining 13 distinct and undisturbed, with the bottom varve certain. Within the possible range of time a dating 724 (bottom varve) to 709 may be regarded as well founded in spite of the few varves. The winter clay layer of varve 720 is divided into three thin layers. The same feature occurs in no. 48. This fact verifies the connection between no. 48 and 49.

49 A. Silvberg södra. 12 F NO, 6928, 4827. Fig. 11.

Test pit in a flat silty field not far from exposed till. The till surface in the pit was met at 1.4 m depth. Only 11 varves could be measured, but they are distinct, and can be safely connected with no. 48 and 49. The datings thus are 724 (bottom varve) to 714.

50. Myckelby. 13 G SV, 7014, 5077, Fig. 12.

Test pit in a clay field 10 m from exposed till, rather rich in boulders. The till surface in the pit was met at 1.0–1.5 m depth, rather uneven due to boulders. Deformations and faults occur among the 14 lowermost varves. By observations in different parts of the pit a reliable measurement of the number and thickness of these varves could be achieved. The upper varves are regular and undisturbed. The dating of the bottom varve is 722, and of the topmost 669.

51. Arkhyttan. 13 G SV, 7012, 5052, Fig. 14.

Test pit in a clay field, 20 m from a morainic ridge, rich in large boulders. At a depth of 2 m a flat surface of a large boulder was found below boulder tops protruding c. 0.5 in the clay. The bottom varves on the surface mentioned were quite clear and undisturbed. A series of more than 100 distinct varves could be measured, from the bottom varve 740 to 632.

52. Landsbro. 12 G NV, 6998, 5024, Fig. 14.

Measurement and sampling by O. Kulling 1937 (not published) in an open pit on the side of the Falun – Svärdsjö esker. The varved silt continues below the oldest varve measured, and no bottom varve was found. This very long, regular varve series (738–533) is reproduced here as a confirmation by an independent investigator of the general chronological pattern in this part of the time scale (the very thin, youngest varves from 557 are omitted here).

53. Hällbo. 12 G NV, 6951, 5005, Fig. 6 and 12.

Four test pits in a silty field 10–80 m from exposed till. The lower, at least 30 rather thick varves are developed as fluvial ripples, with distinct winter layers separating the an-

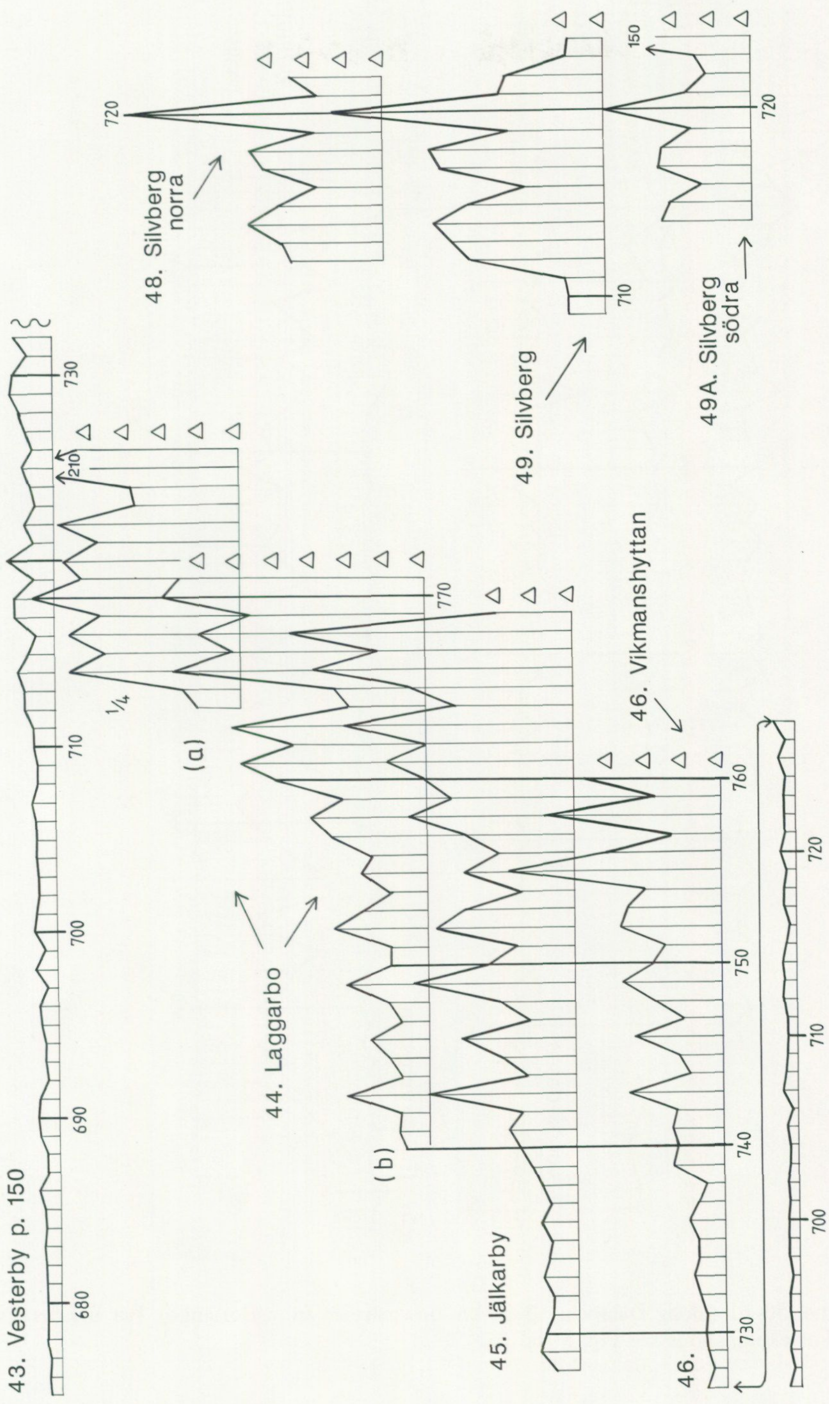

Fig. 11. Additional localities no. 43–49 A (Hedemora – Säter). No. 49 is also plotted in Fig. 14. For explanations see Fig. 8 and 13.

nual deposits, but with very variable thickness of the same varves even within a single test pit. The varves therefore have a wavy appearance. Therefore it was not possible to date the bottom varve in the pits 10–30 m from the till exposure, where only the wavy varves were present above the till. In the remaining two outer pits the till surface was not reached at 2.5 m depth. Above the ripple varves were normal, regular and thinner varves c. 714–660, which permit a reliable dating. From them the lower varves can be dated by counting, but without chronological control. The oldest

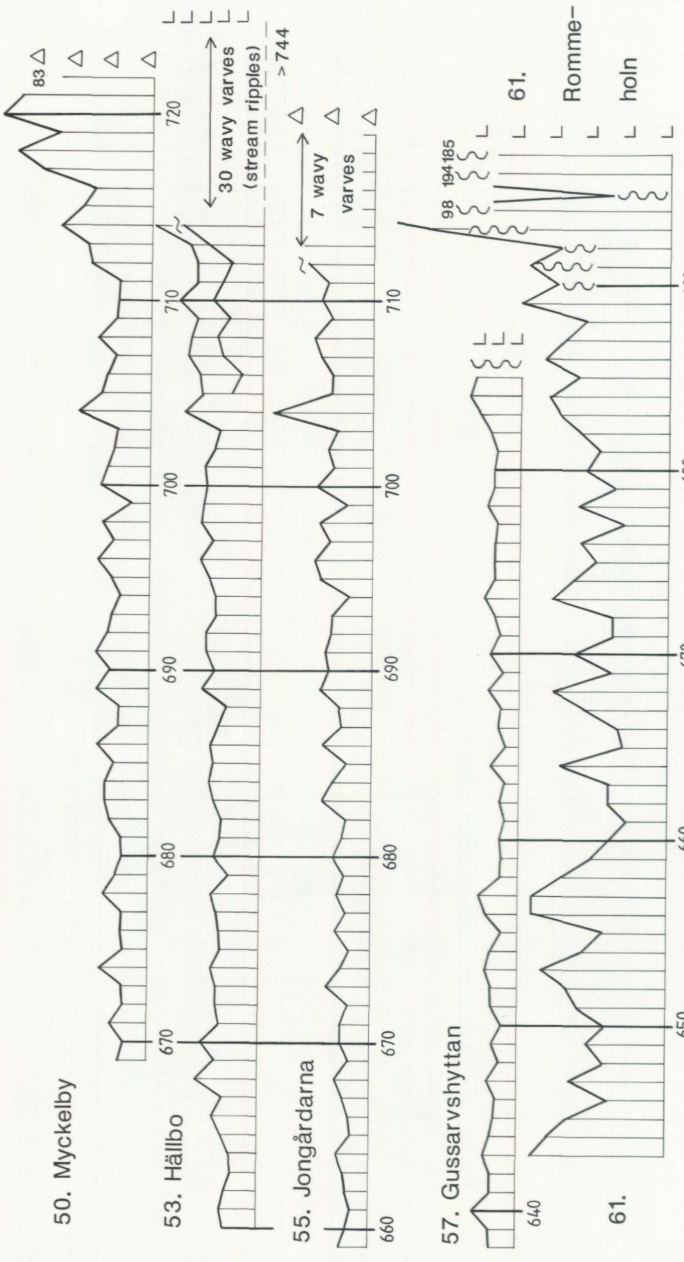

Fig. 12. Additional localities no. 50–61 (along Dalälven 10–30 km downstream from Borlänge). For the details of the lower varves in no. 53 and 55, see Fig. 6. For explanations see Fig. 8 and 13.

varve in the outer pits would thus be 744, to which should be added estimated 10–20 years down to the till surface. The dating of the ice recession would thus be c. 754–764. The significance of the ripple varves at this locality and no. 55 is discussed in Chapter 8.3.

54. Persbo. 12 G NV, 6961, 5009, Fig. 14.

Measurement in a trench for sewage pipes. Neither the till surface nor the lower varves with ripple structures (cf. no. 53 and 55) were reached in the excavation, but a very long series younger regular varves, 706–573, support the general time-scale.

55. Jongårdarna. 12 G NV, 6964, 5006, Fig. 6 and 12.

Two test pits in a silty field 20–40 m from an area of exposed till, down to the till surface at 1.0–1.5 m depth. The oldest varves directly on the till show the same stream ripple structure as described from no. 53. The upper varves from c. 711 are distinct and regular, and permit a reliable dating up to 659. The number of the varves below 711 may not be quite certain, but the interpretation given in the diagrams (bottom varve c. 719) can hardly have an uncertainty of more than a few years. This surprisingly young date for the deglaciation can, however, be explained by the regional development of the sedimentation, as described in Chapter 8.3.

56. St. Skedvi. 13 F SO, 7007, 4989, Fig. 6 and 14.

Two test pits in a silty field 10–20 m from exposed till, one down to the till surface, the other for the younger varves. The bottom varve is only 2 mm thick, consisting of a winter clay layer directly on the till, and is dated to 721. All varves are quite regular, and the measurements in the pits give in combination more than 100 varves up to 608, showing excellent agreement with the other long series in this region, e.g. no. 54 and 60.

57. Gussarvshyttan. 13 F SO, 7028, 4955, Fig. 12.

In spite of trials in six test pits no undisturbed bottom varves were found. The best observation is about 50 regular thin varves, dated 685–638, resting on 120 mm silt with all structures obliterated by slidings, directly above the till surface.

58. Tåå. 13 F SO, 7021, 4917, Fig. 14.

Two test pits with a very long series of thin varves, 656–532 (only the varves older than 546 are reproduced in the diagram). Below 656 in the first pit are about 12 varves, disturbed by slidings and still lower an indeterminate number of strongly deformed varves. In the other pit the varves older than 646 are deformed. Accordingly no dating of the ice recession was possible at this place.

59. Fäggeby. 12 G NV, 6967, 5034, Fig. 6 and 14.

Two test pits in a silty field 15 and 35 m respectively from a morainic ridge, rich in boulders. In the first pit the till was found at 1.5 m depth below regular bottom varves with some layers of gravel and pebbles. The oldest varve is dated 751. By combination with measurement in the other pit the series of regular varves could be followed to 697.

60. Gustafs. 12 F NO, 6990, 4915, Fig. 14.

Measurement by C. Caldenius (1926, Pl. 3) in "Gully 17" close to the southern bank of Dalälven near Gustafs with a number of gullies cut into the thick silty sediments. I present here the locality Gustafs according to Caldenius' original publication, in preference to the version, given by De Geer (1940, Da 6), which is composed by measurements by Caldenius (op. cit.) and R. Lidén 1929, but with no diagram for the oldest varves. The oldest varves measured by Caldenius are about 1 m thick. Below them, according to Caldenius' borings, the silt continues more than 6.5 m. An estimation of the age of the bottom varve may be possible in the following way.

According to Caldenius (op. cit. Pl. 1) there are outcrops of rock and boulders at the former river shore in the neighborhood, corresponding to an altitude c. 102 m a.s.l. (the river is now dammed at the hydroelectric power station Långhagsforsen). According to Wenner (1941, Fig. 3 and tables pp. 92–97), the till or rock surface was found in borings at an altitude of 91–105 m a.s.l., corresponding to 10 - 24 m below Caldenius' oldest varve in "Gully 17" (altitude c. 115 m a.s.l.). With an estimated varve thickness of 1–2 metres the number of remaining bottom varves down to the substratum would be about 5–15. Caldenius' diagram comprises the varves 729–564. The estimated age of the ice recession would thus be about 734–744.

According to De Geer (1940, Da 6) the bottom varve is dated corresponding to 732, but there is no confirmation in diagrams or tables. De Geer's (1938) diagram ends at 727 and in the text a dating 735 is stated for the oldest varve, but no bottom varve is identified. The remaining parts of his diagrams show complete agreement with Caldenius' measurements, except for the two gaps mentioned in Chapter 3.

61. Rommeholn. 13 F SO, 7023, 4850, Fig. 12.

Three test pits in a silty field 20–40 m from a little morainic hill, rich in boulders. The till surface lies at more than 2.5 m depth below thick bottom varves, disturbed by slidings, and no dating was possible. Younger, regular varves above the thick deformed varves are dated 695–643, but are separated from the latter by obvious slidings.

62. Nyby. 12 F NO, 6997, 4803, Fig. 14.

Three test pits down to c. 2 m. In two of them the till surface was found. The varves were regular and could be combined in a long sequence. Some minor slidings could be avoided by comparison of the different measurements. The dating of the bottom varve is 705, and the uppermost measured varve 597.

63. Vallsta. 13 F SO, 7001, 4752, Fig. 14.

Test pit in a silty field in a flat slope down to the rather even surface of the till in c. 2 m depth. A very long, regular sequence of varves was found, with almost complete agreement with the other diagrams from the region. Some slight disturbances occur in the bottom varves around uneven parts of the till, but the bottom varve could be safely dated to 696. The varves continue to 533. Parts of the measurements had to be checked on specimens in the laboratory (see Chapter 6).

64. Halvarsgårdar. 12 F NO, 6980, 4769, Fig. 15.

Test pit with 1 m silty clay, resting on a sedimentary silty fine sand with gravelly layers, and in the upper part with two concordant thin silt layers, containing three and one varve, respectively. The silty clay above the fine sand consists of regular and undisturbed varves, which however had to be measured on specimens in the laboratory (Chapter 6). The lowest varve is 697, the youngest 652. Including the 4 varves within the fine sand, the ice recession may be dated c. 701. Possibly the drainage of an ice-dammed lake at Murbo (Chapter 8.2) has some bearing on the stratigraphy with alternating sand and silt layers.

65. Frostbo. 13 F SO, 7015, 4768, Fig. 15.

Two test pits in a silty field between a slope of till and a hill of rock outcrops surrounded by till. One of the pits represents the upper part of the varve series. The other pit reached the till surface at 1.5 m depth. The bottom varves are slightly disturbed around uneven parts of the till, and an uncertainty of a few years may remain for the dating of the oldest varve. The series thus comprises the years c. 668–532.

66. Gallkya. 13 F SV, 7016. 4731, Fig. 15.

Test pit in a slightly sloping silty field down to a flat surface of rock (or a large boulder) at 1.7 m depth. Above the rock surface is a conform, long series of very thin, regular and undisturbed varves. Due to the slight colour differences in the varves, they had to be measured in the laboratory on specimens. They represent the years 686 (directly upon the rock) to 538.

67. Grevbo. In the limit between 12 F NO and 13 F SO, 7000, 4793, Fig. 15.

About 1 m silty clay, resting upon sandy till with moderate boulder content, in the side of an excavated pond. Only a short series of varves could be measured in the thin clay layer, but the varves are distinct and regular, and permit a safe dating from the bottom varve 694 to 677.

68. Ängarna. In the limit between 12 F NO and 13 F SO, 7000, 4784, Fig. 15.

Test pit in a silty field with a slightly sloping even till surface in 1.1 m depth, and distinct, regular varves from 689 (bottom varve) to 664.

69. Lerbäcken. 13 F SO, 7021, 4755, Fig 15.

Test pit in a sloping silty field near a hill with rock outcrops, till and shore gravel. Regular varves occur down to the till surface, with thin layers or lenses of fine sand in the varves, corresponding to shore erosion in the adjacent hills. The measurements give a safe dating from 655 for the bottom varve, to 629.

70. Barkargärde. 13 F SO, 7088, 4822. Fig. 15.

This very long series from Kulling (1948, Tavla 2), with no bottom varve, is reproduced here as an excellent chronological backbone for the whole area Borlänge – Leksand, and as a confirmation of the long series no. 63, 65 and 66.

71. Gimsbärke. 13 F SV, 7160, 4697, Fig. 15.

This diagram from Kulling (1948) is combined by measurements in a clay pit (op. cit. p. 118 and Tavla 2) without bottom varve and of varves deposited directly upon esker gravel (op. cit. Fig. 38, 39, 40, p. 103–104 and Fig. 44, p. 120). The series thus gives a dating for the deglaciation, 661, as an important link between the observations in the Borlänge region (no. 62 - 69) and the Leksand area (no. 72–74).

For Kulling's remaining varve measurements in the Borlänge – Falun area the reader is referred to the original publication (op. cit. pp. 117 ff. and Tavla 2). The datings of the bottom varves in Fig. 2 are expressed in the revised chronology.

72. Gråda. 13 F SV, six localities, four on the northern bank of the river, 7211–7213, 4567–4574, and two on the southern bank, 7208, 4576–4578, Fig. 15.

Trenches in the river banks, dug under direction of C.G. Wenner as part of engineering-geological investigations 1948 for the hydroelectric power station Gråda. The banks are steep and about 12–14 m high before the damming. The main part consists of thick late-glacial sandy and silty sediments. The youngest deposits consist of delta sediments showing stream ripple structures. In the localities on the northern bank c. 5–50 mm thick regular silty varves are found in the middle part of the sections, in combination representing the years 614–526. These varve series end downwards in slidings and could not be followed into the lower, sandy parts of the banks. However, at the easternmost locality on the northern bank and at both localities on the southern side c. 500–1000 mm thick sandy varves are preserved at the foot of the banks. These varves must be older than the varve 614 mentioned above because of their position and thickness. At 655–634 they show a good correspondence with no. 70 and 71. In view of the limited span of time possible, this dating may be regarded as conclusive. At two of the localities the till surface is determined to 4.1 m below the oldest measured varve 655 by boring, and at one of them were outcrops of boulders not far from the site. The 4.1 metres would correspond to 3–5 thick bottom varves at the most. A probable dating of the deglaciation thus is year c. 658.

73. Hälgnäs. 13 F NV, 7284, 4647 and 7286, 4645, Fig. 15

Two clay pits of an old brickyard, one with till exposed in the bottom of the pit, the other representing the younger varves. Except for the two oldest varves with slight erosion or slidings, all varves are regular and undisturbed. The bottom varves are thick and sandy, the upper varves silty and considerably thinner. The oldest varve is dated 632. The ten varves 629 - 619 are especially thin, probably deposited when the southern part of the present Insjön basin was separated from the main Dalälven valley by the remaining ice front in the north. The varves younger than 619 could be measured up to 556 and agree almost completely with the corresponding varves in no. 72.

Brunnberg (1974, pp. 147–148) has repeated and confirmed the varve measurement at Hälgnäs, with addition of a number of still younger varves. The diagram Hälgnäs (Da 11) by R. Lidén 1917 in De Geer (1940) shows only partial agreement with Brunnberg's and my own diagrams. It is possible to identify some groups of De Geer's (1940) varves with probable datings differing 1–4 years from the diagram presented here, in addition to the general difference of 115 years (Chapter 4).

74. Leksand. 13 F NV, 7353, 4561, Fig. 15.

Excavation for a foundation in the central part of the Leksand township, with an exposure of more than 4 m sediments. The stratigraphy from the surface was:

0–1.6 m	Silt with thin varves. Several small lenses of fine sand and ripple structures indicate streaming water and make varve measurements uncertain.
1.6–2.7 m	Silt with more than 50 regular varves.
2.7–4.0 m	Silt with indistinct varves. Ripple structures and lenses of fine sand indicate streaming water.

At 6 m depth coarser sand was found but no till surface. The stratigraphy can be interpreted in the following way. Immediately after the deglaciation the sediments were deposited in streaming water outside the ice-river mouth of the Dalälven esker. Later, when the ice front receded, but only during about 50 years, there was a regular sedimentation of varves in calm water. Then, the narrow passage of the Baltic Sea into the Siljan basin became so shallow through land elevation that the sedimentation again was influenced by currents. The altitude of the site is c. 175 m a.s.l., the highest shore-line in the surroundings 206 m (Brante 1974).

The regular varves show good agreement with no. 72 and 73, and are dated 587–525. A few of the oldest and youngest of these varves already show ripple structures and sand layers.

About 12 km north of Leksand at Laknäs old brickyard, near the village of Tällberg, Brunnberg (1974) found a varve locality with a confirmed bottom varve observation, probably corresponding to a dating 571. No. 72 Gråda, 14 km south of Leksand, has a dating of the deglaciation c. 658. The rate of the ice recession through the central part of the Dalälven valley from Gråda into the southern part of the open Siljan basin at Tällberg would thus be on average 299 m per year. An approximate interpolated dating for the deglaciation at Leksand according to this calculation is c. 610, some 20 years older than the oldest dated varve at that locality. This conclusion seems rather plausible in view of the stratigraphy described, and Brunnberg's estimated datings of the bottom varves at his localities 2. Rönnäs and 3. Lycka.

75. Karbenning. 12 G SV, 6579, 5152, Fig. 16.

Test pit in an almost horizontal clay field 25 m from slightly sloping till. At 1.5 m depth a rather uneven till surface with numerous boulders was found, and a series of distinct regular varves. The bottom varves, however, are deformed around the boulders, and an uncertainty remains. The bottom varve could be dated 856 or 855 and the youngest varve 785.

76. Livsdal. 12 G SV, 6575, 5093, Fig. 16.

Test pit in a flat clay field 20 m from a slope of till and bed-rock. A flat till surface with few boulders was found in 1.5 m depth. The bottom varves were quite regular and permitted dating to 856. The youngest varve is 748.

De Geer (1940) has a diagram from "Norberg, Livsdalen" (Vsl 8) with the varves corresponding to 850–815 according to his connection, apparently founded mainly on comparison with Uppland. With the aid of the new diagram from Livsdal the old series Vsl 8 can be safely dated to 843–808. The varve corresponding to 843 is said to represent the bottom varve, but the exact location of the site is not given, which may explain the difference from no. 76.

77. Norberg. 12 G SV, 6602, 5066, Fig. 16.

Test pit in a clay field 30 m from a low morainic hill. The till surface in 1.5 m depth was even with few boulders, and permitted a safe observation of bottom varves. 14 varves above the substratum were traces of a horizontal sliding, which has obliterated some varves, The remaining varves above the sliding are safely dated up to 815. The 14 oldest varves give a probable date for the bottom varve as 826, by comparison especially with the adjacent no. 76. This dating implies that four varves are lost in the sliding, which is supported by the fact that traces of three clayey winter layers remained in the sliding zone.

78. Snytsbo. 12 G SV, 6539, 5123, Fig. 16.

Two test pits 15 m apart with the till surface at 1.0 and 1.5 m depth. Both pits contain regular, distinct varves with the same dating of the bottom varve, 878. In the deeper pit the varves could be measured up to 769.

79. Västanfors. 11 G NV, 6499, 5013, Fig 16.

Excavation for a foundation, c. 2 km south of the township of Fagersta (parish of Västanfors) gave an excellent opportunity for varve measurements. The varves were distinct and regular. The bottom varves could be measured with certainty, and minor deformations around protruding boulders avoided. The till surface was situated in 1.3–1.5 m depth. The dating of the bottom varve is 884, which is the oldest varve registered in this study. There is an excellent agreement e.g. with no. 78. The youngest varve is 757.

De Geer (1940) quotes a locality Västanfors ("Bankhouse"), Vsl 9, presumably in the central part of Fagersta near Västanfors church. His dating for the diagram corresponds to 815–758, and seems to be founded upon a rather plausible agreement, especially in the upper part of the diagram, with the nearest localities in Dalarna (Da 1–2 Avesta and Da 3, Krylbo, Fors). However, De Geer's diagram Vsl 9 shows an almost complete agreement with the varves 873–816 in no. 79, 58 years older than De Geer's dating. The bottom varve (op. cit. p. 254) is said to be probably 8 years older than the oldest varve in the published diagram (op. cit. Pl. 77), thus corresponding to 881 in the present time-scale, to be compared with 884 for no. 79. The difference is well compatible with the distance and direction between the localities. Clearly the dating first given by De Geer depends on random agreements between his rather short varve sequence from Västanfors and the long diagrams from Dalarna, without chronological control through intervening localities.

80. Semla. 12 F SO, 6558, 4978, Fig. 16.

Test pit in a flat clay field, 30 m from a low morainic hill. Regular thin varves continue down to the till surface at 1.1 m depth. Some winter layers among the upper, very thin varves, younger than 775, are rather thin and indistinct. This is the southernmost locality with the first signs of a division between lower, distinct clay varves and upper, more silty varves with thin winter layers (see under no. 81–89). The bottom varve is safely dated to 858.

81. Glimbo. 12 F SO, 6576, 4956, Fig. 16.

Test pit in a slightly sloping clay field, 30 m from exposed till. The till surface was found in 1.1 m depth below a series of thin varves (Fig. 7). The bottom varve is safely dated to 855. Below 791 all varves have rather thick and dark winter layers (as is normal in the region to the east and south), but from 791 upwards the winter layers are thinner and less dark, and the varves more silty. As a whole these younger varves appear less distinct. This change of varve facies is found in all localities no. 81–89 and serves also as a useful chronological marker. A more local feature is, that the winter layer of varve 819 is divided into two or three parts in the localities no. 79, 80, and 81, thus supporting the correlation between them. The youngest varve measured at Glimbo is 782 (cf. below).

82. Skogsbyn. 12 F SO, 6565, 4949, Fig. 16.

Test pit in a clay field 10 m from a slope with exposed till. The till surface was found at 1.5–1.75 m depth. Two thick sandy bottom varves are preserved between protruding boulders, but are slightly deformed due to the uneven substratum. The dating, 866, is noted as safe. Higher up in the varve series the change of facies mentioned above is very clear. The youngest varve measured is 782, as in Glimbo. The still younger, very thin varves are too indistinct to be measured at either site.

83. Vad. 12 F SO, 6566, 4911, Fig. 16.

Test pit in the higher part of a sloping clay field. The till surface was found in 1.0–1.5 m depth with several large boulders. The varves are thin and regular, and a reliable observation of the bottom varves was made on a rather even till surface between the boulders. The oldest varve is dated 859. The transition of varve facics at 791 is very clear and supports the dating. The youngest varve measured is 783. As in no. 81 and 82 the still younger varves are too indistinct.

84. Sörbo. 12 F SO, 6579, 4902, Fig. 16.

Test pit in a clay field 10 m from flat exposed till rich in boulders. The till surface was found at 1.6 m depth. The bottom varves could be followed around the pit and allow a reliable dating to 855. Higher up in the series of regular varves lies the transition of varve facies at 791. The youngest varve possible to distinguish is 782.

85. Vreterna. 12 F SO, 6586, 4826, Fig. 16.

Specimen in a zinc box, collected and measured by G. Lundqvist 1933. Thin varves continue down to the till surface, with the transition of varve facies at 791 supporting the dating. The bottom varve is 841, the youngest varve measured 784.

86. Rönningen. 12 F SO, 6604, 4883, Fig. 16.

Test pit in a flat clay field with some low morainic hills with boulders. The till surface was found at 1.0 m depth. A reliable observation of the bottom varves was obtained between protruding boulders. The bottom varve is dated to 838. The transition of varve facies is obvious and supports the dating. The youngest varve measured is 784 (Fig. 7).

87. Söderbärke. 12 F SO, 6606, 4848, Fig. 16.

Specimen in a zinc box, collected and measured by G. Lundqvist 1933 from Näsby, 1.5 km NW of Söderbärke village. The specimen contains thin varves down to the till surface. The change of varve facies is preserved in the upper part of the sample and supports the dating of bottom varve to 819. The silty varves above the facies transition are slightly disturbed and could be measured only to 787.

88. Saxe. 12 F SO, 6650, 4874, Fig. 16.

Test pit in a clay field. The till surface at 1.0 m depth was quite even, permitting a reliable measurement and dating of the bottom varve to 822. The change of varve facies at 791 is very clear. But in contrast to the localities no. 81–87 about 30 still younger varves could be measured, up to 761.

89. Saxhammar. 12 F SO, 6666, 4863. Fig. 16.

Test pit in a slightly sloping clay field. The till surface was found at 1.3 m depth. A series of regular varves permits a reliable dating of the bottom varve to 810. The facies transition at 791 is obvious. Above the transition the measurement could be continued up to 732. In this way no. 89, with support of no. 88, forms a link between no. 81–87, where the youngest varves are too indistinct for measurements, and no. 90–96, which contain varves mainly younger than the facies transition.

The old brickyard of Kvarnsnäs, the location of De Geer's (1940) measurement Smedjebacken (Da 4), is situated c. 1 km west of no. 89 Saxhammar. The oldest c. 20 varves of De Geer's diagram Da 4 (op. cit. Pl. 77) show rather good correlation with varves below the facies transition from the present no. 88 and 89, corresponding to the years 818 – c. 794 in the new time-scale. If 818 is the true bottom varve at Kvarnsnäs, this dating will be in good agreement with the dated deglaciation at no. 88 and 89, but 61 years older than the dating given by De Geer in relation to the other localities in Dalarna. However, the younger varves in De Geer's diagram Da 4 has no similarity at all with the thin varves and small thickness variations in the present localities no. 88–96.

The remaining localities no. 90–96 are all founded upon specimens in zinc boxes, collected and measured by G. Lundqvist 1933–1935 (no. 93 collected by H. Thomasson), during investigations for the geological map-sheet "Smedjebacken". The dating of these varve localities in a common time-scale for Dalarna became possible only by the aid of the present no. 88 and 89.

Neither G. Lundqvist's diagrams from the Smedjebacken region nor no. 85 and 87 (also collected during the mapping work) have been previously published,

90. Smedjebacken A (Viadukten). 12 F SO, 6684, 4781, Fig. 16.

G. Lundqvist 1934. Thin silty varves, 801–745, show close agreement with no. 89. The varves older than 801 are disturbed by slidings, and consequently no dating of a bottom varve was possible.

91. Smedjebacken B (Valsverket). 12 F SO, 6687, 4784, Fig. 16.

G. Lundqvist 1935. Excavation for a foundation on the northern slope of a local esker in the valley of Kolbäcksån, within the industrial central area of the township of Smedjebacken, Thin silty varves are dated 797–721. The varved silt rests on c. 2 m stratified sand without discernible varves, down to glaciofluvial gravel and till. Evidently the sand represents an undefined space of time, probably only some years, between the deglaciation of the site and the sedimentation of the oldest dated silty varve.

92. Västansjö. 12 F SO, 6689, 4776, Fig. 16

G. Lundqvist 1934. Thin silty varves, 796–723, continue downwards in thicker, more sandy varves, assumed to represent the years 804–797 with varying thicknesses due to ripple structures. These varves rest on glaciofluvial sand (cf. the stratigraphy in no. 91). No. 92 thus does not give an exact dating of a bottom varve, but the difference between the oldest counted varve c. 804 and the deglaciation may be estimated to at the most a few years.

93. Morgårdshammar. 12 F SO, 6700, 4762, Fig. 16.

H. Thomasson 1934. Excavation in the western part of the township of Smedjebacken. Silt with thin varves, 797–721, rests on 55 mm stratified sandy silt and more than 1 m fine sand with ripple stratification. No dating of the deglaciation is thus obtained.

94. Torrbo. 12 F SO, 6712, 4817, Fig. 16.

G. Lundqvist 1933. The sample from a silt field between morainic hills and ridges contains silt with thin varves, and a bottom varve, more than 33 mm thick, resting on till. The bottom varve is dated 799, the youngest varve 766.

95. Lugnet. 12 F SO, 6721, 4804, Fig. 16.

G. Lundqvist 1933. Silt with thin varves rests on till. The bottom varve is sandy, with the thickness not defined at the sampling. The bottom varve is dated 790, the youngest varve measured 720.

96. Getbo brunn. 12 F SO, 6732, 4807, Fig. 16.

G. Lundqvist 1934. Silt with thin varves showing a few small deformations of the varves by slidings. The bottom varve, with the thickness not defined in the specimen, rests upon till, and is dated 784. The youngest varve measured is 726.

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Abbreviations:

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SGU = Sveriges geologiska undersökning, Stockholm – Uppsala

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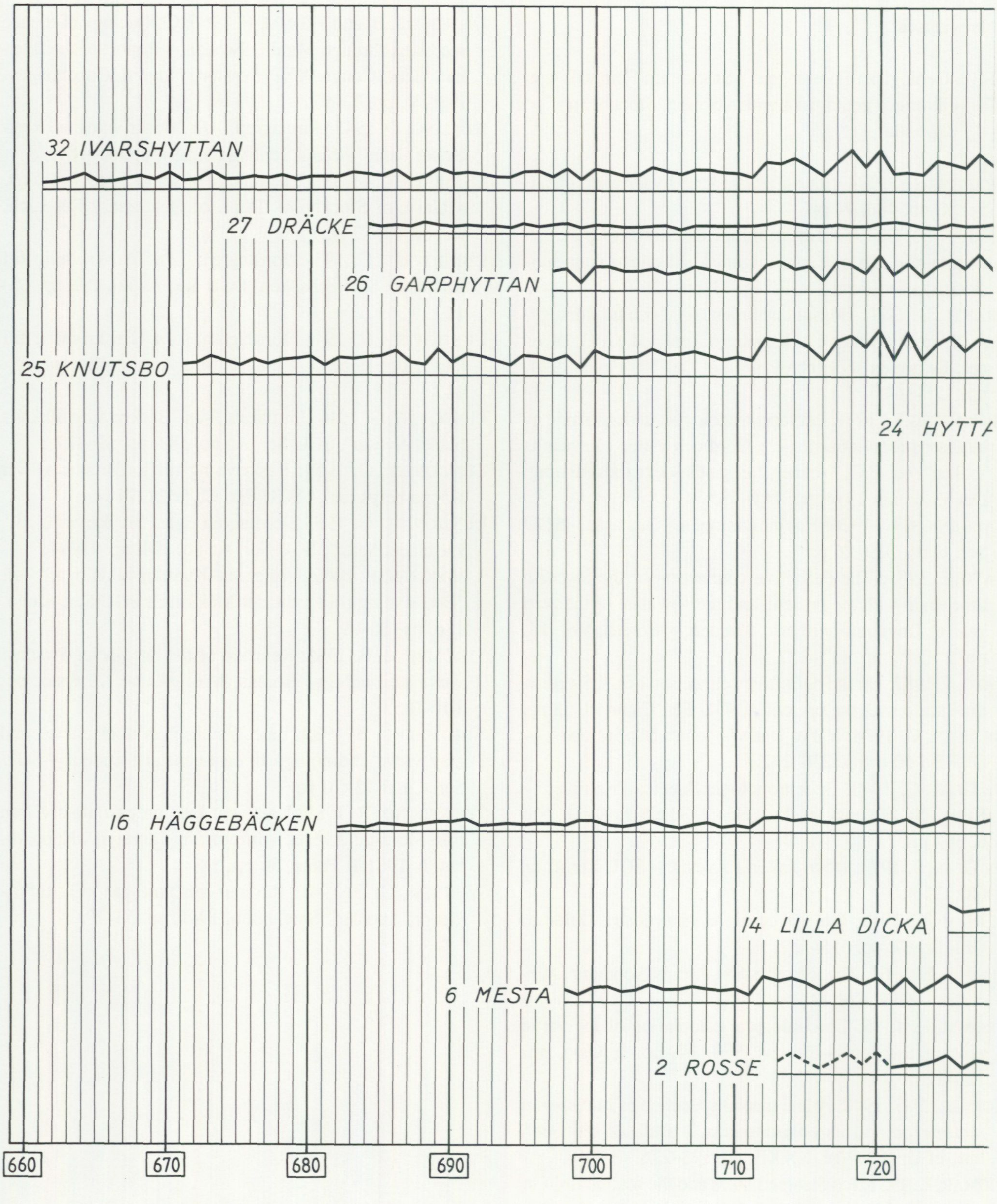


Fig. 13. Varve diagrams for the main time-scale. Localities no. 1–33 (Avesta – Hedemora). Varve numbers in brackets ( ) are according to Järnefors (1963).

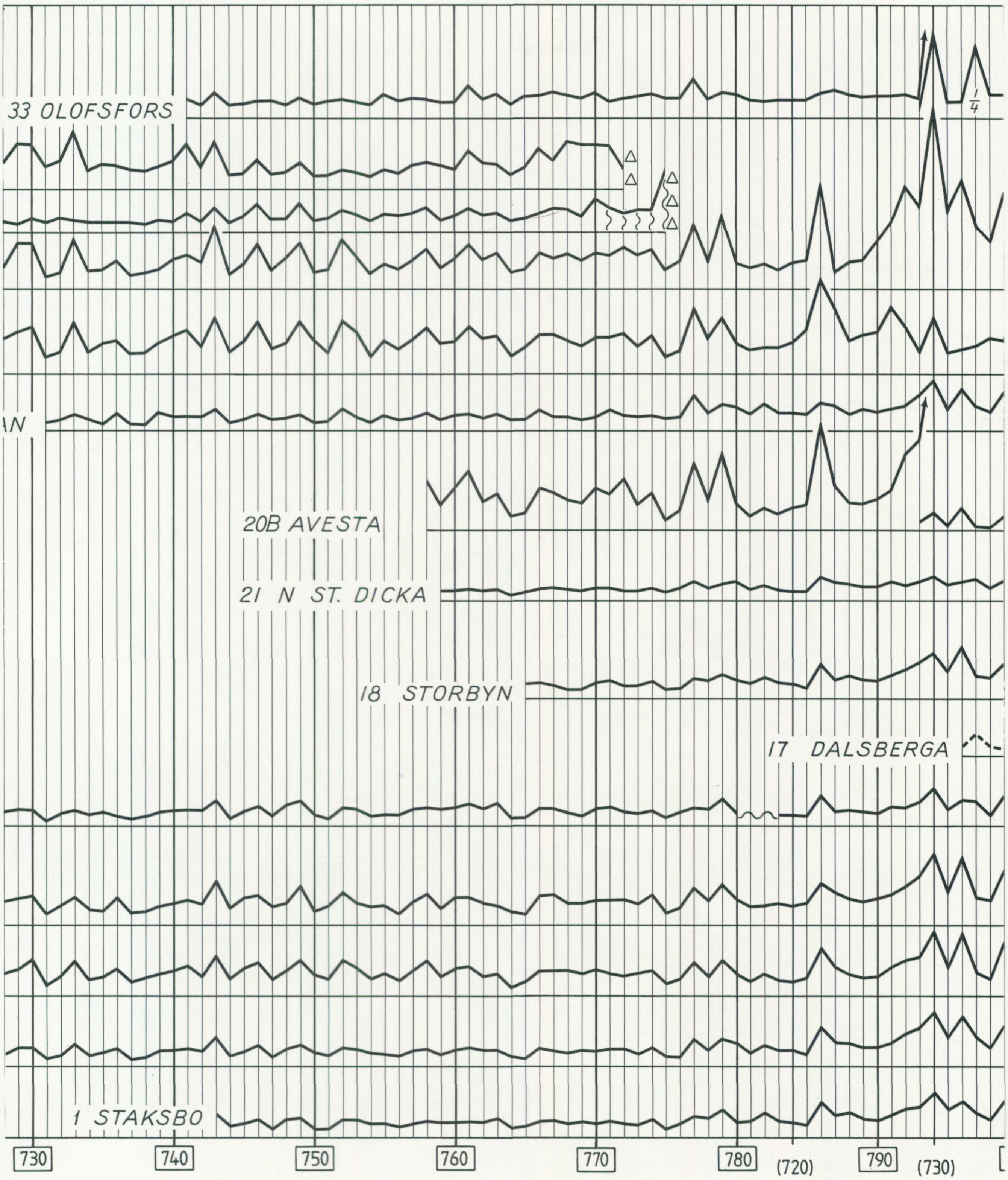

33 OLOFSFORS
1/4
AN
20B AVESTA
21 N ST. DICKA
18 STORBYN
17 DALSBERGA
1 STAKSBO
730
740
750
760
770
780
(720)
790
(730)

Fig. 13, cont.


410 mm
Sand with
ca 4 clay
varves
20A AVESTA
19 ÅFSTA
> 12 m fine sand and sand
1/20
1/20
1/10
1/4
38 mm
39 "
79 "
85 mm
800
(740)
810
(750)
820
(760)
830
(770)
840
(790)
850
(800)
860
(810)
870
Weathered varves
Sliding and folding
Current-bedding
Till
Gravel
Sand
Silt and clay
Thickness scale 1/2, when not remarked

Fig. 13, cont.

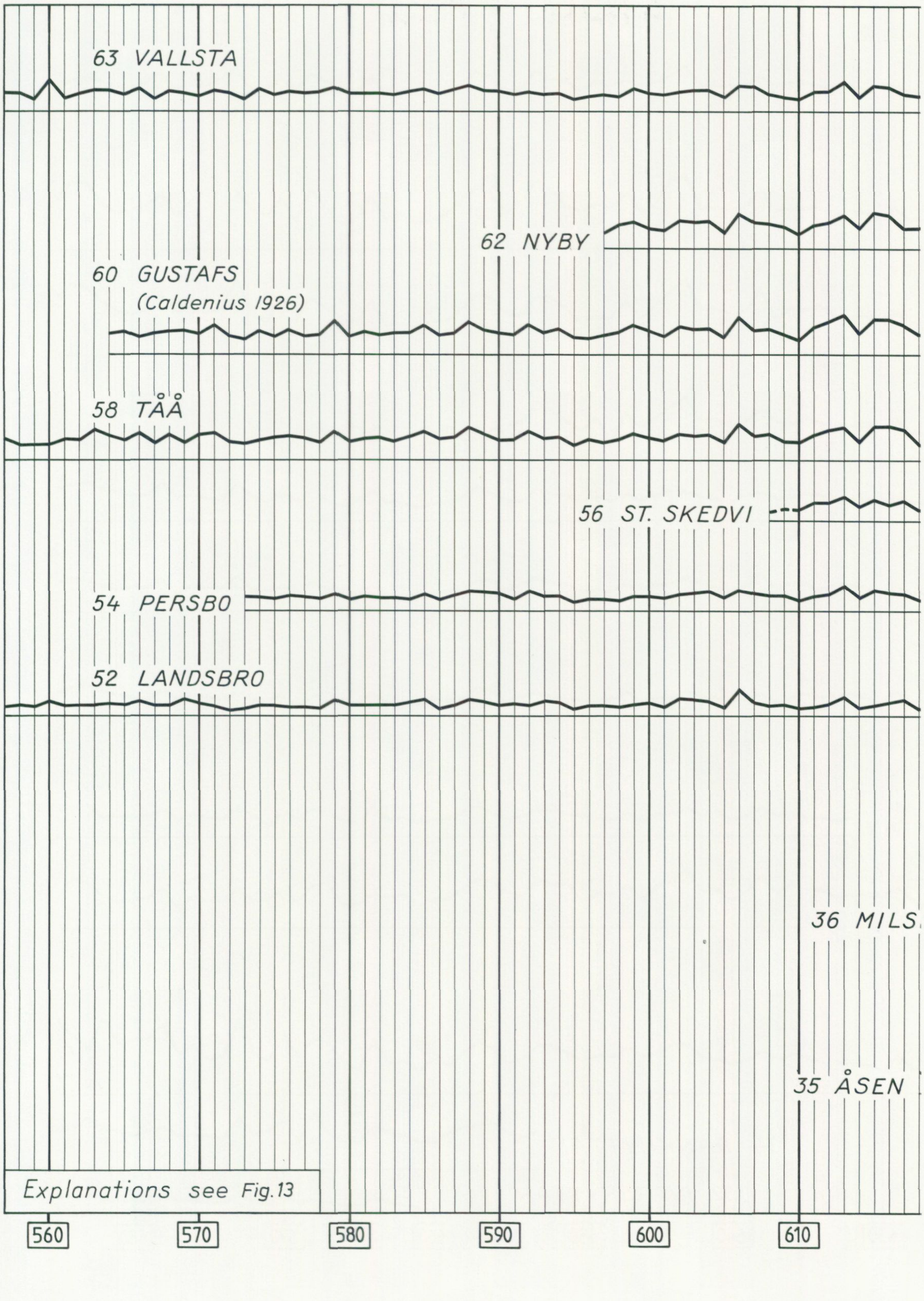


Fig. 14. Varve diagrams for the main time-scale. Localities no. 34–63 (Hedemora – Säter – Borlänge).

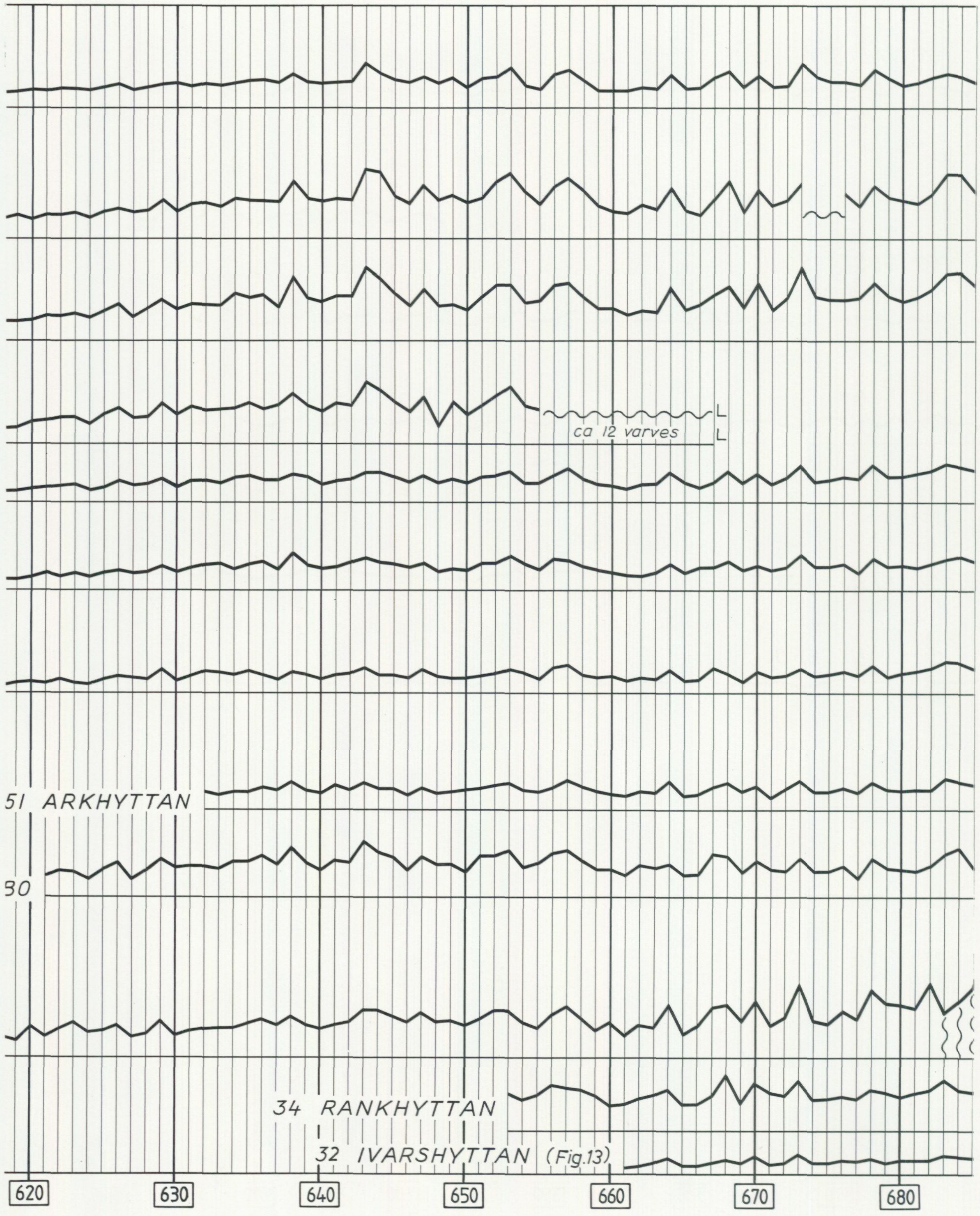
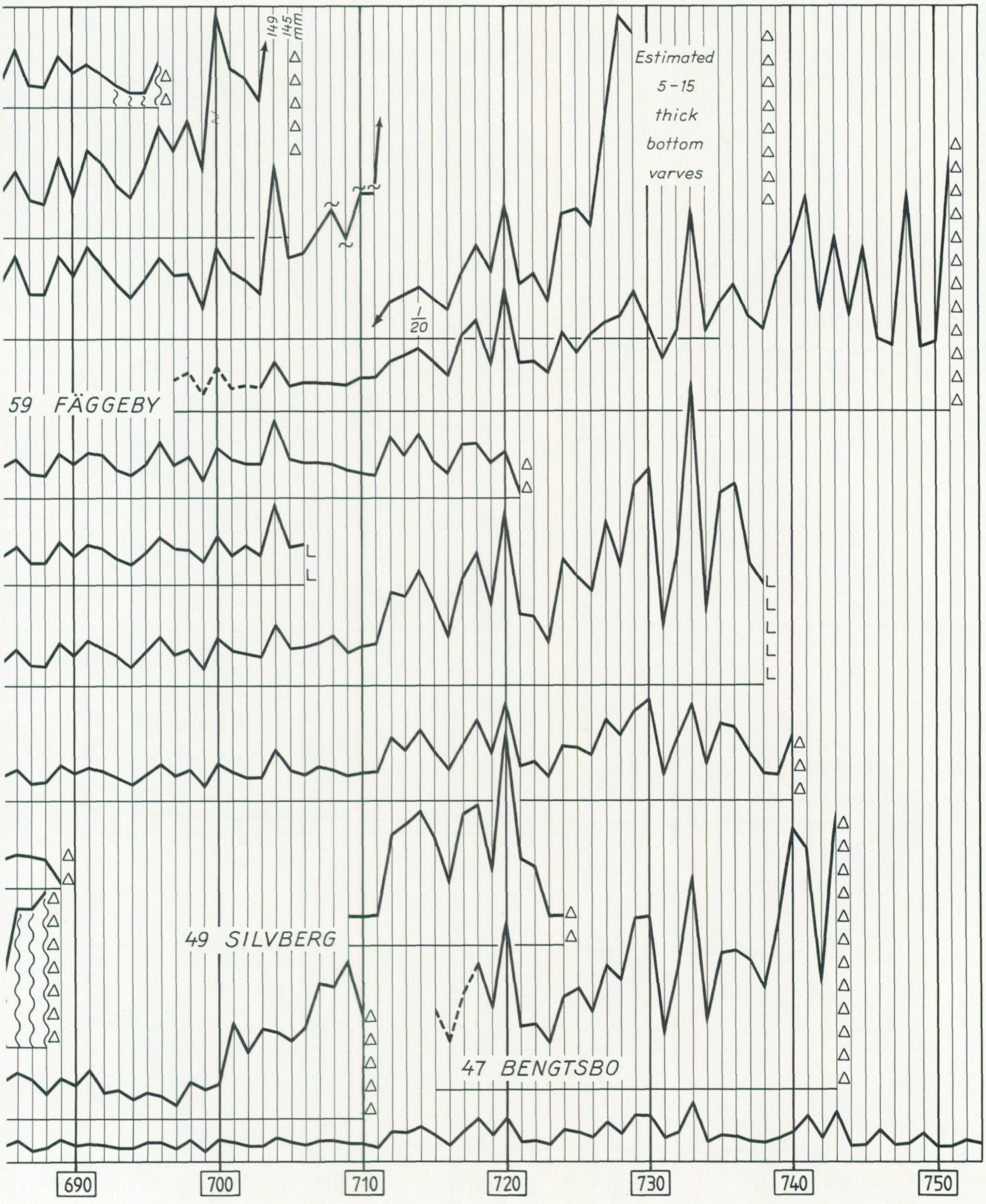

ca 12 varves
L
L
51 ARKHYTTAN
30
34 RANKHYTTAN
32 IVARSHYTTAN (Fig.13)
620
630
640
650
660
670
680

Fig. 14, cont.



149
145
mm
Estimated
5 - 15
thick
bottom
varves
1/20
59 FÄGGEBY
49 SILVBERG
47 BENGTSBO
690
700
710
720
730
740
750

Fig. 14, cont.

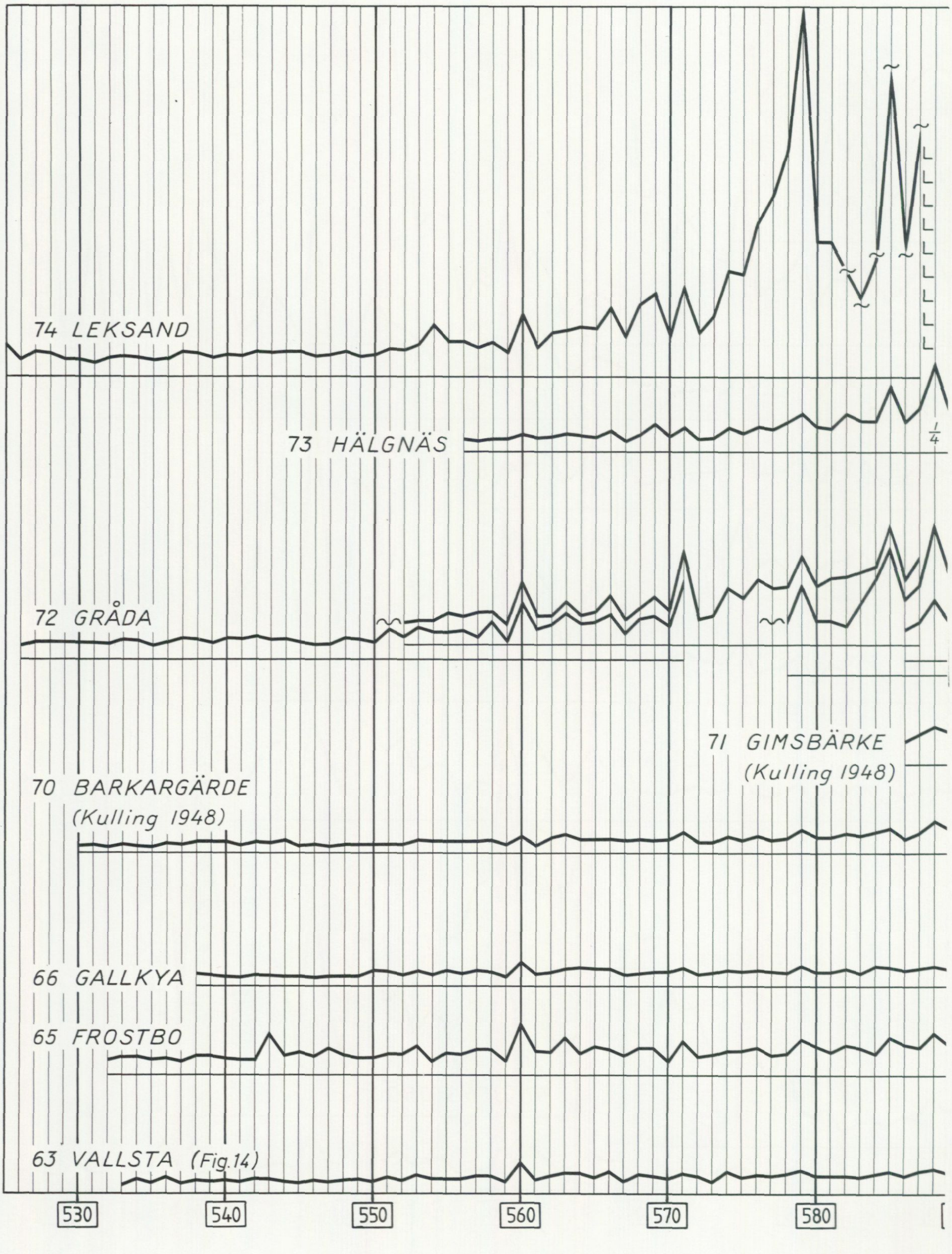
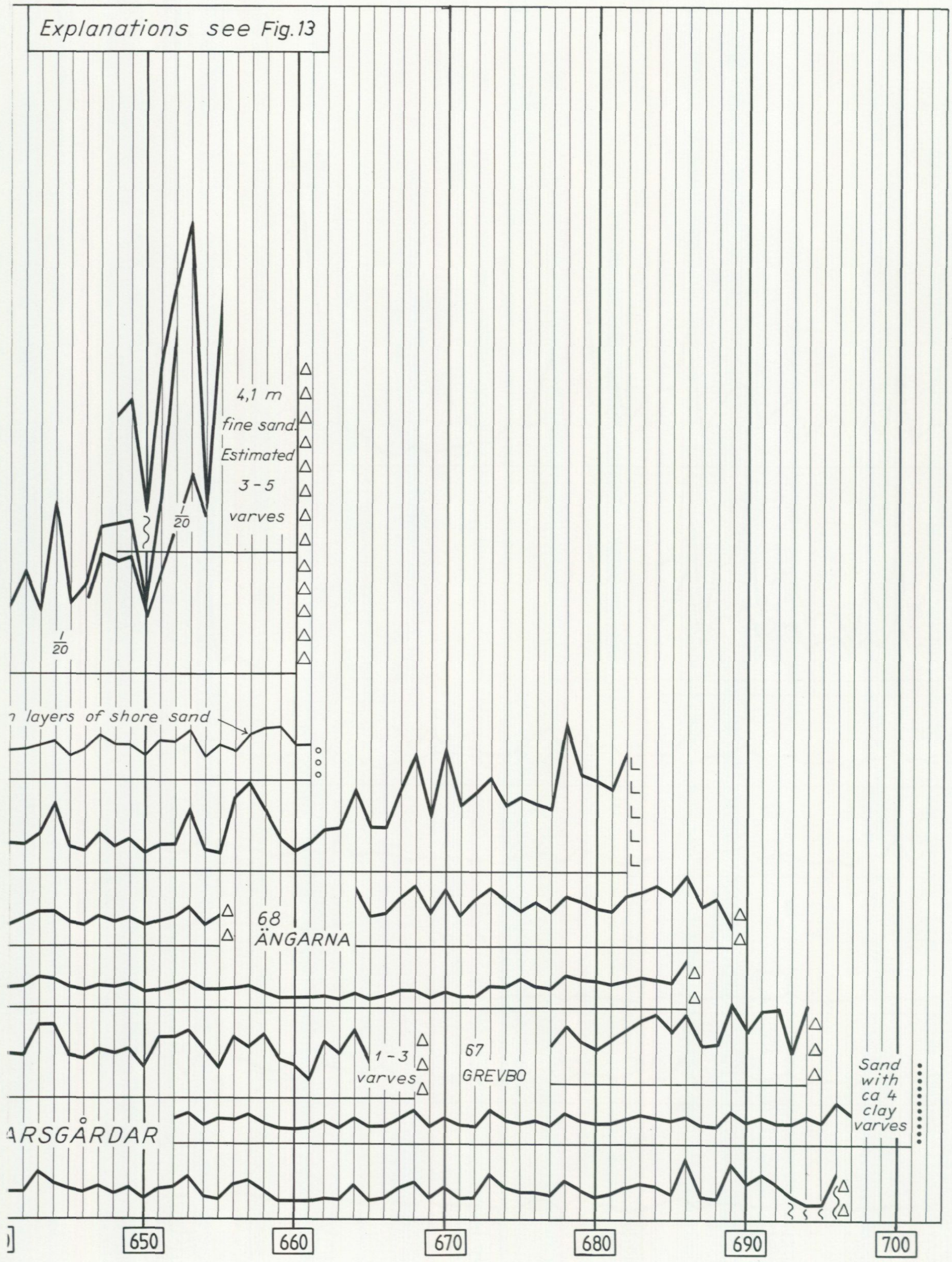


Fig. 15. Varve diagrams for the main time-scale. Localities no. 64–74 (Borlänge – Leksand). For further explanations see Fig. 13.


1/4
1/4
L
L
Varves with thi
69 LERBÄCKEN
64 HALV
590
600
610
620
630
640

Fig. 15, cont.



Explanations see Fig.13
4,1 m
fine sand.
Estimated
3 - 5
varves
1/20
1/20
layers of shore sand
68
ÄNGARNA
1 - 3
varves
67
GREVBO
Sand
with
ca 4
clay
varves
ARSGÅRDAR
650
660
670
680
690
700

Fig. 15, cont.

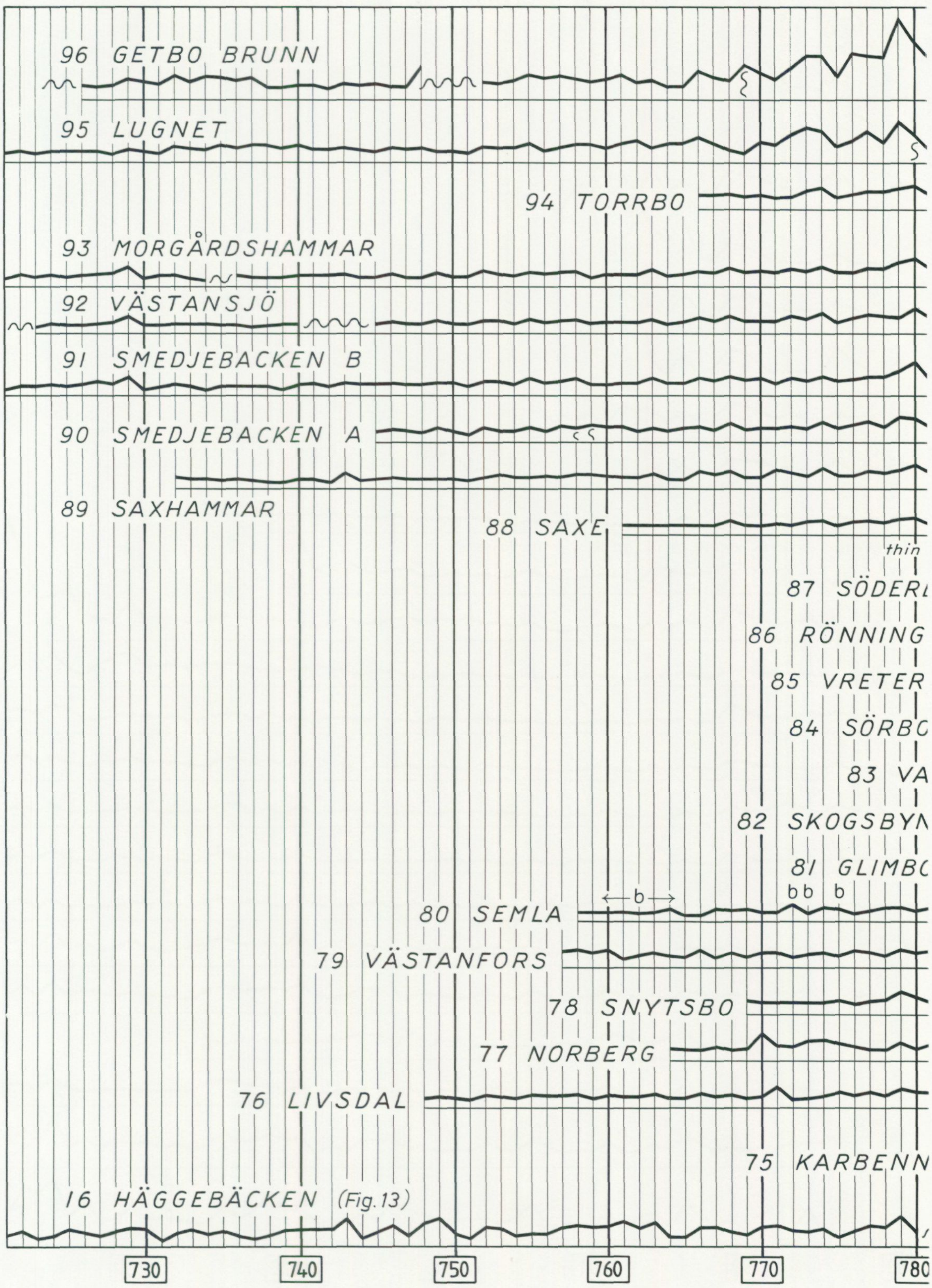
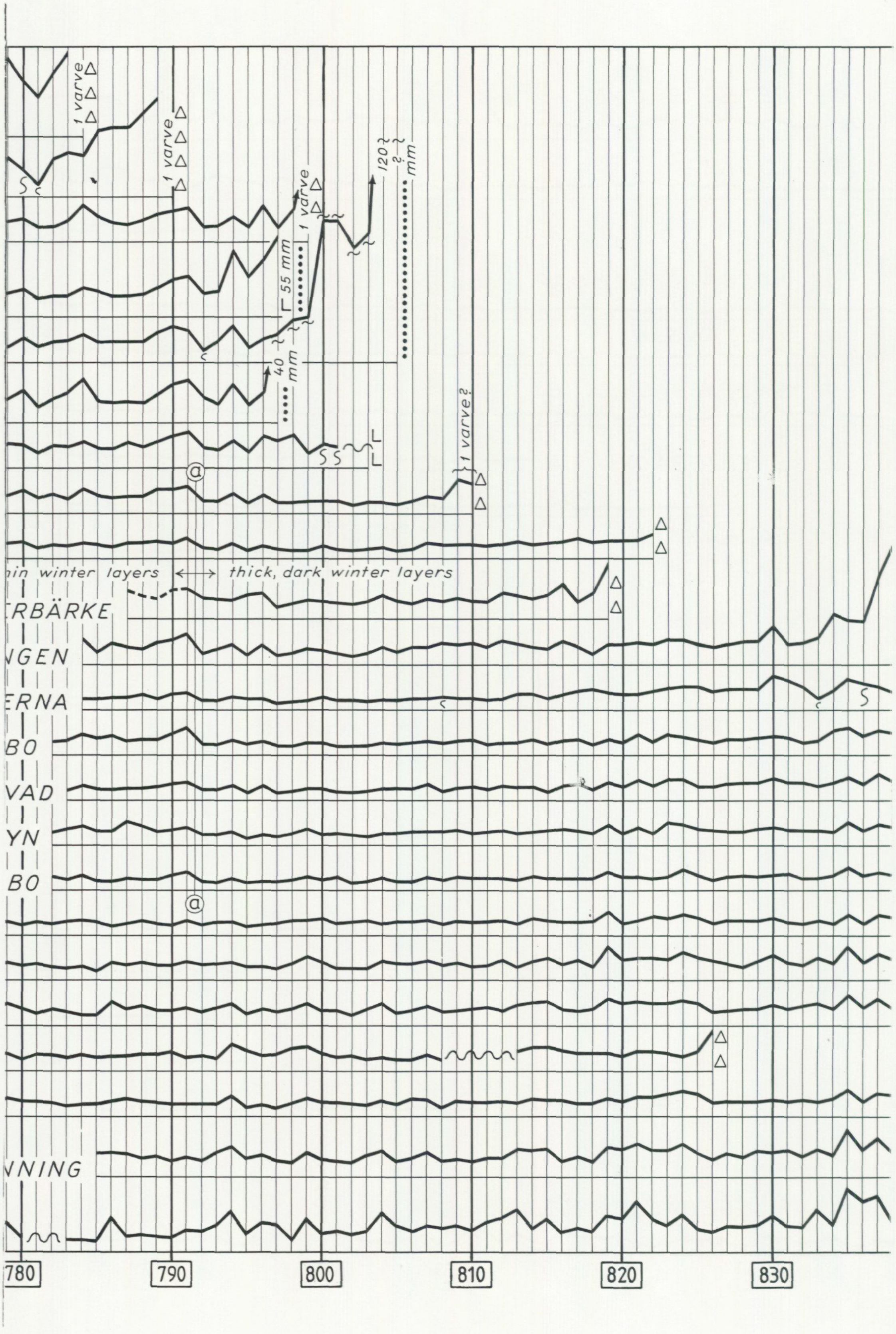
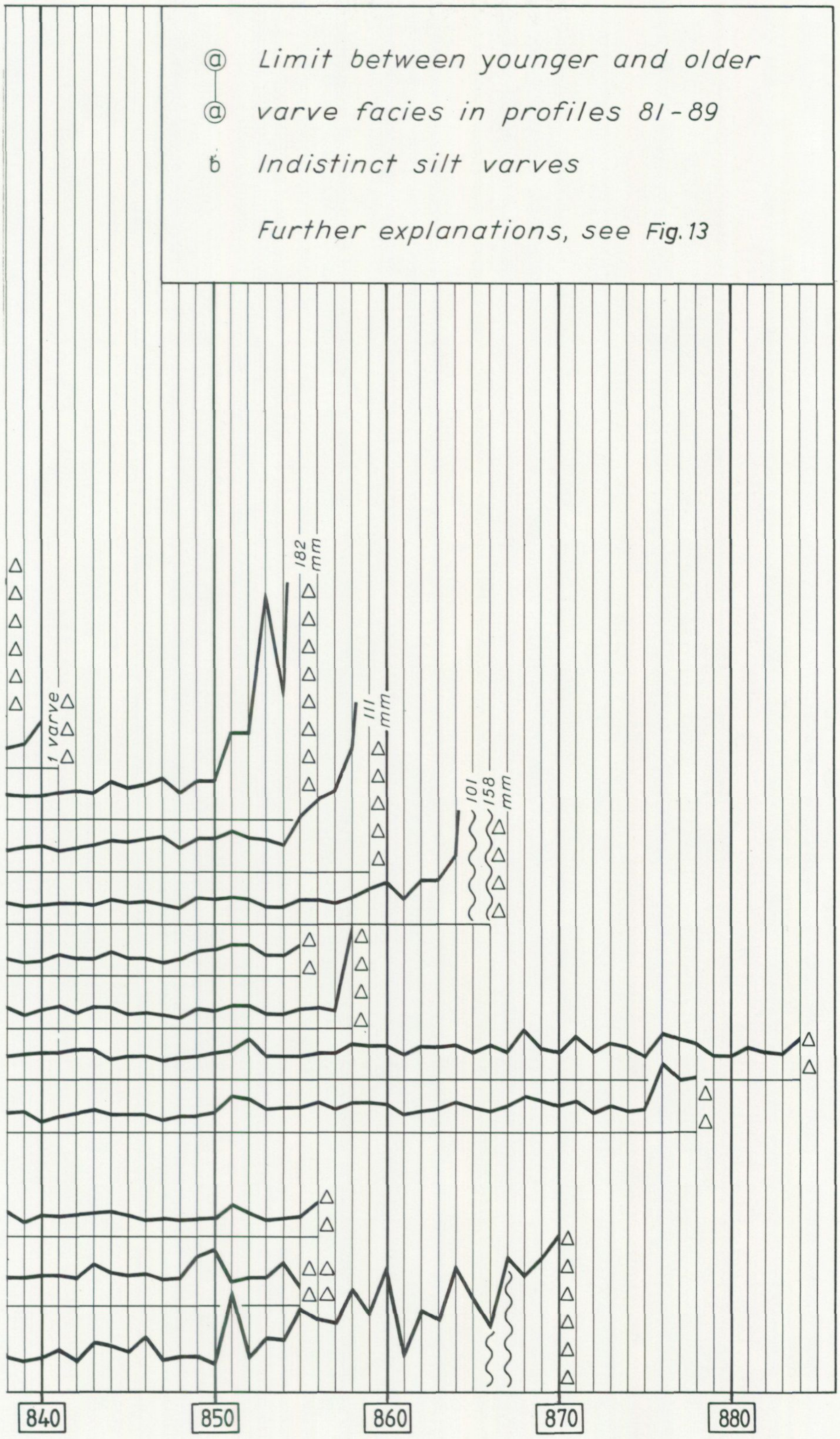


Fig. 16. Varve diagrams for the main time-scale. Localities no. 75–96 (Avesta – Fagersta – Smedjebacken).



1 varve
1 varve
1 varve
1 varve
120?
?
mm
55 mm
40
mm
1 varve?
thin winter layers
thick, dark winter layers
RBÄRKE
NGEN
ERNA
BO
VAD
YN
BO
NNING
780
790
800
810
820
830

Fig. 16, cont.



Limit between younger and older varve facies in profiles 81-89
Indistinct silt varves
Further explanations, see Fig. 13
182 mm
111 mm
101
158 mm
1 varve
840
850
860
870
880

Fig. 16, cont.

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