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Cover: Views from the lower reaches of the Ångermanälven valley showing the northern part of the Gistgårdsön. Photo: I. Cato 1983.

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In the beginning of this century Ragnar Lidén initiated and worked on a systematic measurement of the varved postglacial sediments in the Ångermanälven valley. Upper: An early photo of Ragnar Lidén wearing his student's cap and resting in the shadow of a big tree. (photo anonymous). Lower: Ragnar Lidén's bike in one of the bluffs excavated by river erosion. Note the exposed varved sediments and the long tin box he used as a sampler (photo: R. Lidén c. 1909).

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Abstract

Cato, I., 1998: Ragnar Liden's postglacial varve chronology from the Ångermanälven valley, northern Sweden. *Sveriges geologiska undersökning, Ca 88*, 82 pp. ISBN 91-7158-573-7.

This paper deals with the previously unpublished results of Ragnar Lidén's investigation, in the beginning of this century, of the postglacial varved sediments of the Ångermanälven river valley in central Sweden. Based on these studies, he was able to construct a shore displacement curve (Lidén 1938) and a postglacial varve chronology embracing 7,522 varve years of the entire postglacial part (8,917 years according to Cato 1985, 1987) of the Swedish Geochronological Time Scale. Lidén's correlated varve thickness diagrams were digitized, stored, and plotted in order to assume the form in which they are presented in this paper. The original individual varve numbers of Lidén are kept, and in addition, the calendar year of each varve is given according to Cato (1985, 1987). Other relevant information, for example, site descriptions and photos from the documents Lidén left behind, are also presented. The results are commented upon by the present author.

Preface

The Swedish Geochronological Time scale is mainly associated with two Swedish geologists: the pioneer of varve chronology, Professor Gerard De Geer, and one of his pupils, Dr. Ragnar Lidén. Lidén (1880–1969), born in Dala-Järna, Sweden, received his education as a geologist at the University of Uppsala, where he was examined in 1920. Between 1907 and 1913, he worked for the Geological Survey of Sweden, and from then until his retirement in 1945, he was employed by the Swedish State Railways, first at the Geotechnical Commission and later on at the Technical Division.

Early in this century, Lidén devoted many years to measuring the varved sedimentary series in bluffs ("nipa" in Swedish) along the Ångermanälven river in order to establish a local glacial and postglacial chronology and to extend the Swedish Time Scale to the present. Despite this impressive work, he unfortunately was not able to achieve other than a provisional connection to the present. However, what is most important today is that he succeeded in establishing a local glacial varve chronology of the Ångermanälven valley (Lidén 1913) and that he measured, correlated, and documented 7,522 years out of the 8,917-year-long (up to 1950) postglacial varve chronology. In 1984, i.e., 100 years after the varve chronology was born (G. De Geer 1884), the present author was able to extend Lidén's chronology and thereby complete the connection of the Swedish Time Scale to the present (Cato 1985, 1987). In this paper, Lidén's Postglacial varve data, never before published, are presented and evaluated. These data were found in the documents Lidén left behind.

The driving force behind this paper is the desire of the present author and of others that the famous Swedish Geochronological Time Scale would be shown in its entirety to a larger audience. So far, this time scale is the longest and most complete time scale showing a year-to-year chronology of the last *c.* 13,000 years. Almost 7,000 of these varve years are presented here for the first time.

On board R/V Aranda in the Weddel Sea, Antarctica, February 25th, 1996.

Ingemar Cato

Introduction

Judging by our present knowledge, the valley sediments of the Norrland rivers would seem to be more regularly formed and more completely preserved in the valley of the Ångermanälven (Fig. 1) than in any other of the rivers rising in the mountains of Northern Sweden. These special conditions had already been established at the beginning of the century by Ragnar Lidén when he worked for Gerard De Geer in the extensive geochronological investigations of Sweden in the years 1905–1906. Lidén noticed not only the layered structure of the river valley sediment but also that the lamination of these sediments was highly reminiscent of the stratification in annual varves of the glacial clay. Therefore, he assumed that the postglacial laminae in the Ångermanälven valley were annual (Lidén 1911). Later, the present author's studies showed that this presumption was valid (Cato 1985, 1987). Underneath the delta surface, the varves overlap each other and decrease distally in thickness and grain size.

It was in all probability these observations that eventually led Lidén to the successful testing and application to the river valley sediments of the geochronological method devised by G. De Geer (e.g., G. De Geer 1912, 1940). During the years c. 1909–1913, Lidén worked (i.a. according to his notebooks from 1910–1912 left behind and placed at SGU in 1983 by his sister Imber Lidén) on a systematic measurement of the varved structure of the sediments in the bluffs of the Ångermanälven valley. The purpose of the investigation was to illustrate chronologically the geological and geographical development of the landscape during Late Quaternary time and until the present.

In a lecture entitled "On the deglaciation and the postglacial land upheaval in Ångermanland," Lidén presented his first, preliminary results at a meeting of the Geological Society of Sweden in Stockholm in May 1911 (Lidén 1911).

The definitive results of the geochronology of the deglaciation of Ångermanland were published two years later (Lidén 1913). The postglacial chronology was long delayed, however, even though, according to the documents Lidén left behind, it was probably more or less ready for publication c. 1915. This assumption is based on the finding of his printed varve diagrams (Fig. 2) in the attic of the Natural Science Museum of Stockholm when the Geological Survey

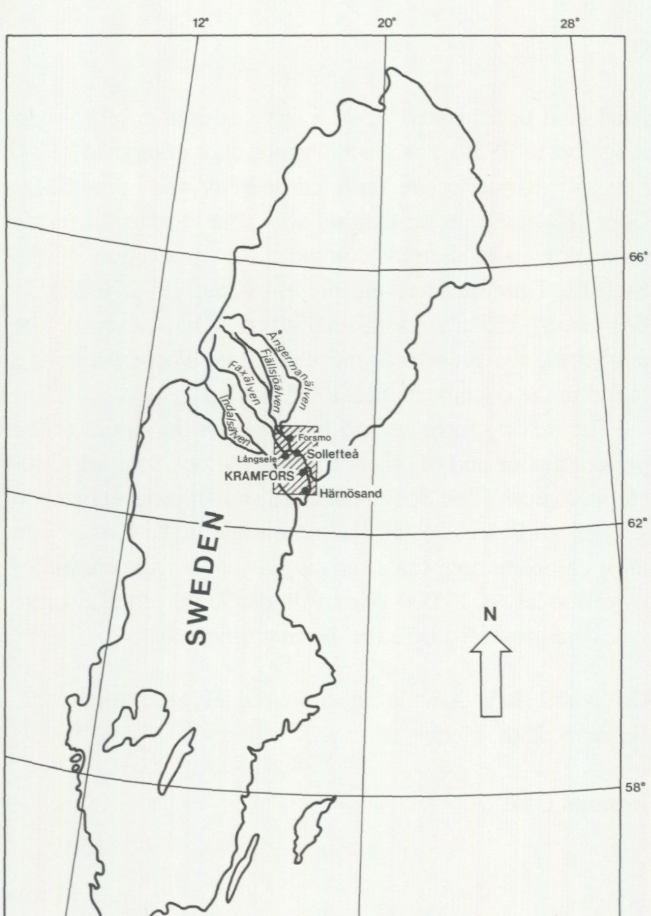

Fig. 1. Outline map showing the location of the Ångermanälven river, its tributaries, the Indalsälven river, and the area investigated by Lidén in the beginning of this century.

of Sweden moved from this building to a new head office in Uppsala in 1979. It is not known if these diagrams were reprints of a possible printed issue, which may have been destroyed during a fire at the publisher in 1915, or if the diagrams were printed in advance of the text. The diagrams are marked with the SGU Serie Ca no.13, but another report (Magnusson 1929) was published with this series number. However, the results in their entirety never became published for one reason or another. Not until 1938 did a brief summary appear of the results of Lidén's very extensive geochronological work on the postglacial sediments in the valley of the Ångermanälven (Lidén 1938). Surprisingly enough, no varve diagrams were included in this work. From each delta surface, only the chronological number of the youngest varve was given in connection with the account of the course of the Late Quaternary shore displacement in the valley of the Ångermanälven.

Lidén's local postglacial chronology embraces 7,522 varves measured at 19 localities along the river (Fig. 3). An outline diagram showing the mutual connections is given in Figure 4. An extended chronology to the present was roughly achieved by Lidén by interpolation of the interval between the formation of his youngest measured varve on the delta surface at Prästmon and two historically datable shore levels in the valley of the Ångermanälven river: the construction of the Styresholm Fortress at Prästmon during the first half of the 14th century and a map of the same area from 1701 indicated that Lidén's youngest varve was probably formed c. 980 years before 1900 AD (Lidén 1938). However, several authors have emphasized Lidén's weak connection of the postglacial time scale with the present, since it was based mainly on extrapolated shore displace-

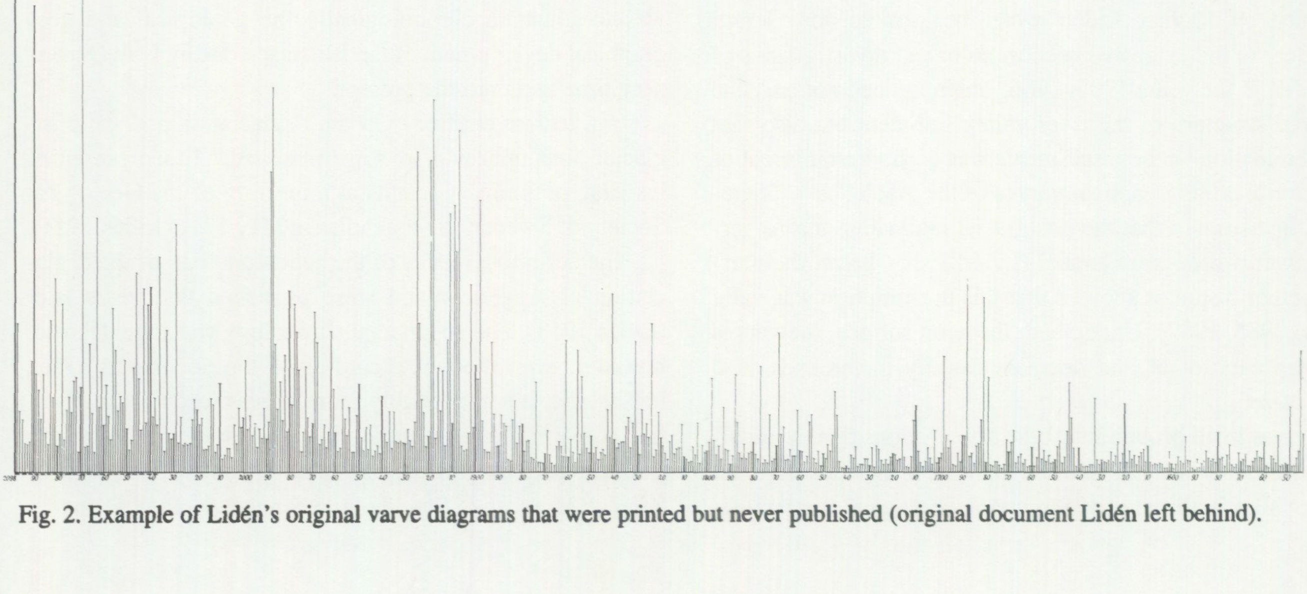

Fig. 2. Example of Lidén's original varve diagrams that were printed but never published (original document Lidén left behind).

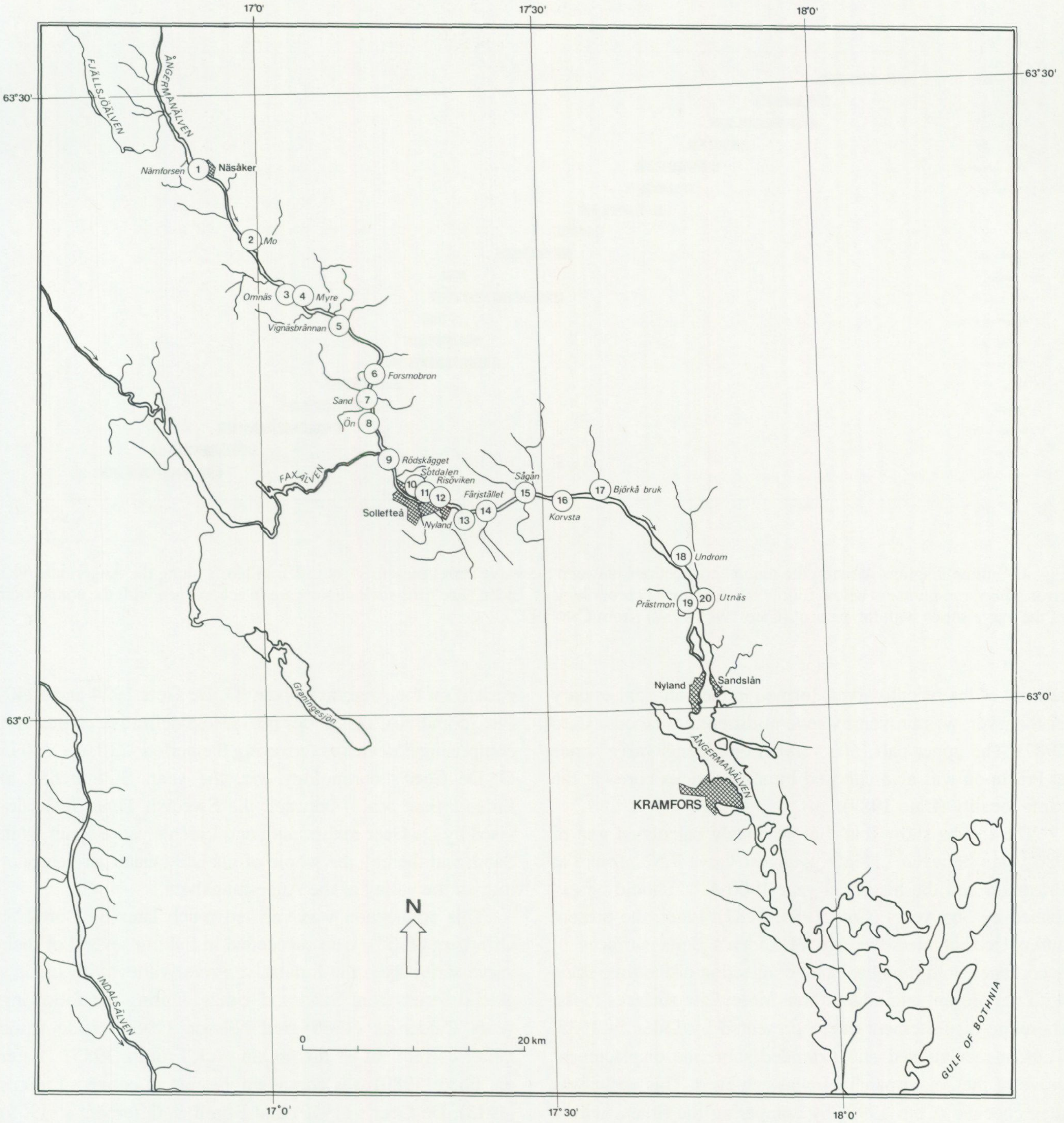

Fig. 3. Map of the Ångermanälven river and estuary showing the locations and site number of the localities investigated by Lidén in the beginning of this century.

ment data (Wenner 1968, Fromm 1970, Tauber 1970).

Repeated attempts have been made to get a more exact extension of the Swedish Time Scale to the present (G. De Geer 1912, Caldenius 1924, E. H. De Geer 1933, Kullenberg & Fromm 1944, Fromm unpubl., and Granar 1956), but no researcher progressed further than Lidén had (1938), until 1984, when the present author presented an exact connection with the present time (Cato 1985, 1987). In order to establish a definitive link between the Swedish Time Scale and historical time, Lidén's chronology was supplemented with new varve sequences that extend to the present. Over 10,000 varves were measured and counted by Cato before all the correlations were clear within the barely 15 km-long stretch of river between Lidén's youngest varve series at Prästmon and the most recently formed sediments downstream from the present delta at Nyland. The calendar year

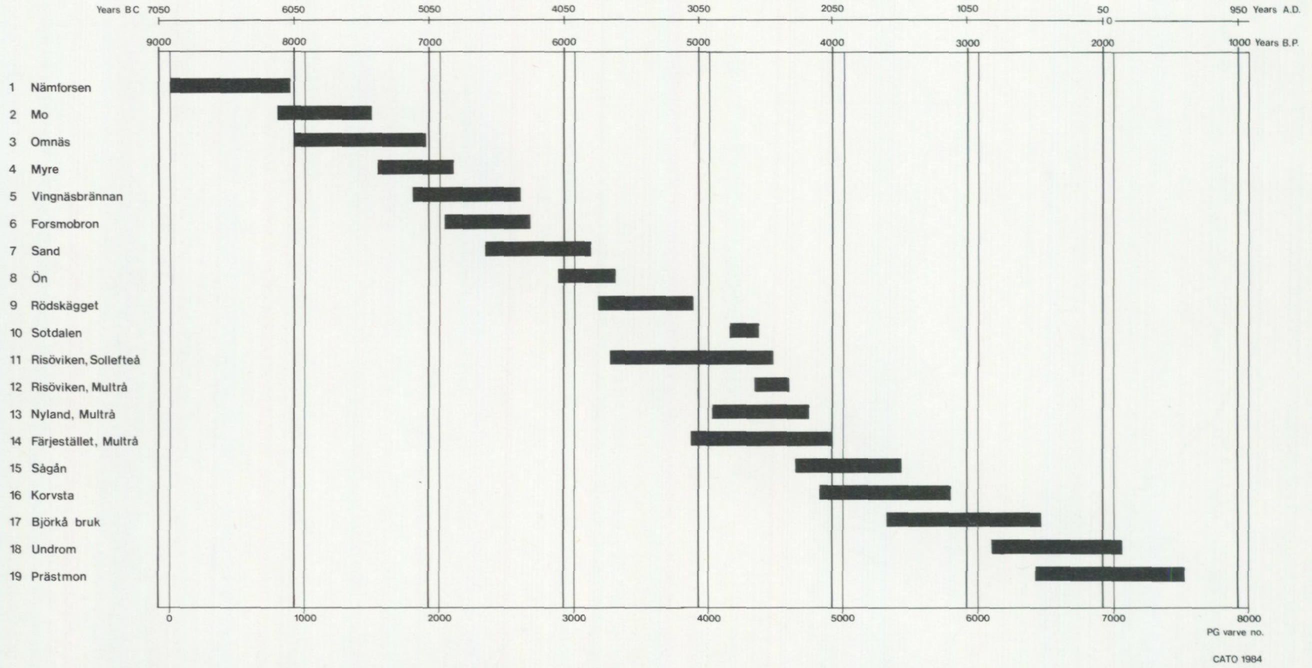

Fig. 4. Outline diagram showing the mutual connections between the varve series measured by Lidén in bluffs along the Ångermanälven river. The varve numbers below follow the postglacial chronology of Lidén. The time scales above are in accordance with the connection of the varve series with the present (Cato 1985, 1987) (from Cato 1992).

affinity of the recent varves, formed in the non-tidal estuary of the river, was proven by several different methods (Cato 1987). The upper part (500 varves) of Lidén's varve series at Prästmon was also checked by a new series cored at the same locality (Cato 1987).

The results show that the previously calculated gap of 980 years between Lidén's youngest varve 7,522 found at Prästmon and the historical year 1900 A.D. should be extended by 365 years (Cato 1985, 1987). Later, the present author recalculated the age of Lidén's delta surfaces in accordance with the new exact connection of the time scale with the present and added three more delta surfaces to the shoreline displacement curve presented by Lidén in 1938. Thus, a recalculated and extended shoreline displacement curve of the Ångermanälven was achieved. This curve was then checked (Cato 1992) by comparing the fitness with a shoreline displacement curve based on lake isolation data (Wallin 1993) in the Ångermanälven valley. The results show good agreement between the curves, which strengthens the validity of the postglacial time scale of the Ångermanälven (Lidén 1938, Cato 1985, 1987, and this paper) and consequently, the entire revised Swedish Geochronological Time Scale (Fig. 5).

Lidén's late glacial and postglacial chronology of Ångermanälven was correlated and connected with the older glacial time series of Sweden by an excellent series of 400 undisturbed varves at a level crossing near Gåsnäs (Resele parish) on the Ångermanälven (G. De Geer 1924 and 1940, Pls. 75 and 76). This series provided a definitive connection comprising 350 varves (covering the period -210 to + 140 in G. De Geer's chronology, viz. the years 300 to 650 in Lidén's time scale) between the Swedish Time Scale devised by De Geer in the south and Lidén's varve series from Sand, and thereby the whole of his late Quaternary chronology in the valley of the Ångermanälven.

This connection was verified much later by Borell & Offerberg (1955), who succeeded in linking several of their varve series from the Indalsälven river valley with Lidén's glacial series from Sand and Utnäs. During the following years Caldenius (1960) and Nilsson (1960) made some minor corrections of this linking (cf. Fromm 1985). Later on, Fözö (1980) was convincingly able to connect Lidén's (1913), De Geer's (1940) and Borell & Offerberg's (1955) series from the valleys of the Ångermanälven and the Indalsälven, respectively, with his own (covering the period from *c.* -310 until +70 in Borell & Offerberg's time scale, viz. the years 117 to 497 in Lidén's glacial chronology) from the water systems of the Ångermanälven, the Faxälven, the Fjällsjöälven, and the Indalsälven (Figs. 1 and 3).

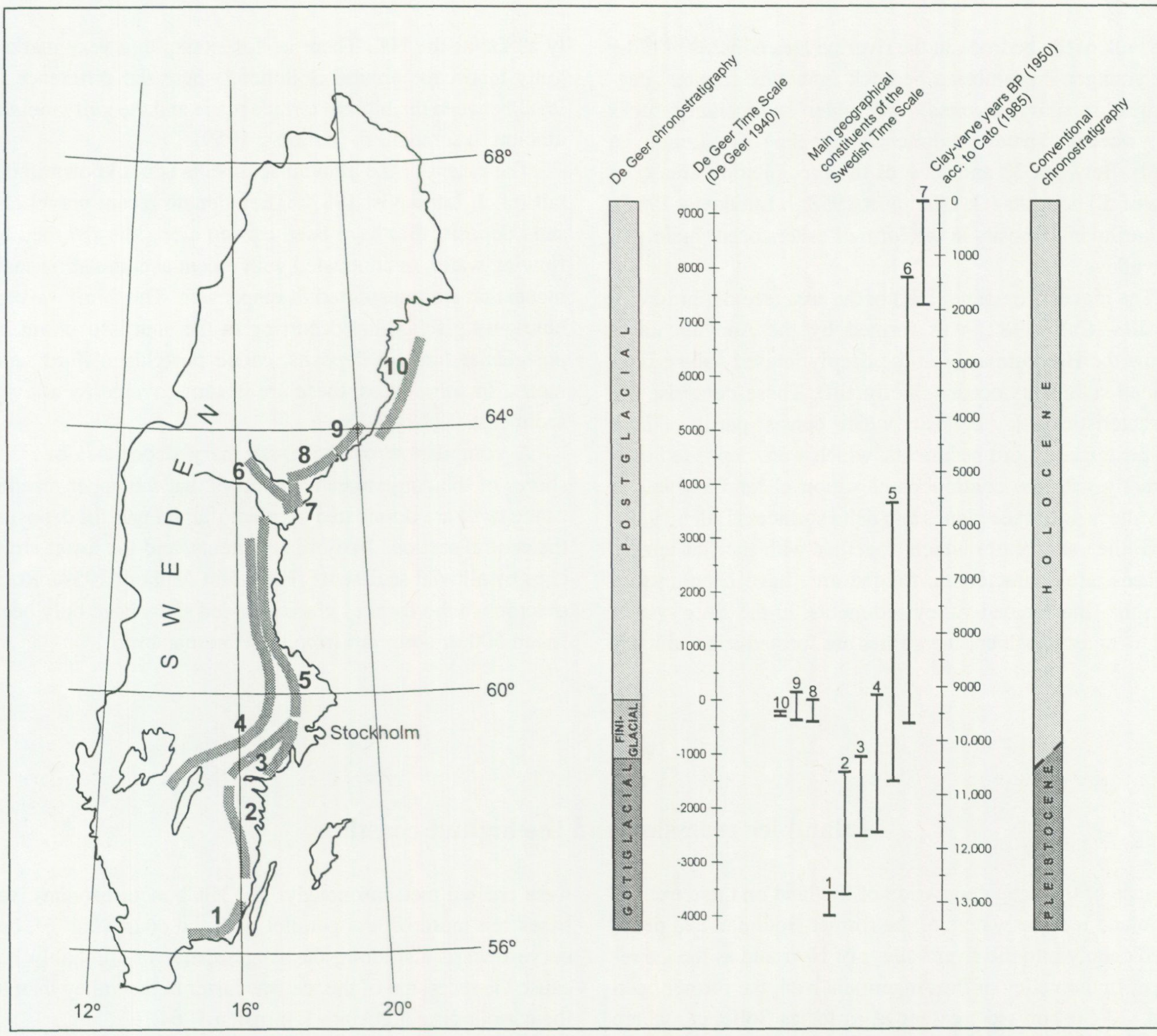

Fig. 5. The geographical and geochronological construction of the Swedish Time Scale, the main constituents and their timespan. 1) Ringberg & Rudmark (1985), 2) Kristiansson (1986), 3) Brunnberg (1995), 4) Strömberg (1989, 1994), 5) De Geer (1940), 6) Lidén (1913), Cato (1998), 7) Cato (1985, 1987), 8) Hörnsten (1964), 9) Bergström (1968), 10) Andrén (in press). Figure partly after Andrén, in press.

The environmental setting

Physiography

The riverine of the Ångermanälven is the third largest in Sweden. From its source in the mountains to the present delta in the Bothnian Sea, its area is 300 km long with a maximum breadth of 150 km in the central parts. The Fjällsjöälven and the Faxälven constitute its most important tributaries (Fig. 1). The total drainage area covers 31,890 km^2, 7.5% of it consisting of lakes. Its height above sea level averages 475 m with a maximum altitude of 1,589 m (Melin 1954). The non-tidal estuary of the river extends some 50 km inland from the Bothnian Sea. The course of the river ends at Nyland, 35 km southeast of Sollefteå, with a 15–25 m-high distal slope in the non-tidal estuary where its fresh water is layered over the penetrating brackish water of the Bothnian Sea (Bruneau 1956).

Geology

The bulk of the bedrock in the riverine area consists of older and younger Precambrian bedrock (gneisses granites, pegmatites, rapakivi granites) and older sedimentary rocks (greywackes, shales, sedimentary gneiss) (T. Lundqvist 1980). Between 30 and 65% of the precipitation area consists of till deposits (G. Lundqvist 1958, J. Lundqvist 1987). Glaciofluvial deposits in the form of eskers occur mainly in the valleys.

The highest coastline (HK) in the area (see definition *inter alia*, Cato 1982) was formed by the Ancylus Lake. Below the HK, primarily in the deeply incised valley, fine-grained sediments occur (chiefly silt). These comprise the characteristic valley deposits which consist partly of Late and postglacial fjord sediments, which were deposited concurrently with the continuous elevation of land and left in the valleys as terrace planes and delta surfaces (Lidén 1913).

Gullies and bluffs which, together with the flat terrace surfaces, are characteristic for the area have been cut out from the fine-grained valley sediments. In the river system of the Ångermanälven, the gullies are formed approximately as far as the HK. There is, for example, a very marked gully landscape around Sollefteå, where the difference in level between the highest terrace plane and the gully mouths amount to some 50 m (Arnborg 1959).

The extent of the alluvial sediments is not known in detail (cf. J. Lundqvist 1987). They denote recent gravel and sand deposits that have been carried along the riverbed by flowing water, as contrasted with recent accumulation sediments that are transported in suspension. The thinly varved, blue-gray glacial clay occurring in the area is overlain by postglacial fine silt deposits, called postglacial fjord sediments. In some areas, these are in turn covered by alluvial sediments (Lidén 1913).

A compilation of the Quaternary deposits along the shores of the Ångermanälven shows that the upper reaches of the river are dominated by glaciofluvial and till deposits, the central sections by fjord sediments, and the lower stretches by alluvial sediments (Fig. 15 in Arnborg 1959). Rock outcrops in the form of glacial eroded slabs have only been found 500 m upstream from the Hammarsbron.

Inland ice recession and the highest coastline

Because of the deep depression of the land on the retreat of the inland ice, the waters of the former Bothnian Sea penetrated deeply into the river valleys of Norrland as the ice receded. In the valley of the Ångermanälven, the former open fjord, 20–30 km wide, extended as far as Sollefteå, where projecting rock peaks and ridges ramified it and divided it into an archipelago landscape. To the west, an arm of the fjord joined the valley of the Indalsälven, and to the north, a great expanse of water extended between the valleys of the Ångermanälven and the Faxälven. Then the fjord ramified and more or less followed the river valleys in stretches several kilometers wide. In the valley of the Ångermanälven, the former fjord reached up to Kortingselet above Junsele, in the Fjällsjöälven to Rossön, and in the Faxälven to Flyn above Ramsele (Fig. 6).

In connection with the receding ice margin mentioned above, the former Bothnian Sea gradually formed the highest coastline (HK), which in coastal regions of Ångermanland is to be found at about 280 m above sea level, only to decline to some 230 m in the inner reaches of the former fjord (*inter alios* Lidén 1913, Hörnsten 1964, Lindström 1973). Since the land was exposed to intensive elevation at the time of the formation of the HK, and in addition was covered by the receding inland ice, the former shore marks were created metachronously. The HK's metachronous isobases run more or less parallel with the coast (Fig. 6), but curve inward just along the Ångermanälven, probably because the recession of the ice was faster in the valley than in the surrounding highlands (Hörnsten 1964).

The deglaciation of the inland ice in Ångermanland covered a period of about 750 years (Lidén 1913). The ice front took 425 years to recede from the present coast to the inner reaches of the former fjord, as recorded by Lidén in the bottom varve of the glacial clay at nearly 30 sites in the valley. Within the area of the former fjord, the rate of recession of the inland ice was 200–400 m/yr (Lidén 1911), and in the valley of the Indalsälven, 240–500 m/yr (Borell & Offerberg 1955). Hörnsten (1964) and Lindström (1973) arrived at similar or somewhat higher values in neighbouring areas.

The recession of the ice from the inner reaches of the former fjord was followed by a period of about 325 years during which the final deglaciation occurred supra-aquatically. Because of the elevation of the land, the river estuary was shifted about 20 km along the valley to Gårelehöjden during this period. The sediments in the upper parts of the valley are purely glacial, because the deposition of varved glacial clay continued after the inland ice had vanished from

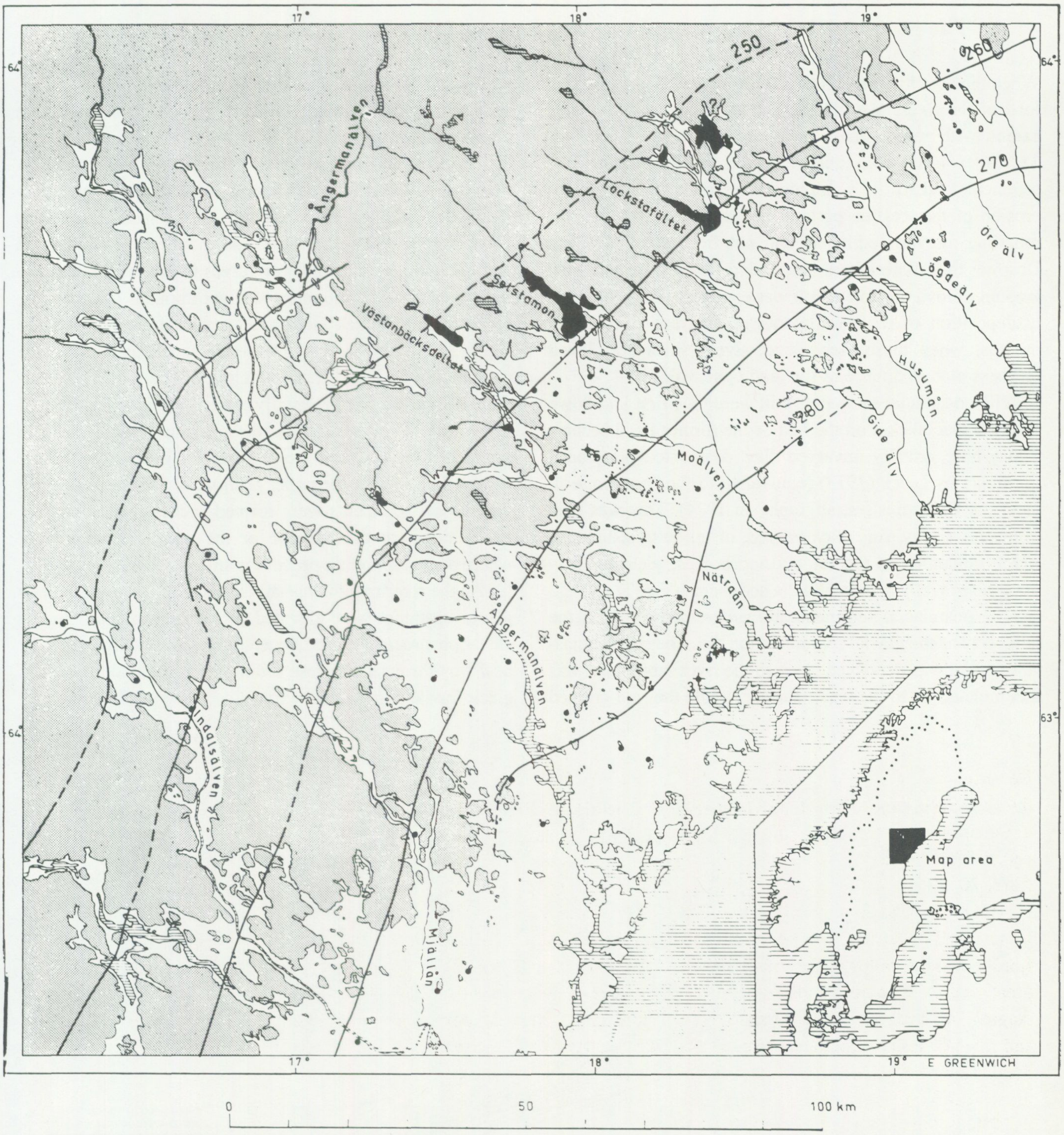

Fig. 6. The metachronous isobases of the highest coastline of the Bothnian Sea in Ångermanland, central Sweden. The gray areas represent land above the highest coastline, and black areas represent ancient glaciofluvial delta deposits (from Hörnsten 1964).

the former fjord. This deposition persisted so long that the meltwater from the remaining ice residue was the determining hydrographical factor. Because of the diminishing accumulation of sediment, the varves of the glacial clay steadily became thinner in the upper layers of the deposits.

According to Lidén (1911), the thickest layers of the glacial clay were deposited along the deep channel of the former fjord. For instance, the clay at Multrå, where the former fjord was about 250 m deep, has a thickness of at least 10 m, while that at Tunsjön, where the depth was 130 m, is only a bare meter thick.

The postglacial development of the area and the formation of the postglacial varves

When the activity of the glacial rivers ceased, the suspended load of the rivers also diminished simultaneously to some extent, with some change in the composition of the load. The latter was a consequence of the fact that the derived sediment load to the watercourses resulted only from the erosion of the ice-free parts of the landscape and the surrounding alluvial sediments and not from the inland ice. Despite the diminished suspended load transport, the amount of load due to erosion was enough to keep the yearly deposition of delta sediments in progress at the river mouths, when these were successively shifted to lower levels as a consequence of the land upheaval.

The postglacial sediments that were thus first laid down over the glacial clay on the bed of the former fjord became a gray-blue, usually unvarved clay, designated postglacial fjord clay by Lidén (1913) (equivalent to the "bottom sediment" in Caldenius's stratigraphy in 1924). This was then overlain by gray, fine silty, varved, distal delta sediments, which gradually, as the estuary approaches, yield to silty-sandy to gravelly proximal delta sediments (Fig. 7).

The postglacial sedimentation progressed much in the same way as the glacial sedimentation did. The coarser clastic material was deposited close to the river mouth and was accumulated up to the water surface, while the fine-grained suspended load was deposited on the bottom of the non-tidal estuary in a distal direction in a gradient of decreasing amount and grain size.

At the river mouth, as it was shifted by the isostatic rebound to lower levels, a coherent delta formation was gradually created, the surface of which was shaped into an even plane sloping down the valley. The sediments are laminated and the number of laminae or varves in the delta formation increases towards the present river mouth. Accordingly, each varve in the delta sediments begins at the delta surface where its proximal end corresponds to the location of the river mouth for the corresponding year. From the delta surface, the varves plunge distally toward the lower reaches of the valley at the same time they gradually become finer grained, thins out, and are overlain by gradually younger varves. In this way, the upper postglacial sediment series of the alluvial sediments were formed successively along the valley down to the location of the present river mouth, where a corresponding process is still in progress.

As the river mouth was shifted to lower levels, the delta planes upstream were elevated above the sea level. As the elevation proceeded, the watercourses frequently cut their new way through the loose sediments to the underlying till, glaciofluvial deposit, or bedrock.

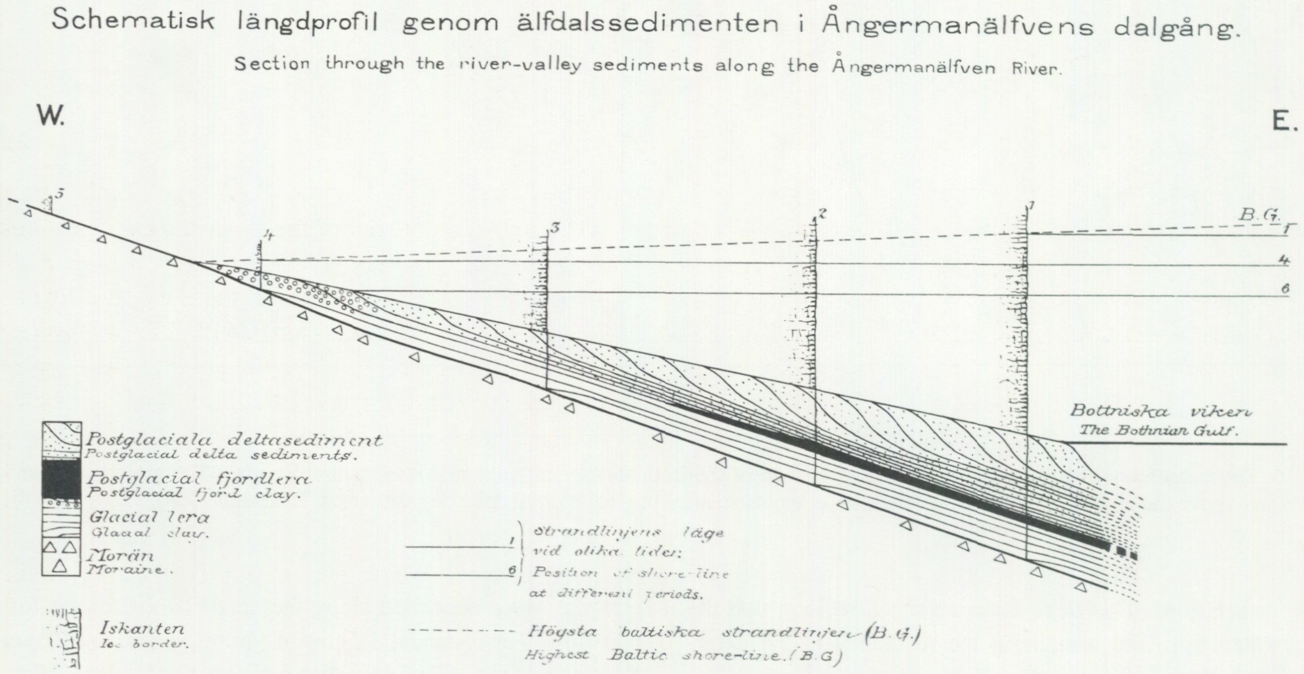

Fig. 7. Typical section through the valley sediments along the Ångermanälven river. The diagram is an improvement on the figure previously shown by Lidén (Lidén 1913). B.G. = HK, the highest coastline (original document Lidén left behind).

As a consequence of this erosion and simultaneous formation of gullies in the delta planes, most of the already deposited delta sediments were transported away and redeposited on the continuous expansion of the delta downstream. The bulk of the material in the postglacial delta sediments therefore derives from these repeated redepositions. According to Lidén (1913), it is the presence of the underlying huge glaciofluvial deposits, the glacial clay, and the till that have made it possible for the deposition of the postglacial sediments to have continued to the thickness found in several of the northern Swedish river valleys.

Thus in the present form, the alluvial sediments are only erosion residues of the original filling, which before the area emerged from the sea, was accumulated right across the valley. The original delta surface is, as a rule, preserved in the uppermost sediment plateau and in the terrace ledges. The lower terraces are floodplain terraces, since they were created when the river's floodplain sank through the sediments as the riverbed shifted position. They are more or less deeply incised in the delta sediments and often enlarged by floodplain sediments with their often typical stratification. At the base of the unconformity to the delta sediment, there is river gravel overlain by stratified sand that was deposited during the river's high-water periods (Fig. 8).

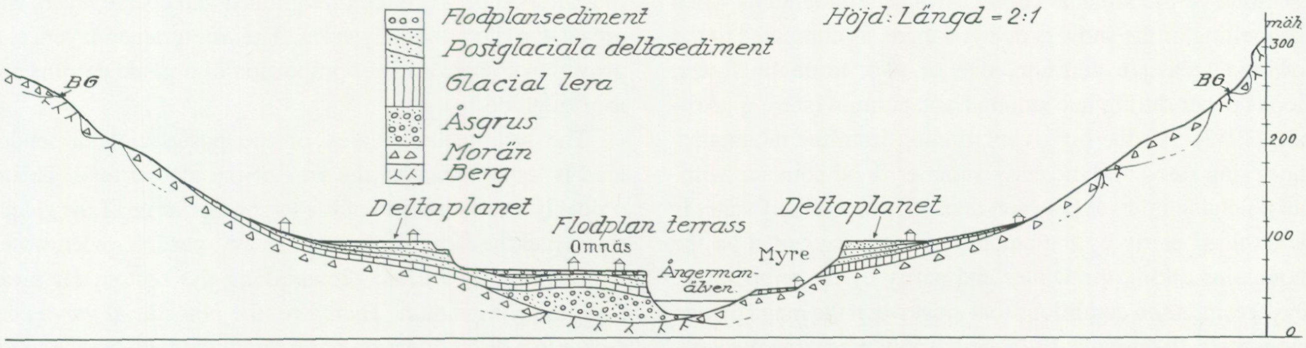

Fig. 8. Cross section (height : length = 2 : 1) through the valley sediments in the Ångermanälven river at Omnäs and Myre. B.G. = HK, the highest coastline (original document Lidén left behind). Legend from above: Floodplain sediments, postglacial delta sediment, glacial clay, glaciofluvial gravel, till, bedrock.

The postglacial varves

As in the case of the glacial clay (e.g., G. De Geer 1940), the postglacial sediments in the valley of the Ångermanälven are varved. Each varve consists of two layers. The upper layer is fine grained, sometimes clayey, and often thin, compared to the lower layer that is thicker and consists of coarser materials, such as coarse silt and sand. The clayey layers also exist in the most proximal varves.

In the sediment stratum, the postglacial varves may easily be distinguished from the glacial one. The difference is most obvious in that the layer of entire clay corresponding to the winter layer in the glacial varves is completely missing in the postglacial varves (cf. Lidén 1911, 1913). In addition, the glacial varves have greater plasticity and elasticity, which is obvious by touching them.

As the source material of the two sediment types – the glacial and the postglacial one – has been the same, the difference between the two varve types is explained by the differences in the sedimentation media. The determining factors are, among others, the stream velocity, the temperature, the salinity, the organic production (i.e., the organic supply) within the sedimentation basin, and the yearly periodicity of the river's water discharge (see *inter alia* Arrhenius 1947, Cato 1987, Leemann & Niessen 1994, Brunnberg 1995).

According to Kullenberg & Fromm (1944), Granar (1956), and Cato (1985, 1987), there is a direct and obvious correlation between the maximum daily mean discharge in the spring and early summer floods in the Ångermanälven and the thickness of the corresponding varve. The correlation with the mean value of the spring flood, or with the mean value for the total annual discharge on the other hand, is far less clear, or in some cases, non-existent. This means that the main part of the annual sediment load transported by the river is transported during those days when the spring and early summer flood results in the largest water discharge, i.e., highest flood (cf. Lidén 1911 and Caldenius 1924).

The glacial rivers probably had only one flood period and one low-water period during the year. During the former period, the water discharge probably fluctuated a lot, but there was no really low discharge. The present rivers of northern Sweden often show several high- and low-water periods during the year. The spring flood is the highest flood of the lowland streams; the early summer flood is the highest flood of the streams coming from the mountains when the melting of the snow is delayed there, as compared to the lowland areas. In addition, one or two, normally lower, floods occur during late summer and autumn (see e.g., Arnborg 1959). For the big rivers running from the mountains, the spring flood and the early summer flood coincide without a notable interval between them. The amount of water is determined partly by the amount of snow deposited on the mountains during the winter and partly by the temperature and precipitation conditions that exist when the magazinized snow melts. Consequently, a large snow magazine does not necessarily involve a large spring and early summer flood. The low-water periods of the rivers occur during the summer and the winter. In general, the latter is the longest one with its minimum in late winter. The appearance of several high- and low-water periods during the year is probably the direct reason for the less distinct feature of the postglacial varves, as compared to the glacial one.

As a consequence of several sedimentation periods during one year, the postglacial varves often consist of several internal layers and structures with a varying grain size and color (cf. Caldenius 1924 p. 41, Bergström 1968 p. 38, and Cato 1987 p. 20). However, in general, the winter layer is the most pronounced and second thickest of these. The thickest is the coarse part created during the maximum discharge in the spring and early summer floods. According to Cato (1987), the winter layer is composed of a lower, thicker, dark part and an upper, thinner, light gray part. Besides this, the upper part of the winter layer often contains larger or smaller sand and gravel grains (sometimes small stones), which normally do not occur within the other internal layers of the varve. These sand and gravel particles have been transported with ice flows, which during the ice break period in the spring have followed the stream current down to the river mouth area, where the flows have melted and dropped the particles. Because of their greater weight, the particles sink down into the most recently deposited and unconsolidated winter layer. However, heavy rains, storms, and slides may also transport coarse material to the sedimentation basin, but except in the case of slides, the coarser particles never coincide with a fine-grained winter layer, since other coarse particles, such as coarse silt and sand, only are discharged during high water periods. Therefore, coarser particles derived from these circumstances always occur in the coarse-grained part of the varve. According to Lidén (unpubl.), the particles mainly appear in more or less distal varves, that is, in the estuary where the ice flows finally melt.

In an approximate study of the grain size composition of the different postglacial varve sections, winter and summer layers, Kullenberg & Fromm (1944) found that all the layers were composed of well-sorted material. The difference in grain size between the fine-grained and coarse layers was greatest in the proximal varves. The fine-grained layers also proved to contain a larger proportion of organic detritus and iron sulphide.

The sedimentation area of the postglacial suspended load is less broad than the area of the glacial load. This is probably a consequence of the larger discharge of the glacial rivers and the fact that the cold, heavy, particle-laden water, like a turbidity current, flows along the bottom far away from the river mouth. Therefore, the postglacial varves decrease in a distal direction more rapidly in thickness than the glacial one, until finally they change into a dense estuarine clay without visible varve limits (cf. Hörnsten 1964 p. 195).

As the number of varves downstream from the river valley grows, the composition of the sediment strata successively changes down to the present river mouth. In the lower stretches of the valley, the postglacial stratum in its deepest part consists of a dense estuarine clay, which in the upper stretches of the valley corresponds to a large number of the yearly formed varved and proximal delta sediments. The estuarine clay is overlain by a large number of distal delta varves, which in their deeper parts are very fine grained and with more or less visible varve limits. Upward in the sediment sequence, the varves get more and more thick and the varve limits more and more distinct, simultaneously with an increasing grain size. In the uppermost part of the sequence, the proximal delta sediments appear. Often they consist of more or less medium and coarse sand and, in general, with a thickness of very local character (see Cato 1987 p. 42).

Single varves of greater thickness may, in some cases, be the result of occasional larger slides or other erosion phenomena along the river shores or in the riverbed (Cato 1987).

In the upstream direction of the valley, the dense estuarine clay successively diminishes with respect to the number of varves, and finally it ceases when its lower part is successively replaced by distal delta varves. Simultaneously, the number of overlain distal delta varves decreases. Where the postglacial deposit starts in the uppermost reaches of the valley, only proximal delta varves occur directly accumulated on the glacial varve series.

Relative to each other, the postglacial varves are different in thickness, and they keep this relative difference within the entire sedimentation area. Deviations from this regularity in varve thickness normally occur only in the most proximal parts of the varve (see Cato 1987 p. 42).

In Figure 7, first created and published by Lidén in 1913 and later modified by him, according to the documents he left behind, a schematic profile through the valley sediments along the Ångermanälven river is shown. It shows the relationship between the formation of the sediment, the inland ice recession, and the shift of the river mouth to lower levels as a consequence of the land upheaval. The sediment series predict continuous yearly deposition during the melting and recession period of the inland ice and the following delta formation period up to the present.

Consequently, if varve counting is carried out in the glacial and postglacial varve series in any of the valleys of northern Sweden, where enough valley sediments have been deposited and stored, an exact chronology of the Late Quaternary is obtained, i.e., from the onset of the deglaciation and onward to the present time. The glacial varves register the recession of the ice border, and the delta sediments register the gradual shift of the river mouth from the HK down to the present river mouth at the Bothnian Sea. The difference in elevation between two sites, at different heights on the delta plane sloping down to the valley, shows the land upheaval that occurred during the period between the formation of the two different surface varves at these respective sites. This time span corresponds to the number of varves found between the surface of the lower site and the varve in the series identical to the surface varve at another site located further up the valley. Thus, through the delta sediments, one can determine the course of the land upheaval and date the shoreline at different times, as has been done, for example, for the Ångermanälven region by Lidén (1938) and Cato (1992).

Methods

Ragnar Lidén carried out his measurement of the varve thickness of the postglacial valley sediments at 19 different sites along a 70 km-long stretch of the Ångermanälven river between Näsåker and Prästmon (Fig. 3). The technique he used followed the accepted principles and the method that was first devised by G. De Geer (1912 and 1940). The measurement of the varves was executed in bluffs excavated by river erosion. The stratigraphical descriptions performed by Lidén from these sites are presented in Figures 9a–9c and 10. The figures, never before published, were found in their original form among the printed plates left behind by Lidén. However, English text has been added by the present author.

From the documents Lidén left behind, it is obvious that Lidén executed the varve measurements directly on the excavated bluff wall by marking the varve limits on paper strips (see Fig. 16), starting from the sediment surface and going as far down in the excavation as the varves were discernible. When the varve thickness became too thin and/or when the laminae became too invisible at the existing humidity of the sediment, he sampled these sequences by using a long tin box. This procedure was, according to Lidén, carried out down to a specific depth wherever a visible distinct varve or unique horizon occurred, and which was also visible in the stratigraphy of all other sites along the river. At several of these sites, this procedure had to be carried out down to the uppermost part of the glacial clay. At the sites of Undrom and Prästmon, the complete postglacial sequence was sampled up to the sediment surface. The sampled series were then air dried until the sediment assumed the degree of humidity at which the limits of the varves were most distinct before he transferred the varve limits to the paper strips. The measurements of the varves were then executed as far down in the series of layers as the varves were discernible.

When the varve series from the 19 sites had been correlated to each other and connections were obtained, Lidén was able to link one long and continuous time series of varves, in which the chronological varves were numbered in a continuous series (in Figs. 36:1–36:38, given as PG varve no.). Thus, Lidén was able to create a time scale that starts with the year 1 corresponding to the first postglacial varve deposited.

Lidén's original paper strips containing the varve thicknesses and varve limits that he measured are stored together with the partly sampled varve series in the Geochronological Museum (formerly the Geochronological Institute) in the Department of Quaternary Research, Stockholm University. According to Erik Fromm (pers. com.), Lidén's original paper strips do not always correspond to the version of the varve thickness diagrams that were eventually printed. Lidén made some final revisions before the diagrams were printed.

In the present paper, Lidén's printed but less comprehensible diagrams (see Fig. 2) have been digitized (with a precision of varve thickness of +- 0.5 mm), worked up, and

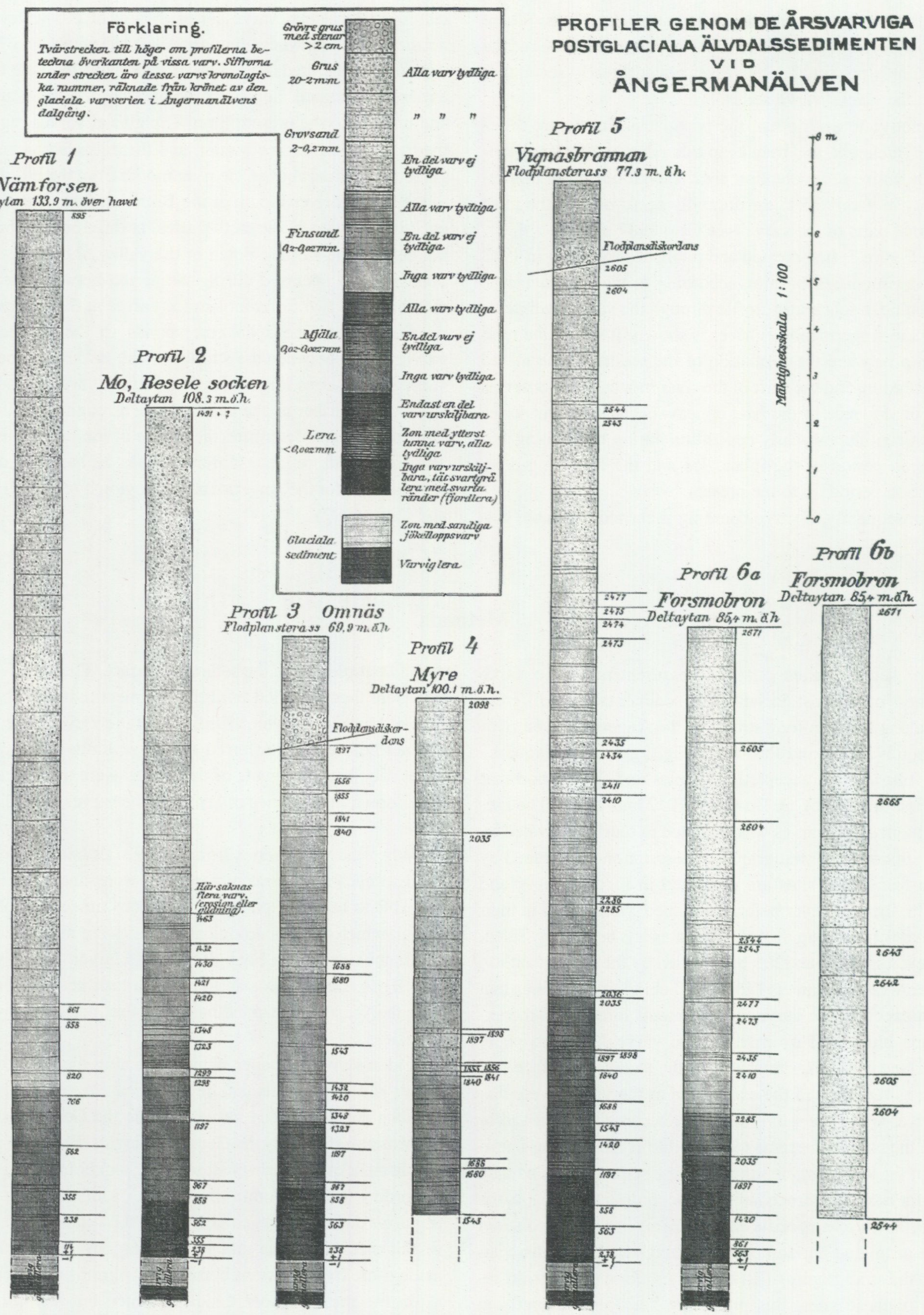

Fig. 9 a–c. The stratigraphy of the sites investigated by Lidén (original document Lidén left behind). The cross lines to the right of the sections mark the upper limit of some varves. The figures below the lines mark the varve number according to Lidén's chronology.

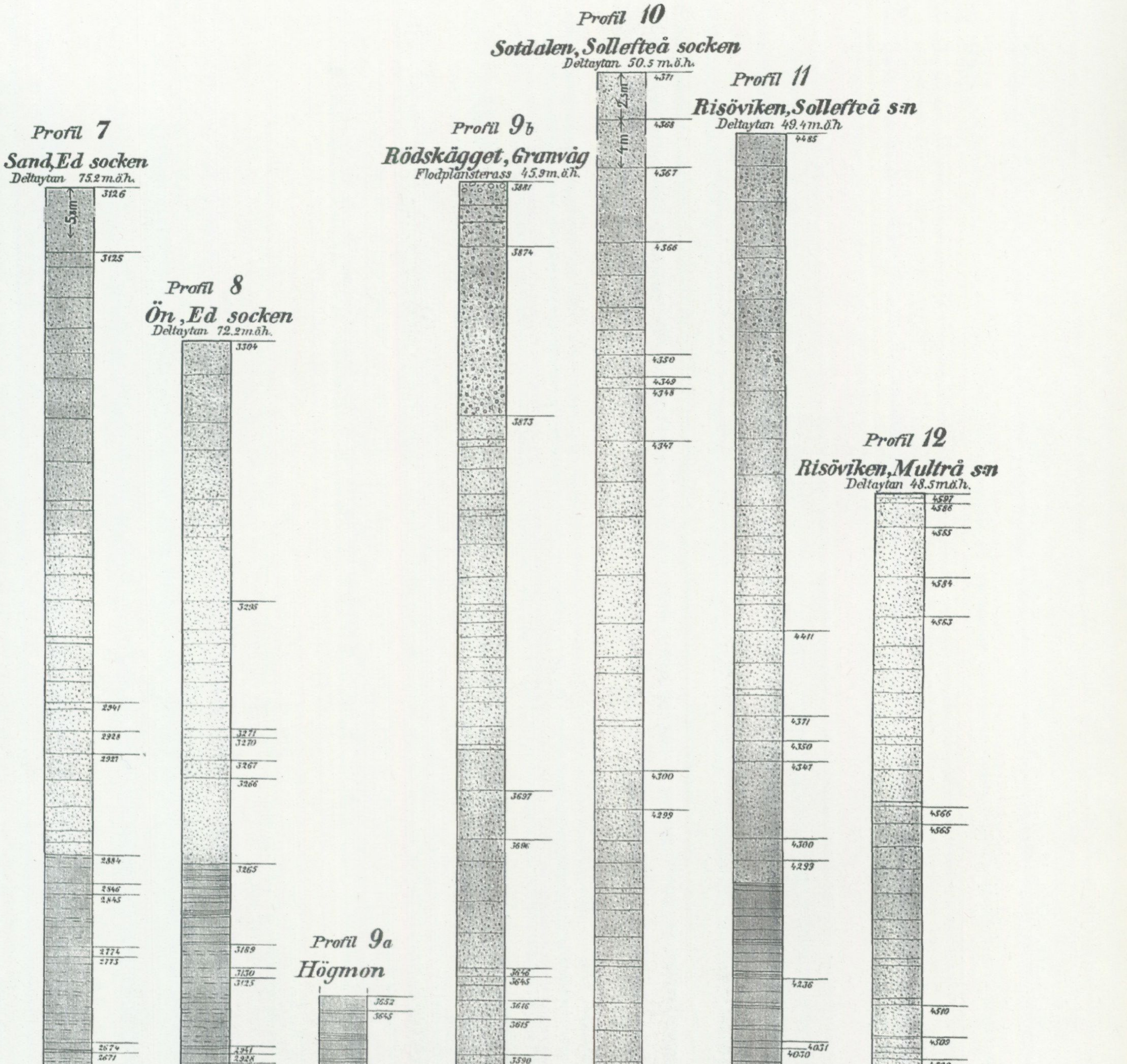

Fig. 9 b. (*Cont. text from p. 16*). At the top of each section the height above sea level is given for the delta surface and floodplain terraces respectively. The legend in Fig. 9a shows from above: coarse gravel with stones (>2 cm), gravel (20–2 mm), coarse sand (2–0.2 mm),

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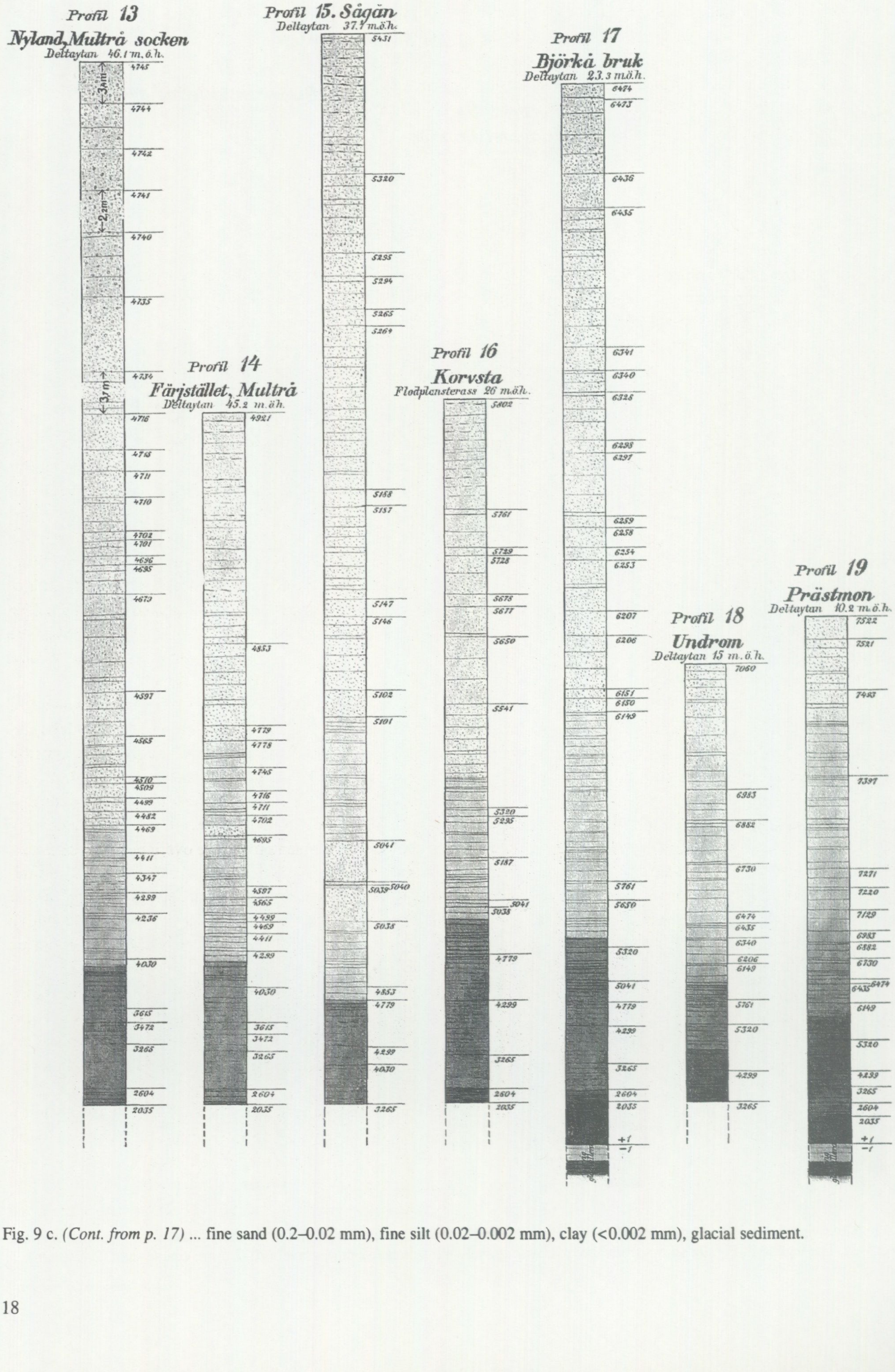


Fig. 9 c. *(Cont. from p. 17)* ... fine sand (0.2–0.02 mm), fine silt (0.02–0.002 mm), clay (<0.002 mm), glacial sediment.

finally plotted in a more comprehensible and conventional way. They are all presented in their entirety in Figures 36:1–36:38. During the work carried out by the present author, all the correlations made by Lidén have been controlled and simultaneously checked with other documents and notes Lidén left behind.

Lidén leveled the highest coastline (HK) with the aid of an Elfing mirror and a Tesdorpfs tube, using the height stations of the Geographical Service Office of Sweden, now the National Land Survey of Sweden. It is probable that he also leveled the delta surfaces in the same way.

Description of the localities and varve series investigated and correlated by R. Lidén

To the descriptions given below of the sites and varve series investigated and documented by Lidén during the beginning of this century have been added some other data:
- the position of the highest coastline, HK, (Lidén used the older term, now replaced, "the highest Baltic shore-line", BG) in meters above sea level (from documents Lidén left behind),
- the position of the surface of the delta level in meters above sea level (from Lidén 1938),
- the year in Lidéns chronology when the ice border was located at respective sites (from Lidén 1913),
- the calendar year according to the connection of the varve chronology to the present (Cato 1985, 1987).

With exception of the latter, some of these data were also found in the documents left behind by Lidén. According to him, the values presented, with the exception of the levels of the delta surface, were partly interpolated. HK refers to the limit of wave washing, but it was reduced by Lidén to what he considered to be the mean water level at that time (see Lidén 1913, p. 5). The HK values and, according to his chronology, the years given for the location of the ice border at respective sites are probably based on data already given by Lidén in 1913 (p. 6 and plate 1). In addition, the varve number of the uppermost varve in each series, corresponding to the delta surface, has, in most cases, been previously published by him (Lidén 1938). In order to give a complete description of each site, these previously published data are repeated in this paper. The present author has cross-checked all data between the documents Lidén left behind and those he previously published, and no discrepancy could be found.

As was mentioned above, Lidén's glacial time scale for the ice recession in Ångermanland embraces 747 years. In his work from 1913, he starts the time series at Fällön (Lidén 1913); i.e., year 1 is when the ice border was located at Fällön. In the unpublished documents left behind by Lidén and in the printed but never published varve diagrams (see Figs. 2 and 10), he did the opposite; i.e., he starts the time scale by giving the last glacial varve 747 the number -1 and the first glacial varve the number -747. The latter glacial time scales is used in this paper in order to correspond with Lidén's figures presented here (Figs. 2, 9 and 10). This time scale is referred to as Lidén's chronology. In the postglacial time series, Lidén has given the first or oldest postglacial varve the number +1 and the last or youngest varve he found the number +7522.

In the following, a description of each of his localities is given.

1. Nämforsen – in Ådalsliden parish (Figs. 3, 9a, 10, 11 and 36:1–36:5). The excavation consists of a bluff, i.e., a river cut into a high vertical bank presenting a precipitous front, on the left side of the Ångermanälven river close to the bridge-hold at the Nämforsen rapids. The highest coastline (HK) is situated 249 m above sea level and the ice border was, at that time, located at Nämforsen -419 (Lidén's chronology), i.e., 329 years after it was located at Fällön (Lidén 1913) or 9,336 years BP (acc. to Cato 1985, 1987). The sediment surface, equal to the delta surface, is located 133.9 m above sea level (Lidén 1938).

According to Lidén's notes, the postglacial sequence of the stratum embraces 895 distinct varves up to the delta surface. This means that the Ångermanälven river debouched at Nämforsen year 895 (Lidén's chronology), i.e., 8,022 years BP (acc. to Cato 1992). The maximum varve thickness is 400 cm. The upper 96 varves (799–895 in Lidén's chronology) of the Nämforsen profile are overlapped by the lowermost part of the varve series from Mo (Fig. 36:5). The similarities between these two series are obvious in the case of the varves between 799 and 873 (Lidén's chronology), while the uppermost 20 varves of the Nämforsen profile are of the proximal type, i.e., very thick and coarse-grained varves, formed in a position until the sedimentation ceased and the area emerged by the elevation of the land. These types of varves have a very local character and can seldom be correlated confidently to more distal varves (see above).

2. Mo – in Resele parish (Figs. 3, 9a, 10, 12 and 36:5–36:8). The excavation consists of a bluff close to the east side of the road at the left side of the Ångermanälven river, in a gully about 600 m north of Mångmanån river mouth. According to Lidén's notes, there are several disturbances by small slides in the stratum. The sediment surface, equal to the del-

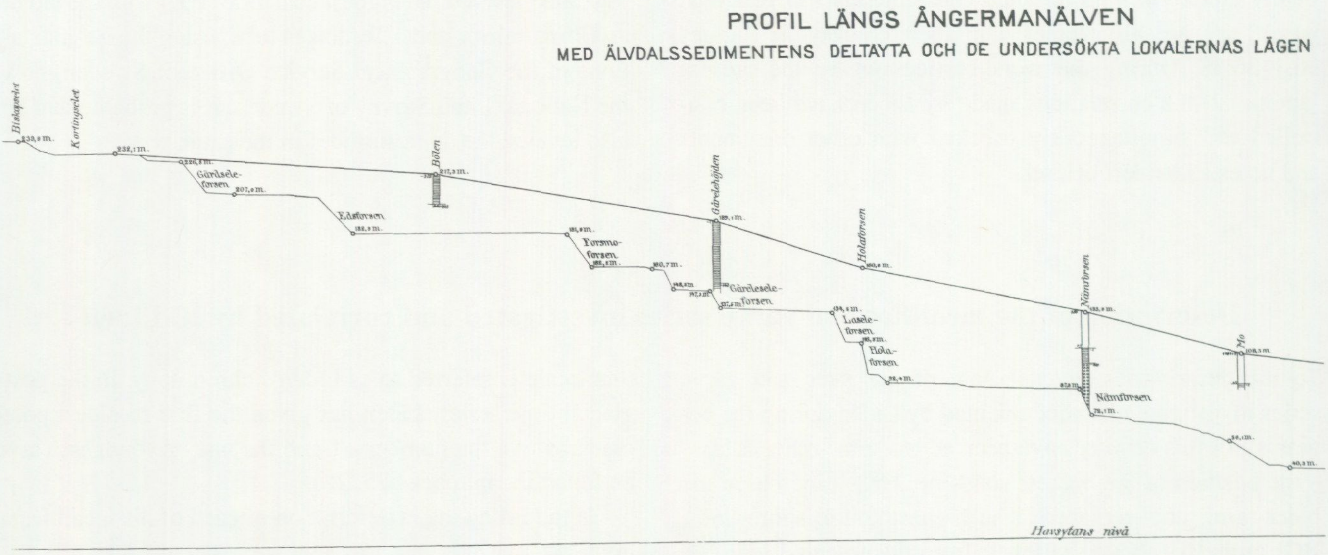


Fig. 10. Section through the Ångermanälven valley showing the location and height above sea level of the former delta surfaces and floodplain terraces, the location of the varve series, the stratigraphy, and the present water surface of the river. The lower line refers to the sea level. The legend shows from above: Floodplain sediment, postglacial valley sediment (the figures show some varve numbers according to Lidén's chronology), glacial clay (varved), glaciofluvial gravel, till. At the top of each locality the height above the sea level is given for the former delta surfaces (solid line) and the floodplain terraces (hatched line) respectively. The lowermost solid line marks the height above the sea level of the present river surface (original document Lidén left behind).

Fig. 11. The "Präst" bluff (site 1) to the right of the Nämforsen fall in the Ångermanälven river, Ådalsliden parish. (Photo: G. H. Mildhs c. 1910).

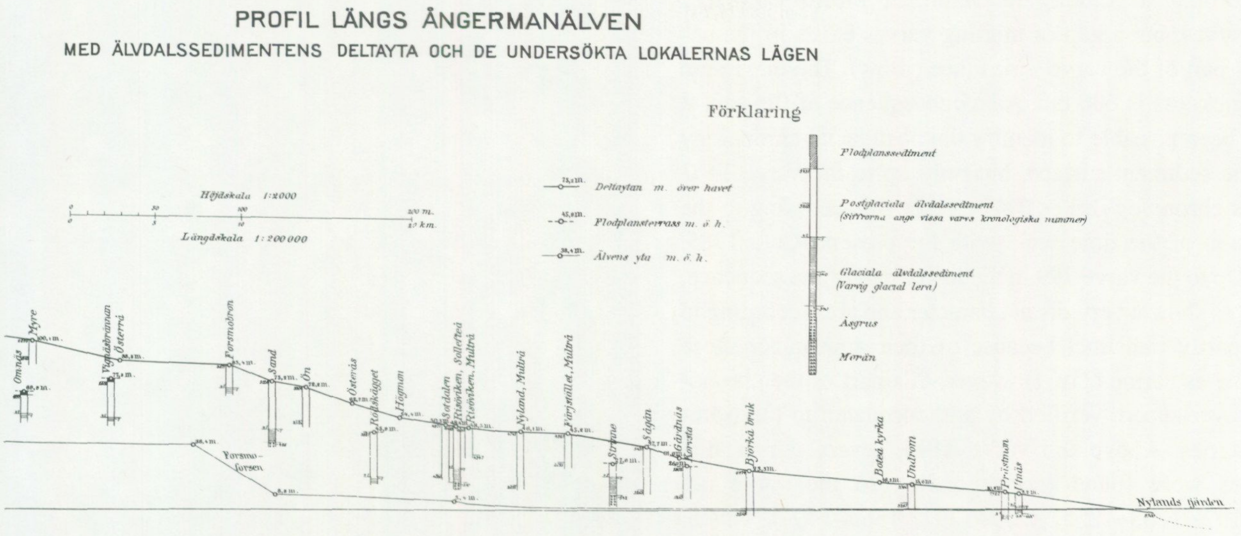


Fig. 10, cont.

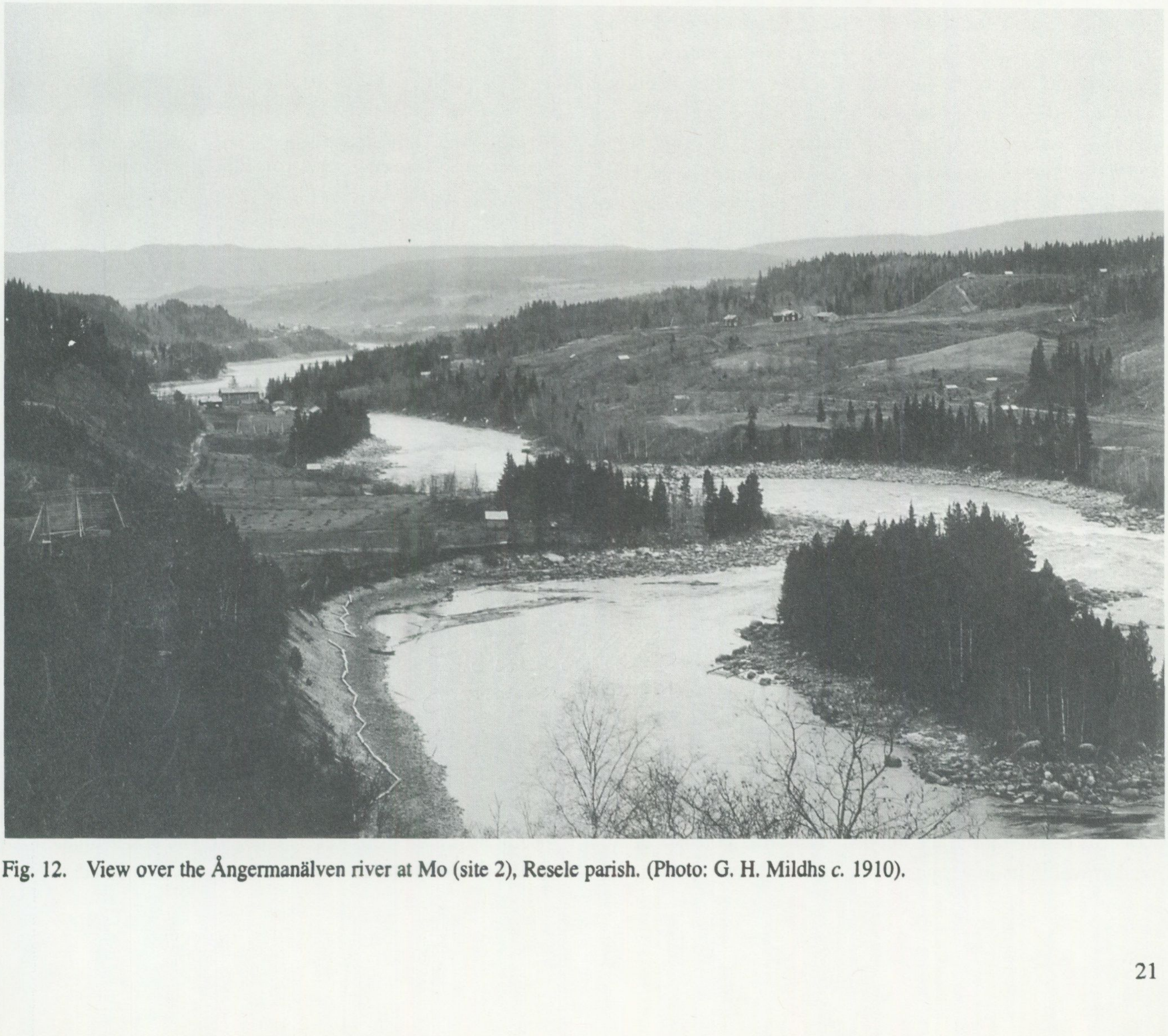


Fig. 12. View over the Ångermanälven river at Mo (site 2), Resele parish. (Photo: G. H. Mildhs *c.* 1910).

ta surface, is located 108.3 m above sea level.

According to Lidén, the sediment profile embraces 1,491 varves, but a gap of missing varves exists in the uppermost part of the varve series (see below). The maximum varve thickness is 600 cm. As a consequence of the gap, it has not been possible to identify the postglacial chronology up to the sediment surface, but only up to the varve 1463 (Lidén's chronology), i.e., 7,454 years BP according to the connection of the time scale with the present (Cato 1985, 1987). Up to the varve 799 in the lower part of the sequence, the varves show a very distal character and are, according to Lidén, partly indistinct because of their appearance close above the estuarine clay. However, this part of the chronology is overlapped, verified by and correlated to the Nämforsen series. Above the varve 1195, several larger disturbances were found (corresponding to the varve no. 1196–1197, 1233–1255, 1272–1291, 1365–1409), which, according to Lidén, might have been a consequence of slides or erosion during the sedimentation phase. Lidén was able to identify the number of varves missing in these gaps by comparing them with the Omnäs varve series (Fig. 36:7–36:8 and below).

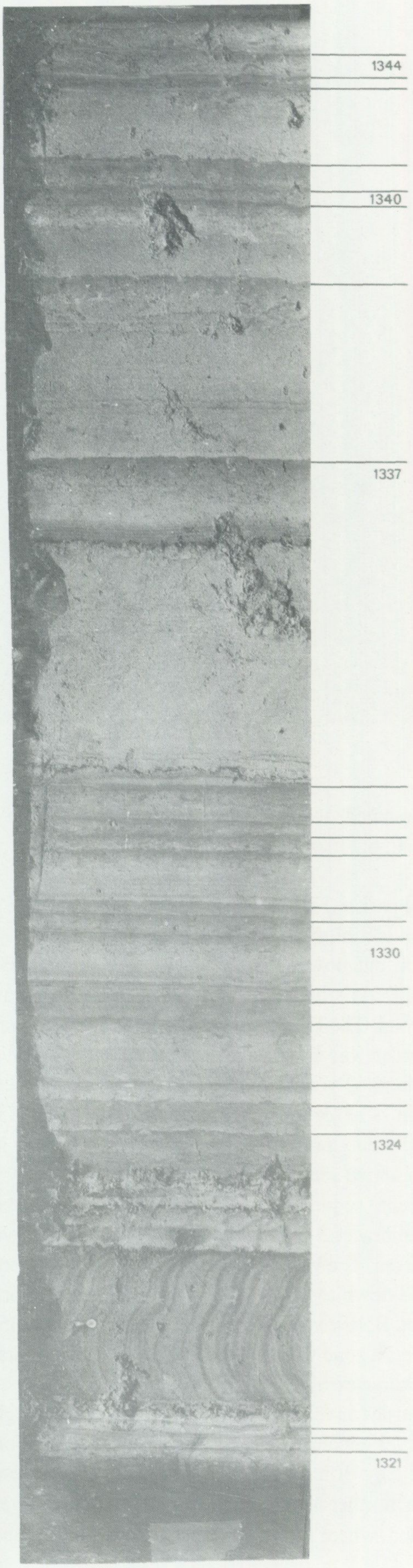
In the uppermost part of the Mo varve series (between varve 1463 and 1464, see Fig. 36:8), Lidén concluded that an unknown number of varves were probably destroyed by erosion and therefore missing. Because of their proximal character, it was not possible for Lidén to correlat the uppermost varves from the delta surface down to this hiatus with the Omnäs series and thus to place them into the chronology. Therefore, according to Lidén's notes, it was not possible for him to date the debouch of the Ångermanälven river at Mo. If a comparison is made between the results from Mo and the shoreline displacement curve given by Cato (1992), it can be seen that few, if any, varves can be missed between the varves 1463 and 1464. It is essential to point out that this assumed gap does not affect the chronology. The lower part, without gaps, of the varve series at Mo is overlapped with 96 and 273 varves in the Nämforsen and the Omnäs varve series, respectively. They show an excellent agreement and verify each other. The only part not verified in the Mo varve series is the part that embraces the varves 874–922. Neither the Nämforsen nor Omnäs documented varve series embraces these varves.

3. Omnäs - in Resele parish (Figs. 3, 9a, 10, 13 and 36:5–36:10). The excavation consists of a bluff on the right side of the Ångermanälven river about 1,200 m upstream from Resele Church. The sediment surface or terrace surface is located 69.9 m above sea level.

According to Lidén's notes, the upper part of the stratum consists of fluvial terrace deposit. The latter consists of fluvial gravel in its lower part, which discordantly rests on delta sediments. The delta sediment embraces 1,897 varves up to the discordance. The lower 921 varves are very indistinct and may be classified as estuarine clay. An example of the distinct varves is given in Fig. 14. The maximum varve thickness is 26 cm. The Omnäs varve series does not lack any varves. The lower part up to varve 1463 is covered, verified by and correlated to the Mo varve series (varves 922–1463), and the upper part between the varves 1547 to 1897 is covered, verified by and correlated to the Myre varve series. There is a good agreement between these varve series. The only part of the Omnäs series that has not been verified by other varve series are the varves 1464 to 1546. Because of the lack of a delta surface, Lidén was not able to date the debouch of the Ångermanälven river at Omnäs.

Fig. 13. The bluff at site 3 in Omnäs, Ångermanälven river in Resele parish, showing varved floodplain sediments. (Photo: R. Lidén 1909).

4. Myre - Resele parish (Figs. 3, 9a, 10, 15, 16 and 36:8–36:11). The excavation consists of a bluff to the east of the road on the left side of the Ångermanälven river, about 700 m upstream from Resele Church. The HK is located 253 m above sea level, and the ice border was located at Myre



year -450 (Lidén's chronology), i.e., 298 years after it was located at Fällön (see Lidén 1913) or 9,367 years BP (acc. to Cato 1985, 1987). The sediment surface, equal to the delta surface, is located 100.1 m above sea level (Lidén 1938).

The postglacial stratum up to the delta surface embraces 2,098 varves. According to Lidén, all varves are distinct, but his varve diagram shows only the varves down to the varve 1543. The maximum varve thickness is close to 29 cm. The whole varve series has been verified by the overlap of the Omnäs (varves 1543–1897) and Vignäsbrännan (varves 1802–1897) varve series, respectively. Between the varves 1802 to 1897, all three series overlap each other. All together, there is a strong agreement between these varve series. According to Lidén, the Ångermanälven river debouched at Myre year 2,098 (Lidén's chronology), i.e., 6,890 years BP (Cato 1992).

5. Vignäsbrännan - in Resele parish (Figs. 3, 9a, 10 and 36:10–36:14). The excavation consists of a bluff on the right side of the Ångermanälven river about 4 km downstream from Resele Church. The sediment surface or river terrace is located 77.3 m above sea level. The upper part of the stratum consists of fluvial terrace deposits, which in its lower part consists of fluvial gravel discordantly resting on delta sediments.

The sequence embraces 2,605 varves with a maximum varve thickness of 430 cm. From the top down to the varve 1150, the varves are distinct, but in the estuarine clay below this distinct sequence, only a few varve zones could be discerned. An example from the former sequence is given in Figure 17, which shows the varves 1307 to 1381. The printed varve thickness diagram left behind by Lidén does not embrace the whole series. Only the uppermost 803 varves are shown (varves 1802–1897). The Vignäsbrännan varve series is overlapped, verified by and correlated to the Myre (varves 1802–2098), the Forsmobron (varves 2035–2605) and the Sand (varves 2307–2605) varve series, respectively. The similarities between the graphs are strong and the correlation obvious.

6. Forsmobron - in Ed parish (Figs. 3, 9a, 10, 18 and 36:11–36:14). The site embraces two excavations: one in a bluff on the right side of the Ångermanälven river about 30 m north of the railway bridge (profile 6a, Fig. 9a) and the other one in the northern slope of the railway cut close to the western side of the bridge (profile 6b, Fig. 9a). The HK is placed 257 m above sea level and the ice border was located

Fig. 14. Part of the varved postglacial sequence from site 3 Omnäs. The numbering of the varves is according to Lidén's chronology, where varve 1 corresponds to the first postglacial varve in the valley of the Ångermanälven. (Photo: R. Lidén 1909).

Fig. 15. The bluff at site 4 Myre, Resele parish. (Photo: R. Lidén 1909).

at Forsmobron year -480 (Lidén's chronology), i.e., 268 years after it was located at Fällön (see Lidén 1913) or 9,397 years BP (acc. to Cato 1985, 1987). The sediment surface, equal to the delta surface, is located 85.4 m above sea level (Lidén 1938).

The postglacial sequence up to the delta surface embraces 2,671 varves with a maximum varve thickness of 221 cm. With the exception of two small zones containing the varves 2045–2052 and 2058–2069, respectively, the varves are all distinct down to the varve 2035. At deeper levels, the sequence consists of estuarine clay in which only a few varve zones can be discerned. The number of varves in the two small indistinct zones mentioned above has been verified by the overlap from the Vignäsbrännan varve series.

The varves between the varve 2605 and the delta surface are considerably thicker in profile 6b compared to profile 6a. The maximum varve thickness is 221 cm. Below the varve 2605, the varve thickness is the same in both profiles. In the varve diagram (Fig. 36:14), the varves 2671–2605 arise from profile 6b, while the others arise from profile 6a. The Forsmobron varve series is overlapped and verified by the Myre, the Vignäsbrännan, and the Sand varve series with 63, 570 and 271 varves, respectively. There is a good agreement between the two latter series and the Forsmobron varve series, and the correlation is obvious. The Ångermanälven river debouched at Forsmobron year 2,671 (Lidén's chronology), i.e., 6,246 years BP (Cato 1992).

7. Sand - in Ed parish (Figs. 3, 9b, 10, 19 and 36:13–36:16). The excavation is a bluff on the northern side of the gully, which has been cut down by the stream from the Vignästjärn. The profile is situated halfway between the railway and the main road. The HK is placed 258 m above sea level and the ice border was situated at Sand year -486 (Lidén's chronology), i.e., 262 years after the ice border was located at Fällön (Lidén 1913) or 9,403 years BP (acc. to Cato 1985, 1987). The sediment surface, equal to the delta surface, is located 75.2 m above sea level (Lidén 1938).

The postglacial sequence of the fluvial deposit up to the delta surface embraces 3126 varves with a maximum varve thickness of 80 cm. The varves 3126 to 2884 are distinct, but below this zone down to varve 2605, most of the varves are rather indistinct. Below varve 2605 and down to varve 2035, there again exists a zone with sharp and distinct varve limits. This distinct character of the varves within this zone exists at all other profiles investigated downstream, even though those other varves accumulated in a far more distal position and consist of clay. It is also possible to distinguish these varves from each other at the site closest to the recent river mouth, Prästmon, where the varve thickness within the zone

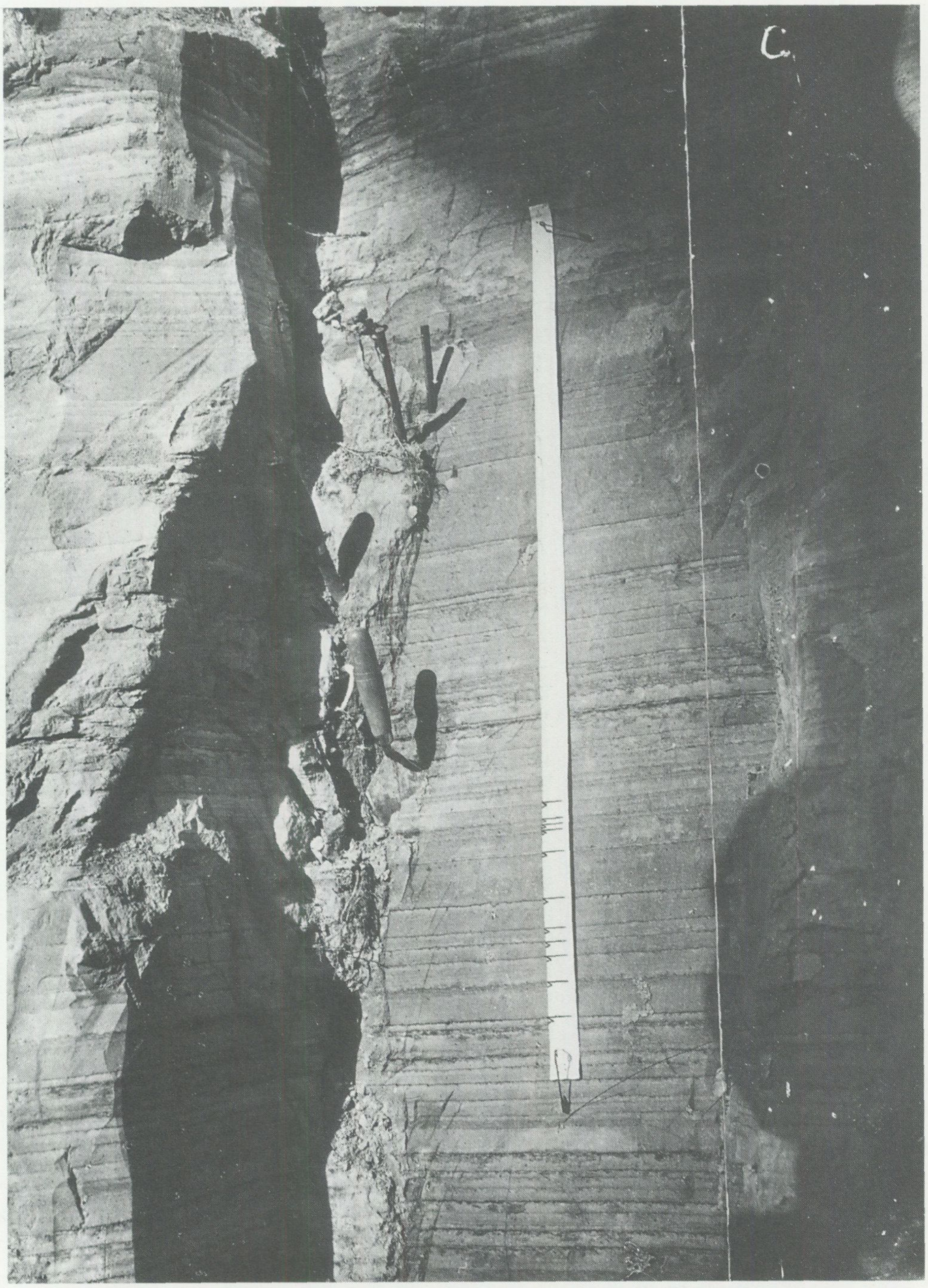
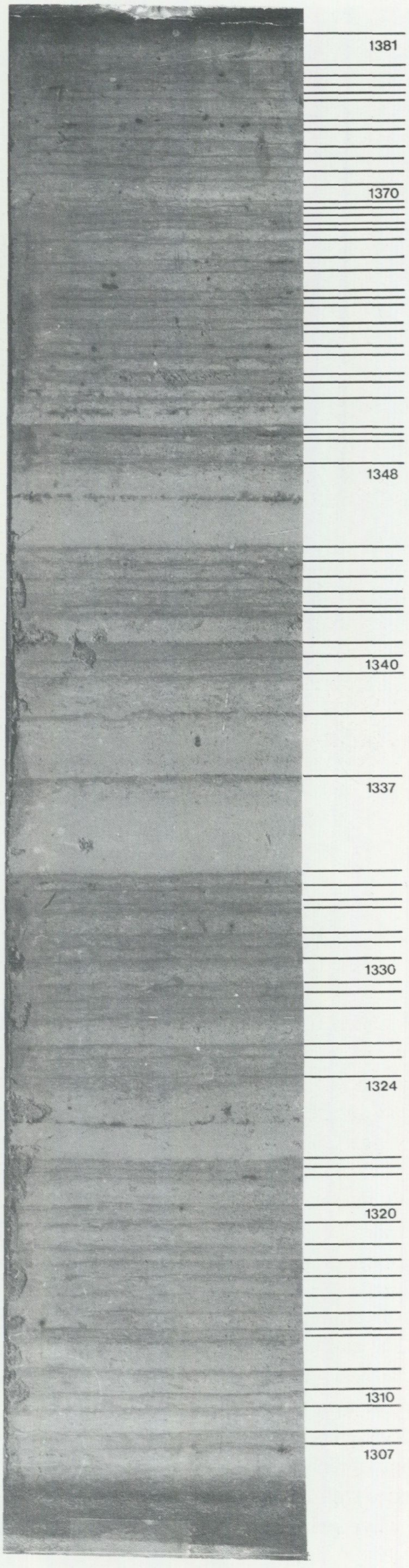


Fig. 16. Varved postglacial sediments at site 4 in Myre, Resele parish, showing the measurement technique used by Lidén. (Photo: R. Lidén 1909).

just mentioned never exceeds 0.5 mm. These varves 2036–2605, called by Lidén "the sequence with the distinct varves," form a characteristic feature in the postglacial sequence of the Ångermanälven fluvial deposit. These varves are sharply distinguished from the other types of varves, which normally in a distal direction pass into fine silt and clay with more or less looming varve limits. Below the varve 2036 and down to varve 1, the profile consists of estuarine clay without discernible varve limits. In addition, this sequence with its successively decreasing thickness downstream from Sand can easily be identified in the fluvial deposit studied down to the river mouth.

The Sand varve series is overlapped, verified by and correlated to the Vignäsbrännan, the Forsmobron, and partly by the Ön varve series with 263, 326 and 293 varves, respectively. In the Ön varve series, part of the overlap is indistinct



(see below). There is a strong agreement between the Sand, the Vignäsbrännan, and the Forsmobron varve series, and the correlation is obvious. There is no overlap and therefore no verification of the varves 2671 to 2885 in the Sand varve series by other varve series studied by Lidén. According to him, the varves within this part of the series were less discernible. Because of the indistinct varves between the varves 2941 and 3027 in the Ön varve series, none of this part of the Sand series has been verified. The uppermost 99 varves can be verified by the Ön series, and the correlation is acceptable.

The Ångermanälven river debouched at Sand year 3,126 (Lidén's chronology), i.e., 5,791 years BP (Cato 1992).

8. Ön - in Ed parish (Figs. 3, 9b, 10 and 36:15–36:17). The excavation is a bluff on the right side of the Ångermanälven river about 3 km upstream the Faxälven river outlet in the Ångermanälven. HK is situated 258 m above the sea level and the ice border was located at Ön year -490 (Lidén's chronology), i.e., 258 years after it was located at Fällön (see Lidén 1913) or 9,407 years BP (acc. to Cato 1985, 1987). The sediment surface, equal to the delta surface, is located 72.2 m above sea level (Lidén 1938).

The postglacial stratum up to the delta surface embraces 3,304 varves with a maximum thickness of 240 cm in the uppermost part. The varve sequence has been measured down to the "sequence of the distinct varves." The varves above this sequence are distinct except for two zones. One zone between the varves 2941 to 3027, where part of the varve limits were indistinct, and one zone between the varves 2620 and 2884, where there were no varve limits, could be discerned. The varve 3027 at the delta surface and down to the varve 3126 is overlapped by and correlated with the varve series of Sand. In addition, the varves 2884 to 2941 are overlapped and clearly correlated to the Sand series, but as mentioned above, there is a zone of indiscernible varves in between these correlated parts in the Sand series. The varves 3127–3184 have not been verified by any series. From varve 3185 and to the delta surface, the Ön varve series has been verified by and correlated with the Rödskägget varve series. The only exception is a small part of seventeen indistinct and indiscernible varves between the varves 3233–3250. The Ön varve series is also overlapped by and correlated to 38 varves in the Risöviken–Sollefteå varve series.

The Ångermanälven river debouched at Ön year 3,304 (Lidén's chronology), i.e., 5,613 years BP (Cato 1992).

Fig. 17. Part of the varved postglacial sequence from site 5 Vignäsbrännan, Ångermanälven valley. For the numbering of the varves, see Fig. 14. (Photo: R. Lidén 1909).

Fig. 18. View over Österåsen and the Forsmobron bridge crossing the Ångermanälven river close to site 6 in Ed parish. (Photo: Nordisk konst, Stockholm *c.* 1910).

9. Rödskägget - Granvåg, Sollefteå parish and **Högmon** (Figs. 3, 9b, 10, 20, 21 and 36:16–36:20, see also Fig. 6 in Lidén 1913). The excavation at Rödskägget consists of a bluff in an eroded terrace about 1 km downstream from the Faxälven river outlet in Ångermanälven. In addition, the Högmon site consists of a bluff situated about 300 m downstream from Rödskägget. The profile in Högmon has been measured as a complement to the profile in Rödskägget, since the basal postglacial varves in the latter were destroyed by slides. The ice border was located at Högmon year -493, i.e., 255 years after it was located at Fällön (Lidén 1913) or 9,410 years BP (acc. to Cato 1985, 1987).

The sediment surface at Rödskägget consists of a fluvial terrace plane located 45.9 m above sea level. The series embraces 3,881 varves with a maximum thickness of 250 cm. With the exception of the varves 3233–3250, the varves are distinct down to the varve 3185. Between this sequence and "the sequence with the distinct varves," most of the varves are indistinct. In Fig. 22 an example is given of the lower part of "the sequence with the distinct varves" resting on estuarine clay. An example of varves from Högmon is given in Fig. 23.

The varves 3185 to 3304 in the Rödskägget–Högmon varve series are overlapped and verified by the Ön varve series. From varve 3266 and up to the terrace surface, varve 3884, the Rödskägget varve series is overlapped by the Risöviken (Sollefteå) varve series. However, the latter series contains fifteen zones varying from 9 to 80 mm in thickness where the varves are not discernible and consequently cannot verify the Rödskägget–Högmon series. Those parts which Lidén was able to measure show a good correlation with the Rödskägget–Högmon series. Thus, the correlation to downstream sites is mainly based on the uppermost 75 proximal varves in the Rödskägget–Högmon varve series and the corresponding varves in the Risöviken–Sollefteå varve series that depict a distinct character. The correlation is probably right but not obvious.

10. Sotdalen - Sollefteå parish (Figs. 3, 9b, 10, 24, 25 and 36:21–36:22). The excavation consists of a bluff on the left side of the Ångermanälven river close to the eastern side of the gully in Remslemon. The HK is situated 260 m above sea level and the ice border was located at Sotdalen year -506 (Lidén's chronology), i.e., 242 years after it was located at Fällön (see Lidén 1913) or 9,423 years BP (acc. to

Fig. 19. The bluff at site 7 in Sand, Ångermanälven river, Ed parish. (Photo: R. Lidén 1909).

Cato 1985, 1987). The sediment surface, equal to the delta surface, is located 50.5 m above sea level.

The postglacial stratum up to the delta surface embraces 4,371 varves with a maximum varve thickness of 399 cm found in the uppermost part. According to the notes left behind by Lidén, he measured the varves from the top of the sediment bed down to the varve 4030. However, in his printed but unpublished diagrams, the varve measurement ends downwards with varve 4157. The Sotdalen varve series is overlapped and correlated to the two series in Risöviken (Sollefteå and Multrå) with 216 and 23 varves, respectively, and completely (214 varves) with the Nyland and Färjstället varve series. However, the Nyland series has four zones, varying in thickness between 1.5 and 20.6 cm, with indistinct varves that Lidén was not able to measure. In the part of the Risöviken varve series that overlaps the Sotdalen varve series, ten varves are missing according to Lidén's diagram. In total, the overlaps from the three sites mentioned cover the whole Sotdalen series, and the correlation and number of varves is obvious.

The Ångermanälven debouched at Sotdalen year 4,371 (Lidén's chronology), i.e., 4,546 years BP (according to Cato 1985, 1987).

11. Risöviken–Sollefteå - Sollefteå parish (Figs. 3, 9b, 10, and 36:17–36:23). The excavation consists of a bluff on the left side of the Ångermanälven river close to the eastern part of the gully, which separates Petersborg from the Remslemon sediment plateau. HK is situated 260 m above sea level and the ice border was located at Risöviken year -510, i.e., 238 years after it was located at Fällön (Lidén 1913) or 9,427 years BP (acc. to Cato 1985, 1987). The sediment surface, equal to the delta surface is located 49.4 m above sea level (Lidén 1938).

The postglacial stratum up to the delta surface embraces 4,485 varves with a maximum varve thickness of 330 cm. The profile embraces several parts with iron-hydrous-oxide zones (the varves 3929–3941, 4058–4068 and 4107–4138), in which it has been impossible to establish the exact number of varves. Therefore, these varve zones have been omitted in Figures 36:20–36:21. With the exception of these three zones, the varves above the varve 3265 are distinct (see example in Fig. 26). Below this limit, the varves successively fail and become indistinct. According to Lidén, the varves 4313–4323 are missing in the series, an assumption that is obvious according to the Sotdalen and the Färjstället varve series. The Risöviken series is overlapped, verified by and correlated to the Ön (the varves 3266–3304), the Rödskägget (the varves 3266–3881), the Färjstället (the varves 3873–4485), the Nyland (the varves 4031–4485), the Sotdalen (the varves 4157–4371), and the Risöviken–Mutrå (the varves 4358–4485) series. Consequently, the number of varves has been overlapped and verified by as many as three other series. They all show a good agreement, and the correlations are obvious.

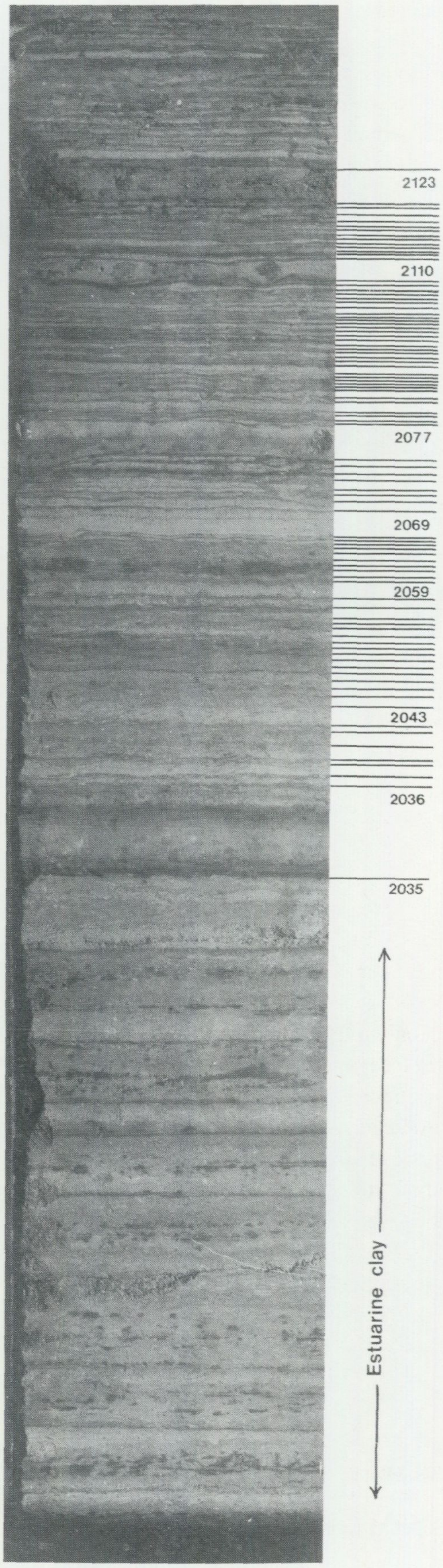
The Ångermanälven river debouched at Risöviken year 4,485 (Lidén's chronology), i.e., 4,432 years BP (Cato 1992).

12. Risöviken–Multrå - Multrå parish (Figs. 3, 9b, 10, 27 and 36:22–36:23). The excavation consists of a bluff on the left side of the Ångermanälven river about 1 km east of the profile in Risöviken–Sollefteå (locality 11 above). HK is situated 260 m above sea level and the ice border was located to this part of Risöviken year -514, i.e., 234 years after it was located at Fällön (see Lidén 1913) or 9,431 years BP (acc. to Cato 1985, 1987). The sediment surface, equal to the delta surface, is located 48.5 m above sea level.

The postglacial stratum up to the delta surface embraces 4,597 varves with a maximum varve thickness of 127 cm. The varves have been measured down to the varve 4347. The measured series is overlapped by and correlated to the

Fig. 20. View over the Ångermanälven river showing the isolated erosion residues of the original delta plateau: the bluffs called Högmon and Rödskägget (site 9). (Photo: Dahlbergs AB *c.* 1910).

Fig. 21. The bluff called Rödskägget (site 9) at the Ångermanälven river in Granvåg, Sollefteå parish. (Photo: Dahlberg AB *c.* 1910).



Sotdalen (the varves 4347–4361), the Risöviken–Sollefteå (the varves 4347–4485), and in total (250 varves), with the Nyland and Färjställct series. Consequently, the varve series is overlapped and verified by as many as three other series.

The Ångermanälven river debouched at this part of Risöviken year 4,597 (Lidén's chronology), i.e., 4,320 years BP (Cato 1985).

13. Nyland - Multrå parish (Figs. 3, 9c, 10, 28 and 36:21–36:24). The excavation consists of a bluff on the right side of the Ångermanälven river about 800 m east of the Övergård railway station. The HK is situated 261 m above sea level, and the ice border was located at Nyland year -521, i.e., 227 years after it was located at Fällön (see Lidén 1913) or 9,438 years BP (acc. to Cato 1985, 1987). The sediment surface, equal to the delta surface, is located 46.1 m above sea level (Lidén 1938).

The postglacial stratum up to the delta surface embraces 4,745 varves with a maximum varve thickness of 335 cm. With the exception of the varves 4150–4156, 4179–4184, 4308–4323, 4340–4347, and 4374–4408, they are all distinct down to the varve 4031. At a deeper level, they are indistinct, but despite this, it is possible to discern most of the varves down to the varve 3265. At deeper levels, the varve limits fail out. It has been possible to determine the number of varves in the indistinct varve zones just mentioned from the correlations and connections with the Risöviken–Sollefteå (varves 4031–4485), Sotdalen (varves 4157–4371), Färjställett (varves 4031–4745), and the Risöviken–Multrå (varves 4348–4597) varve series. Thus, the Nyland varve series is overlapped and clearly verified with up to four other varve series. The correlations are obvious.

The Ångermanälven river debouched at Nyland year 4,745 (Lidén's chronology), i.e., 4,172 years BP (Cato 1992).

14. Färjställlet - Multrå parish (Figs. 3, 9c, 10 and 36:20–36:25). The excavation consists of a bluff on the left side of the Ångermanälven river close to the road going down to the old ferry berth, about 700 m east of Multrå Church. The HK is situated 262 m above sea level, and the ice border was located at Färjställlet year -532, i.e., 216 years after it was located at Fällön (see Lidén 1913) or 9,449 years BP (acc. to Cato 1985, 1987). The sediment surface, equal to the delta surface, is located 45.2 m above sea level (Lidén 1938).

The postglacial stratum up to the delta surface embraces 4,921 varves with a maximum varve thickness of 40 cm.

Fig. 22. Part of the varved postglacial sequence at site 9 Rödskägget, Ångermanälven valley, Sollefteå parish. For the numbering of the varves, see Fig. 14. (Photo: R. Lidén 1909).

They are distinct down to varve 4030, but at deeper levels, the varve limits successively become more and more diffuse. However, according to Lidén, it was possible to measure the varves down to varve 3873, but deeper down in the "zone with the distinct varves," only a few varve zones and single varves could be discerned. Among the latter, the varve 3266 should be pointed out, as it appears distinctly with its relatively great thickness in other profiles also. The Färjstället varve series is overlapped, verified by and correlated to the Rödskägget (varves 3873–3881), the Risöviken–Sollefteå (varves 3873–4485), the Nyland (varves 4031–4746), the Sotdalen (varves 4757–4371), the Risöviken–Multrå (varves 4348–4597), and the Sågån (varves 4651–4921) varve series. The correlations are obvious.

The Ångermanälven river debouched at Färjstället year 4,921 (Lidén's chronology), i.e., 3,996 years BP (Cato 1992).

15. Sågån - Sånga parish (Figs. 3, 9c, 10 and 36:24–36:27). The excavation consists of a bluff on the left side of the Ångermanälven river, about 700 m to the west of the outlet of the Sågån stream in the Ångermanälven. The outlet is situated about 4.4 km east of the Multrå Church. The HK is situated 263 m above sea level, and the ice border was located at Sågån year -545, i.e., 203 years after it was located at Fällön (see Lidén 1913) or 9,462 years BP (acc. to Cato 1985, 1987). The sediment surface, equal to the delta surface, is located 37.7 m above sea level (Lidén 1938).

The postglacial stratum up to the sediment surface embraces 5,431 varves with a maximum varve thickness of 100 cm. With the exception of the varves 4689–4708, 4741–4763, and 4809–4835, they are, according to the notes left behind by Lidén, distinct down to the varve 4500. (However, in his diagram, he shows only the varves down to varve 4651.) Deeper down in the "zone with the distinct varves" (Fig. 29), only a few varve zones and single varves could be discerned (see example in Fig. 30). The number of varves in the indistinct varve zones just mentioned were identified by the aid of the Nyland and Färjstället varve series. The Sågån varve series is overlapped, verified by and correlated to the Nyland (varves 4651–4745), the Färjstället (varves 4651–4921), the Korvsta (varves 4829–5431), and the Björkå bruk (varves 5331–5431) varve series. They all show a good agreement, and the correlations are obvious.

The Ångermanälven river debouched at Sågån year 5,431 (Lidén's chronology), i.e., 3,486 years BP (Cato 1992).

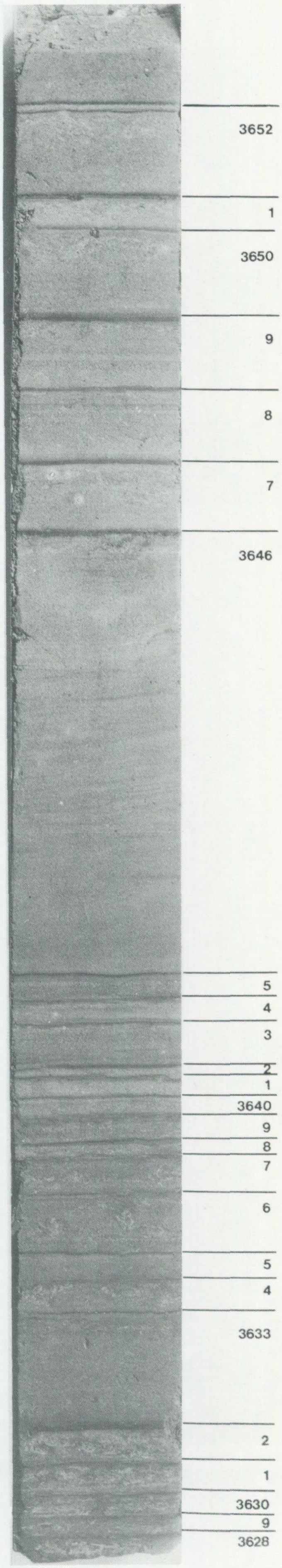


Fig. 23. Part of the varved postglacial sequence from Högmon, about 300 m downstream from site 9 Rödskägget, Ångermanälven valley, Sollefteå parish. For the numbering of the varves, see Fig. 14. (Photo: R. Lidén 1909).

Fig. 24. The bluff at Remslemon, just opposite Sollefteå. The delta varves, visible in the upper part of the bluff, incline downriver. (Photo: R. Lidén 1909).

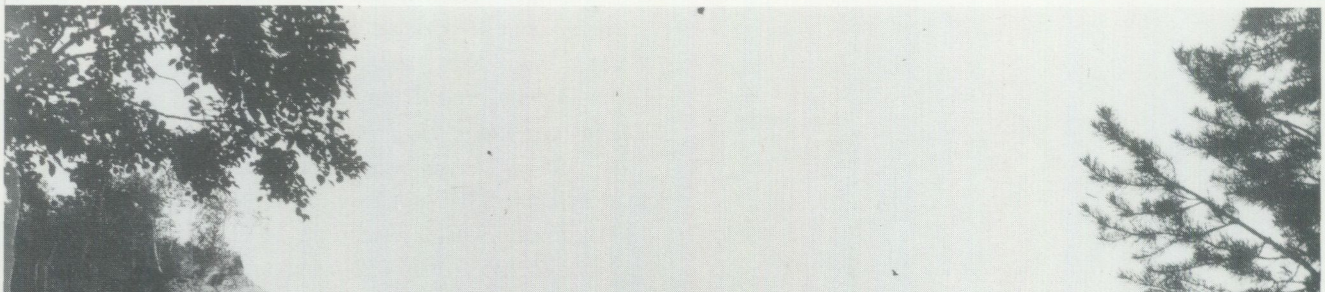


Fig. 25. Part of the bluff at Remslemon, site 10 Sotdalen, Ångermanälven valley, Sollefteå parish. (Photo: Anonymous *c.* 1910, document Lidén left behind).

16. Korvsta - Sånga parish (Figs. 3, 9c, 10, 31 and 36:25–36:30). The excavation consists of a bluff at the lower end of a gully situated about 600 m east of the Gårdnäs station. The sediment surface or river terrace is located 26 m above sea level.

The postglacial stratum embraces 5,802 varves, which are distinct down to varve 4500. In Lidén's original diagram, he shows only the varves down to the varve 4829. Between the varve 4500 and the "zone with the distinct varves," only a few varve zones and single varves could be discerned, according to Lidén. The maximum thickness of the varves is 40 cm. The Korvsta varve series is overlapped, verified by and correlated to the Färjstället (varves 4829–4921), the Sågån (varves 4836–5431), and the Björkå bruk (varves 5331–5802) varve series, respectively. There is a good agreement between the varve series, and the correlations are obvious.

17. Björkå bruk - Överlännäs parish (Figs. 3, 9c, 10 and 36:27–36:33). The excavation consists of a bluff on the right side of the Björkå stream close to its outlet in the Ångermanälven river. The HK is situated 266 m above sea level and the ice border was located at Björkå bruk year -565, i.e., 183 years after it was located at Fällön (see Lidén 1913) or 9,482 years BP (acc. to Cato 1985, 1987). The sediment surface, equal to the delta surface, is located 23.3 m above sea level (Lidén 1938).

The postglacial stratum up to the delta surface embraces 6,474 varves with a maximum varve thickness of 81 cm. According to Lidén, with the exception of the varves 6409–6415, they are all distinct down to the varve 5000, but in his original diagram, he shows only the varves down to the varve 5331. Two varves, 6437 and 6438, are missing in the profile. According to Lidén, they have been pressed away. He does not give any explanation of what he means by "pressed away" and the eventual process behind this. The overburden pressure from the overlying 37 varves could most probably not have squeezed out these two varves. However, the two missing varves have been verified from the Undrom and Prästmon varve series.

Deeper than the varve 5000 and down to the "zone with the distinct varves," only a few varve zones and single varves could be discerned. At this site in the "zone with the distinct varves," a small shell of blue mussel (*Mytilus edulis*) was found. The Björkå bruk varve series is overlapped and verified by and correlated to the Sågån (varves 5331–5431), the Korvsta (varves 5331–5802), the Undrom (varves 6111–6474), and Prästmon (varves 6431–6474)

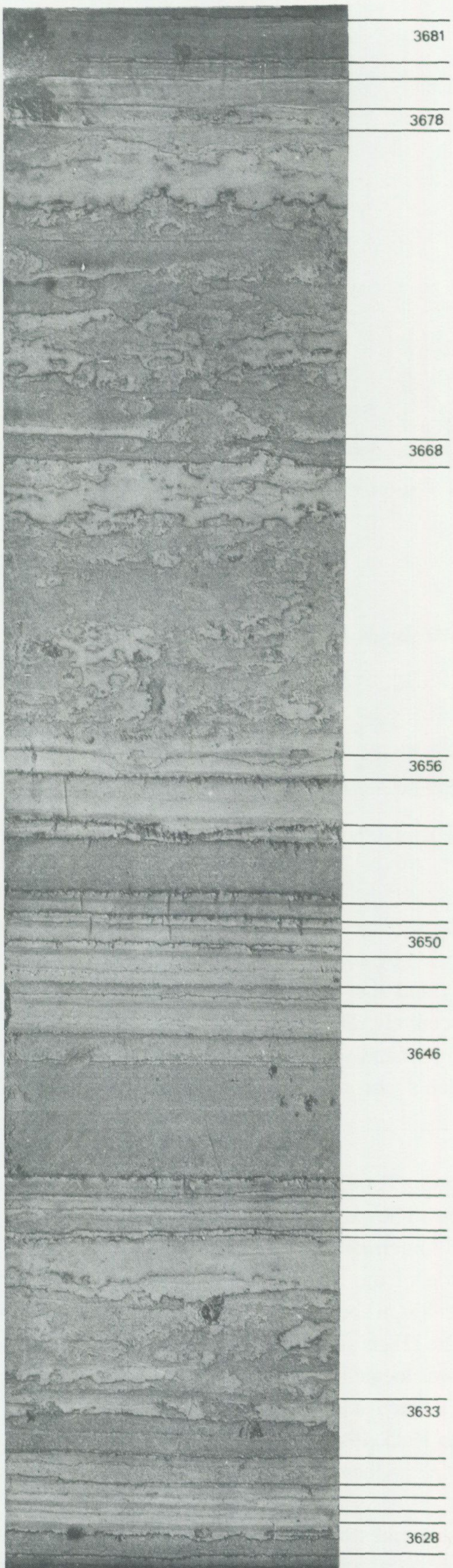


Fig. 26. Part of the varved postglacial sequence from site 11 Risöviken–Sollefteå, Ångermanälven valley. For the numbering of the varves, see Fig. 14. (Photo: R. Lidén 1909).

Fig. 27. View over the Ångermanälven at Multrå showing the steep bluffs along the river. (Photo: Dahlbergs AB *c.* 1910).

varve series, respectively. There is a good agreement between these series, and the correlations are obvious. However, the varves 5802–6111 are not verified by any other profile.

The Ångermanälven river debouched at Björkå bruk year 6,474 (Lidén's chronology), i.e., 2,443 years BP (Cato 1992).

18. Undrom - Boteå parish (Figs. 3, 9c, 10 and 36:31–36:36). The excavation consists of a bluff on the left side of the Ångermanälven river about 1.6 km southeast of Boteå Church. The HK is situated 272 m above sea level and the ice border was located at Undrom year -580, i.e., 168 years after it was located at Fällön (see Lidén 1913) or 9,497 years BP (acc. to Cato 1985, 1987). The sediment surface, equal to the delta surface, is located 15 m above sea level (Lidén 1938).

The postglacial stratum up to the delta surface embraces 7,060 varves with a maximum varve thickness of 51 cm. According to Lidén, they are all distinct down to the varve 5500. In his original diagram, he shows only the varves down to the varve 6111. Deeper and down in "the zone with the distinct varves," only a few varve zones and single varves could be discerned. The Undrom varve series is overlapped, verified by and correlated to the Björkå bruk (varves 6111–6474) and the Prästmon (varves 6431–7060) varve series, respectively. The correlations are obvious.

The Ångermanälven river debouched at Undrom year 7,060 (Lidén's chronology), i.e., 1,857 years BP (Cato 1992).

19. Prästmon - Torsåker parish (Figs. 3, 9c, 10, 32, 33 and 36:33–36:38). The excavation consists of a bluff on the right side of the Ångermanälven river close to the ditch on the southern side of the Styresholm fortress from the Middle Ages, about 400 m southeast of the former railway station at Torsåker. The HK is situated 275 m above sea level, and the ice border was located at Prästmon year -600, i.e., 148 years after it was located at Fällön (Lidén 1913) or 9,517 years BP (acc. to Cato 1985, 1987). The sediment surface, equal to the delta surface, is located 10.2 m above sea level (Lidén 1938).

The postglacial stratum up to the delta surface embraces 7,522 varves with a maximum varve thickness of 57 cm. With the exception of the varves 6564–6601, they are all distinct down to the varve 6400 (see example in Fig. 34). In

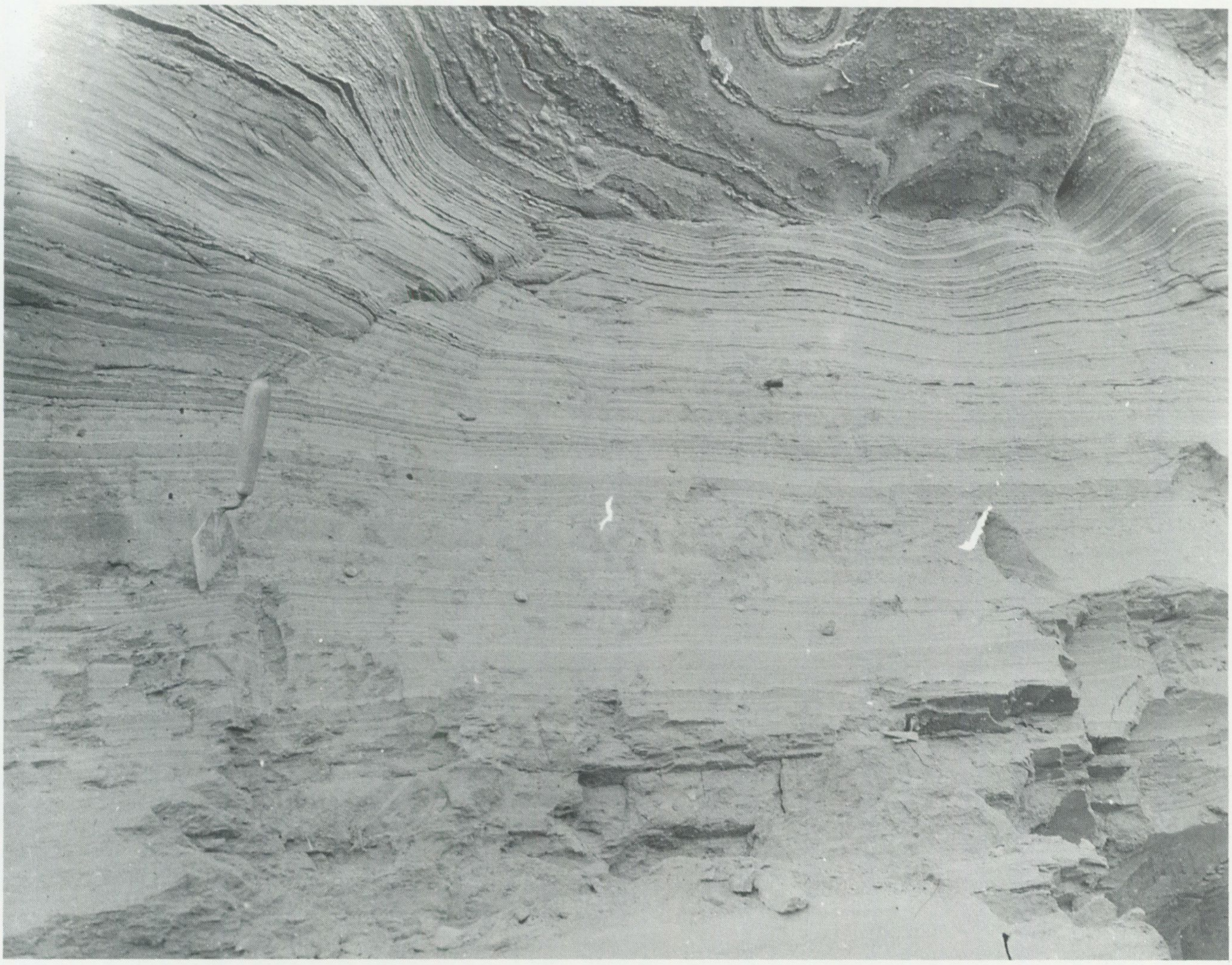


Fig. 28. The postglacial varves visible in the bluff at site 13 Nyland, Ångermanälven valley, Multrå parish. (Photo: R. Lidén 1909).

Lidén's original diagram, he shows only the varves down to the varve 6431. Deeper than the varve 6400 and down in "the zone with the distinct varves," only a few varve zones and single varves could be discerned, according to Lidén. The number of varves in the indistinct varve zone mentioned above was verified from the Undrom varve series. The Prästmon varve series is overlapped, verified and correlated to the Björkå bruk (varves 6431–6474) and the Undrom (varves 6431–7060) varve series, respectively. By means of new varve measurements on foil piston cores, Lidén's Prästmon profile has been overlapped, verified and correlated to a new Prästmon profile (varves 7105–7286) and to the varve series from Fröksholmen (varves 7021–7522), Gistgårdsön (varves 7004–7522), and Dannero (varves 7368–7522), respectively (see further Cato 1987 p. 41–42). There was a strong agreement between all these varve series, except between the most proximal varves.

The Ångermanälven river debouched at Prästmon year 7,522 (Lidén's chronology), i.e., 1,395 years BP (Cato 1992).

20. Utnäs - Torsåker parish (Figs. 3 and 10). On the other side of the Ångermanälven river, opposite from the Prästmon site, Lidén observed a contact between the glacial clay and the overlying estuarine clay (Fig. 35). In the document he left behind, he does not further comment upon this observation. However, he was able to identify the typical and pronounced postglacial varves no. 2036 and 2604, depicting the start and the end of "the zone with the distinct varves" observed and measured in the Myre, the Vignäsbrännan, Forsmobron, and the Sand varve series (cf. Figs. 36:11–36:14). According to Lidén, these distinct varves can be followed all the way along the investigated area.

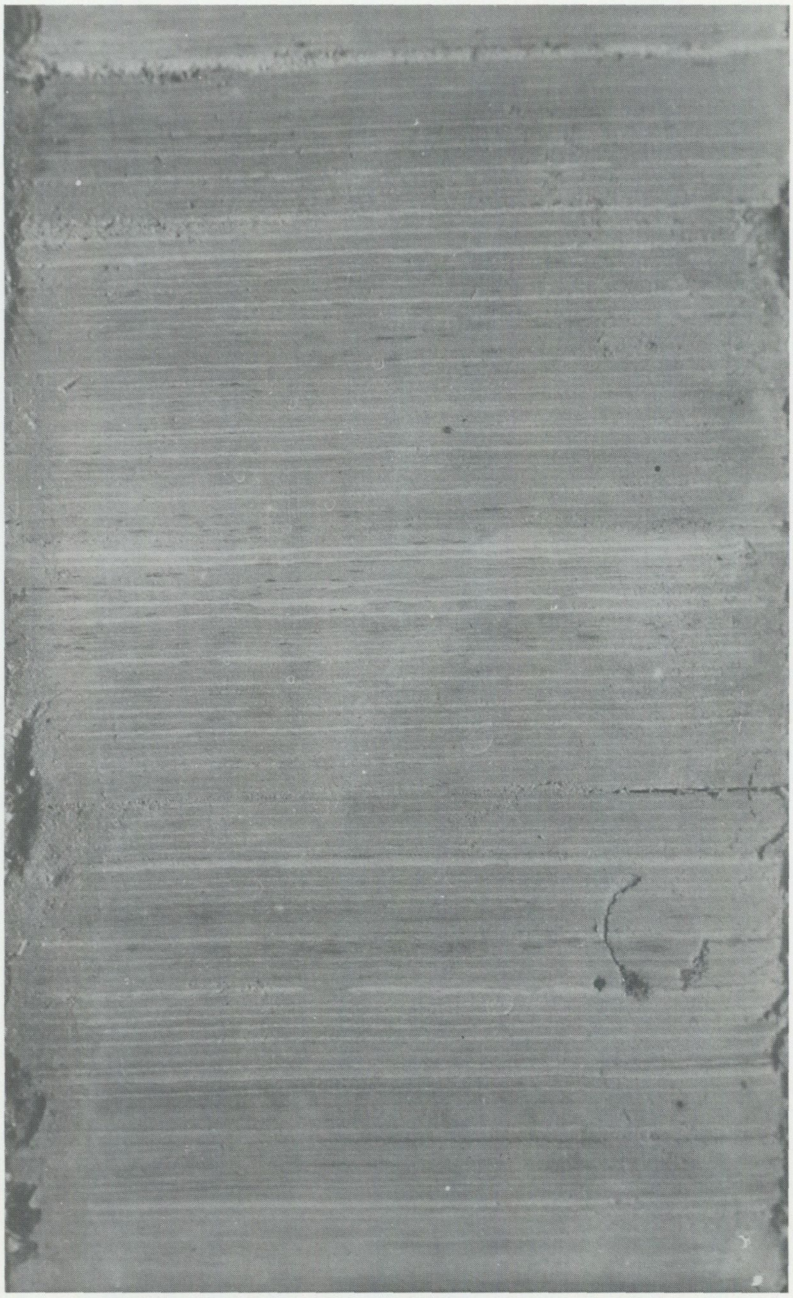


Fig. 29. Photograph showing part of the "zone with the distinct varves" in the bluff at site 15 Sågån, Ångermanälven valley, Sånga parish. (Photo: R. Lidén 1909).

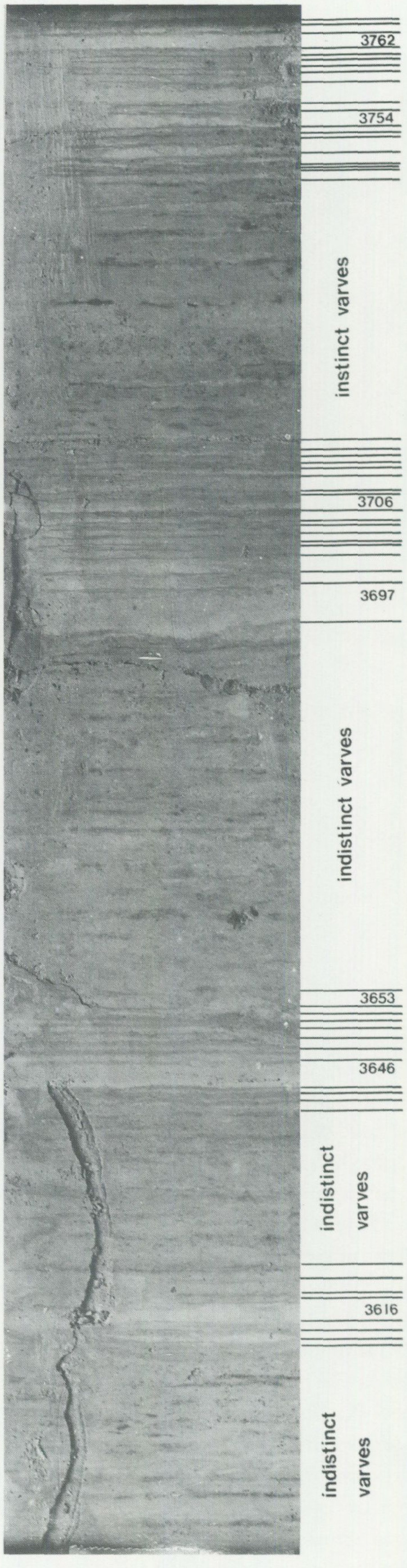


Fig. 30. Part of the varved postglacial sequence from site 15 Sågån, Ångermanälven valley, showing both distinct and indistinct varves. For the numbering of the varves, see Fig. 14. (Photo: R. Lidén 1909).

Fig. 31. View over the delta sediments at the Gårdsnäs gravel pit, site 16 Korvsta, Ångermanälven valley, Sånga parish. (Photo: R. Lidén 1909).

Fig. 32. The bluff at the Styresholm Fortress by the Ångermanälven river in 1909. On the left, one of the moats where Lidén found residues from the destruction of the fortress is visible. (Photo: R. Lidén 1909).

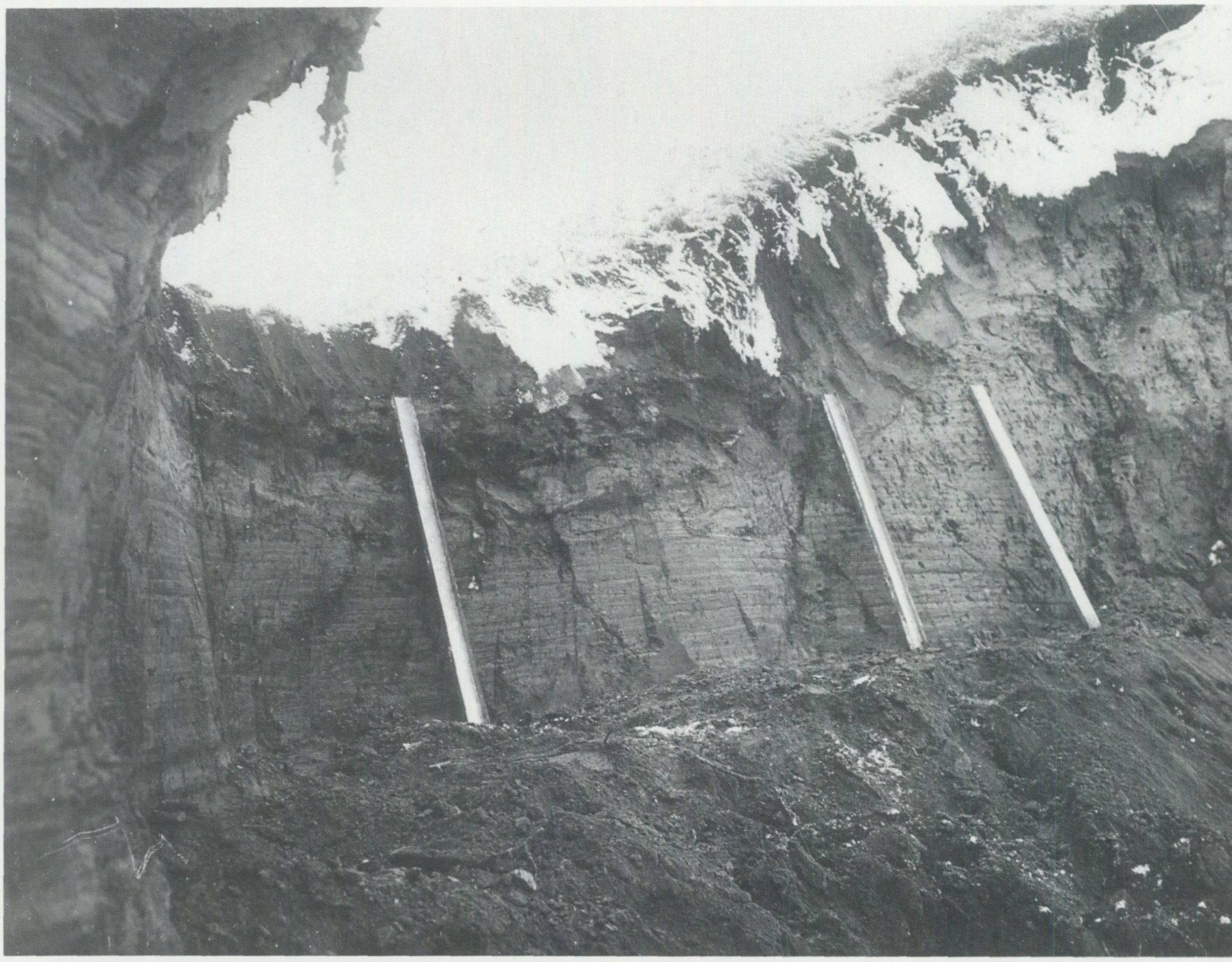


Fig. 33. Detail of the bluff at the Styresholm Fortress by the Ångermanälven river in 1909, showing the varved sequences under one of the moats. Three of the tin boxes Lidén used for sampling are visible. (Photo: R. Lidén 1909).

Evaluation of Lidén's varve diagrams and correlations

The accuracy of varve counting and varve thickness measurements is dependent on several factors: the individual carrying out the job, the distinctness and the individual feature of the varves, the occurrence of disturbances, the number of parallel cores overlapping each other, and the correlations made. However, even if this requirement of accuracy are fulfilled, several uncertainties may still remain as a consequence of primary and secondary sedimentological processes. The most important sources of error have been compiled by, for example, G. De Geer (1940) and Cato (1987).

Looking at the first factor mentioned, both Fözö (1980) and Cato (1987) have found that Lidén's measurements seem to be very accurate. In those glacial parts of Lidén's varve series studied by Fözö (the varves -117 to 497 in Lidén's glacial chronology), he could establish that Lidén's measurements never lack a single varve. Cato came to the same conclusion when he linked Lidén's postglacial varve series from Prästmon with a new profile measured at the same site and three other profiles (Fröksholmen, Gistgårdsön and Dannero) downstream from the Prästmon site, covering in total about 500 varves of Lidén's profile (see Cato 1987 p. 41–42). The comparison also demonstrated that the accuracy of varve thickness studies has to be very high if different individuals, as in this case, come to the same results. These circumstances have also been demonstrated in a comparison between varves measured by Fromm and Cato at different cores but from the same site (see Cato 1987 p. 47–48).

Concerning the second and third factors, it can be stated, judging from the notes Lidén left behind, that he measured and relied on only distinct and undisturbed varves. In his diagram, he correctly marked all zones that not fulfill these requirements. He verified the number of varves within these indistinct and disturbed zones by other profiles with an obvious correlation on both sides of the gap left in the varve series.

Concerning the fourth factor, one can state that Lidén's chronology based on varve series lacks several sequences overlapped by other profiles, or in some cases, overlapped only by proximal varves with a very local character, and therefore, the number of varves in these parts of the chronology cannot be considered verified in the most desirable way, even if the measurements are correct. This is the case in the following sequences:

- the varves 1–798 in the Nämforsen varve series,
- the varves 874–921 in the Mo varve series,
- the varves 1196–1197, 1232–1256, 1272–1291, 1363–1410, and 1461–1543 in the Omnäs varve series,
- the varves 2665–2884 and 2942–3025 in the Sand varve series,
- the varves 3068–3184 and 3234–3254 in the Rödskägget varve series, and in several zones between the varves 3204–3805 because of the 16 gaps of indistinct varves in the Risöviken–Sollefteå varve series,
- the varves 4741–4763 and 4809–4828 in the Färjställer varve series,
- the varves 5717–6110 in the Björkå bruk varve series,
- the varves 6409–6415 and 6564–6601 in the Undrom varve series, and
- the varves 6997–7003 in the Prästmon varve series. The remaining upper part of the Prästmon series is verified by Cato (1987).

However, this does not mean that Lidén's chronology is incorrect. All varves are represented and measured in at least one varve series, but for a complete verification, it is desirable that the number of varves be verified from at least one more or, even better, several other varve series. The latter is not the case for the sequences given above, but there is no reason to distrust Lidén's varve measurements. This statement is based on Lidén's information about the distinct varve limits within the varve sequences in question.

The fifth factor is the correlation between the different varve series. In Lidén's chronology, all, except two correlations and connections, are clear and obvious. The varves

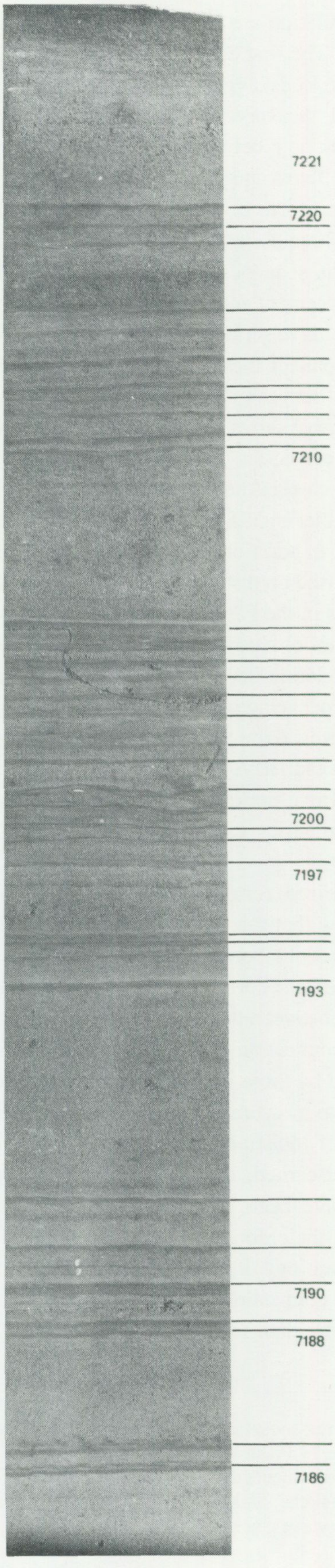
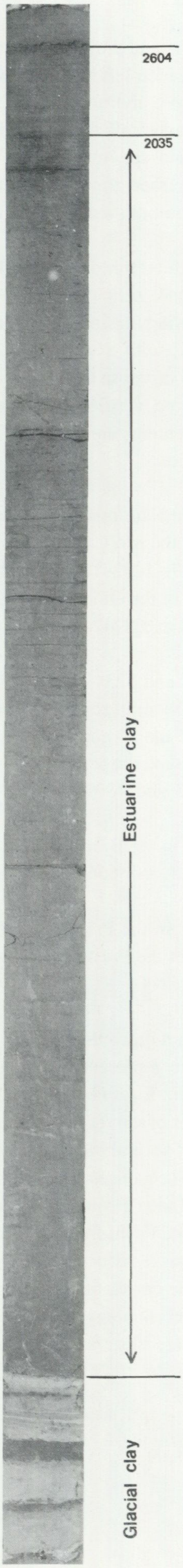


Fig. 34. Part of the varved postglacial sequence from site 19 Prästmon, Ångermanälven valley. For the numbering of the varves, see Fig. 14. (Photo: R. Lidén 1909).



from the different series in these cases all show a very strong agreement in relative thickness and easily recognizable varve configurations. However, in the two exceptions mentioned, the correlation are not very obvious, although there are similarities. The first case is the correlation and connection between the Rödskägget and Risöviken–Sollefteå varve series based on the varves 3806–3872. In this case, it is based on correlation between distal varves in the Risöviken–Sollefteå series and proximal delta varves in the Rödskägget sediment terrace. However, deeper in the Risöviken–Sollefteå varve series, there are 17 gaps due to indistinct varves. The sequences of varves between these gaps show a good agreement and configuration with the varves in the Rödskägget varve series, and it was possible for Lidén to correlate and connect these sequences. Judging from this, the connection between the Rödskägget and the Risöviken–Sollefteå varve series cannot be far wrong, even if it is not completely correct.

The second case is the correlation and connection between the Färjstället and Sågån varve series based on the varves 3872–4809. In addition, in this case, the correlation and connection is based on distal varves in the Sågån and proximal delta varves in the Färjstället varve series, respectively. Although it is not obvious, similarities exist between these series. The correlation between these series is strengthened by the three deeper lying sequences separated by small gaps of indistinct varves in the Sågån profile. These sequences of about 40 varves each have been correlated and connected to the Färjstället varve series. Thus, the connection between these two varve series cannot be too wrong, if they are wrong at all.

The summarized results of the evaluation of Lidén's chronology show that there are strong and obvious correlations and connections between all varve series except two. In the latter cases, the correlations are weaker, but there are still similarities between the varves and the series. No alternative to these connections has been found. In addition, they are strengthened by those deeper lying varve sequences that Lidén was able to measure. If these had not been interrupted by small gaps of indistinct varves, where the varve limits could not be discerned, the correlations and connections would never have been questioned. However, these two "weak" parts of the chronology are not sufficient reason to distrust the chronology. If, against all probability, these two correlations and connections are wrong, the chronology cannot be off by more than some tens of years.

Fig. 35. Part of the sequence from site 20 Utnäs, located by the river opposite site 19 Prästmon, Ångermanälven valley. The photograph shows some identified postglacial varves and the contact between the glacial clay and the overlying estuarine clay. For the numbering of the varves, see Fig. 14. (Photo: R. Lidén 1909).

It should also be stressed that varve correlations are also based on the occurrence of single varves showing an individual and characteristic feature. These types of varves appear in all varve series, and it is most probable that Lidén also used this technique in the correlation work. Furthermore, Lidén was helped in the correlation work by several characteristic zones, such as "the zone with the distinct varves" embracing the varves 2036–2605. According to Lidén, this zone could be found all along the stretches of the Ångermanälven river.

The margin of error

As was mentioned above, the accuracy of a varve chronology is dependent on several factors and uncertainties based on the individual carrying out the measurements and on the primary and secondary sedimentological processes (see Cato 1987). One problem that is sometimes overlooked is the problem with slides giving rise to turbidity currents. The created bottom load accumulates in deeper water with a graded bedding structure very similar to that of annual varves and may yield a "double varve," which during varve measurements might be counted as two varves. Double varves may also ensue from heavy autumn rains that increase the water discharge to a level close to that of the spring flood.

Overlooking one varve can easily be done if the winter layer is very indistinct and thin or if the sequence has been compressed so that two or several varves "melt" together.

In most cases, the problems arising from these sources of error could be solved by verifying the number of varves in a given varve sequence via other varve series taken outside the area if these series overlap each other. According to studies carried out by Cato (Cato 1987), in the lower reaches of the Ångermanälven river, one may count on two double layers per one hundred varve years. On the basis of this, the margin of error in Lidén's part of the postglacial varve chronology can be set at 7,522 +10/-150 varve years, or as a minimum, 7,522 +10/-30 varve years, if only those parts of the chronology that lack verification by other series, all together *c.* 1,490 varves, are taken into consideration.

Summary

As a consequence of the need for an exact chronology as a basis for studies of diverse Late Quaternary cyclicities, the Swedish Geochronological Time Scale is a matter for not merely Swedish but also international geology (cf. Fairbridge 1981, Schove & Fairbridge 1983). This time scale covers about 12,800 varve years (Björck et al. 1992), depicting a year-to-year chronology exactly connected to the present.

In 1975 a revision program for the time scale was started and undertaken within the framework of the International Geological Correlation Programme (IGCP Project 24). From that time on, almost all parts of the chronology have been checked and, in some cases revised (see review in Björck et al. 1992), the latest case being in the area south of Stockholm (Brunnberg 1995). The largest part of the time scale is the postglacial chronology based on the varved river valley sediments along the Ångermanälven river in central Sweden.

These sediments were formed after the Scandinavian ice sheet had retreated from the interior portions of the Ångermanälven valley, which at that time formed a fjord, and receded up to the areas above the highest coastline. At the river mouth in the former fjord, the sediment was deposited as a delta. Through the land upheaval, caused by isostatic movement, which occurred after the recession of the inland ice, the outlets of the rivers moved successively from the highest coastline at 230 m above sea level in the inner reaches of the former fjord down to the present level of the Bothnian Sea. New delta planes were constantly built up upon lower levels covering the older glacial sediments. This succession created the postglacial varved river valley sediments with a surface that more and less forms a continuous sloping delta plane from the highest coastline to the present outlet of the river.

The postglacial part of the Swedish Time Scale embraces 7,522 varve years, as measured by Lidén in the beginning of this century (Lidén 1938 and this paper), and a remaining part up to the present time embracing 1,395 varve years, as measured by Cato during the beginning of the 1980s (Cato 1987). Through the latter work, the whole time scale was connected to the present, and the calendar

varve years, as measured by Cato during the beginning of the 1980s (Cato 1987). Through the latter work, the whole time scale was connected to the present, and the calendar year affinity was proved by several independent methods.

The present paper deals with the previously unpublished varve measurements and results of Lidén's investigation carried out in bluffs at 19 sites along a 70 km-long stretch of the Ångermanälven river between Nämforsen in the northwest and Prästmon in the southeast. These results were never published in their entirety, although they were more or less ready for publication *c.* 1915. Only a brief summary, dealing with the age of the surface varve at some deltas and a shoreline displacement curve of the river area based on this, was published by Lidén (Lidén 1938).

Now, these varve data, together with other documents Lidén left behind, have been worked up, digitized and plotted by the present author in order to assume the form in which they are presented in this paper. All the correlations and connections have been checked and evaluated. The results show that Lidén's chronology seems most reliable, although some varve sequences of the 19 varve series have not been verified by more than one varve series. In general, there are strong and obvious correlations between all varve series except two. In these latter cases, the connections are partly based on correlations between distal varves in Sågån and Risöviken–Sollefteå varve series viz. proximal delta varves in Färjstället and Rödskägget varve series, respectively. However, no alternatives to these connections have been found, and there are other circumstances, such as deeper lying varve sequences, that speak in favor of the connections Lidén has made. Thus, these two so-called "weak" parts of the chronology are not sufficient to distrust his chronology. If, against all probability, these two correlations and connections are wrong, his chronology cannot differ by

However, the accuracy of a varve chronology depends on several other uncertainties as a consequence of primary and secondary sedimentological processes. According to studies carried out by Cato (1987), one may, on average, count on two double varves per one hundred varves. If this assumption is valid, the margin of error in Lidén's part of the postglacial varve chronology can be set at 7,522 +10/-150 varve years, or as a minimum, 7,522 +10/-30 varve years, if only those parts of the chronology that lack verification by other series, all together *c.* 1,490 varves, are taken into consideration.

ACKNOWLEDGMENTS

In 1983 Miss Imber Lidén generously placed the unpublished documents Ragnar Lidén left behind at the disposal of the Geological Survey of Sweden for storing and research. The drawings in this paper were made by A.-C. Sjöberg, and the varve data was digitized by Irma Ortman and stored and plotted by the present author in a system developed by J. Schedin, at SGU, on a Prime/550 Computer. The paper was linguistically revised by Proper English Ltd. Valuable comments on the manuscript were offered by Professor Jan Lundqvist and Assoc. Professor Bo Strömberg, Stockholm University.

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However, the accuracy of a varve chronology depends on several other uncertainties as a consequence of primary and secondary sedimentological processes. According to studies carried out by Cato (1987), one may, on average, count on two double varves per one hundred varves. If this assumption is valid, the margin of error in Lidén's part of the postglacial varve chronology can be set at 7,522 +10/-150 varve years, or as a minimum, 7,522 +10/-30 varve years, if only those parts of the chronology that lack verification by other series, all together *c.* 1,490 varves, are taken into consideration.

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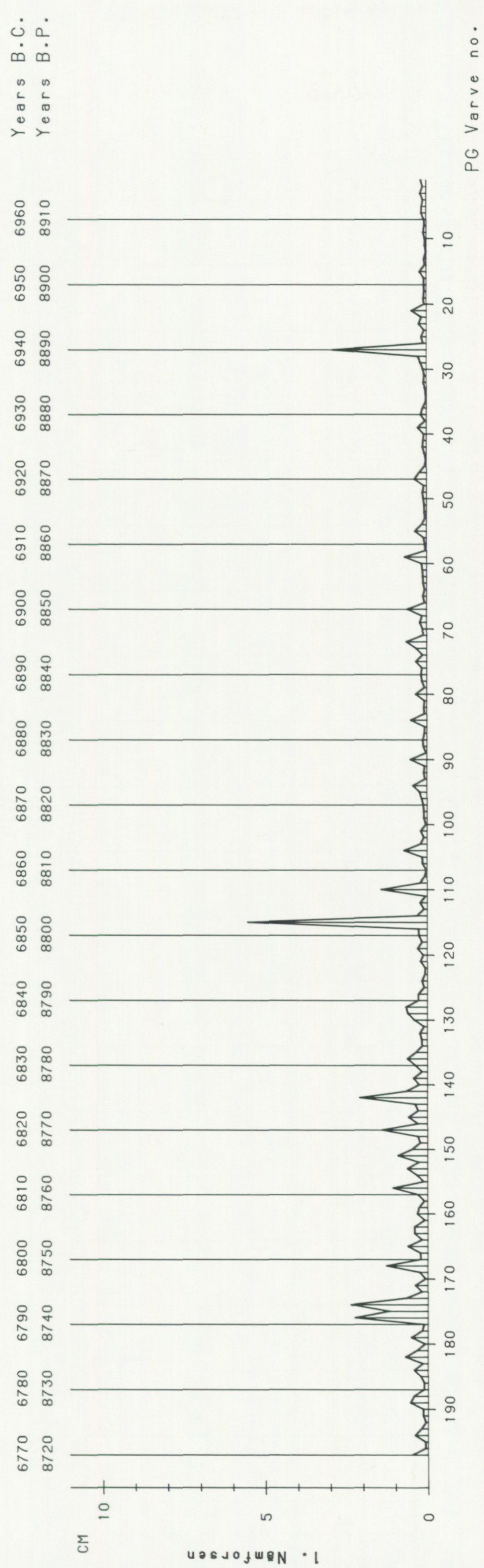

Fig. 36:1. Lower part of varve graph from site 1 Nämforsen showing the first 200 varves of Lidén's postglacial chronology (given below) of the Ångermanälven valley. The varve number 1 corresponds to the first postglacial varve in the valley. The time scales above are in accordance with the connection of the varve series with the present by Cato (1985, 1987). The continuation of the series is given on the next page.

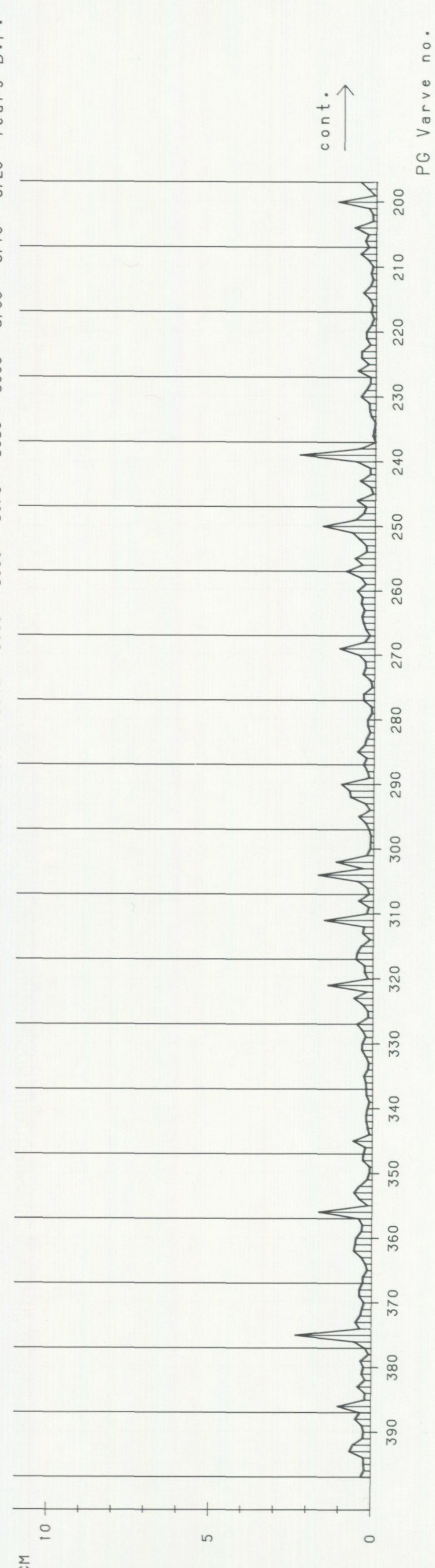

Fig. 36:2. Continuation of the Nämforsen varve graph from the Ångermanälven river in 6770–6570 B.C. (for further explanation, see Fig. 36:1).

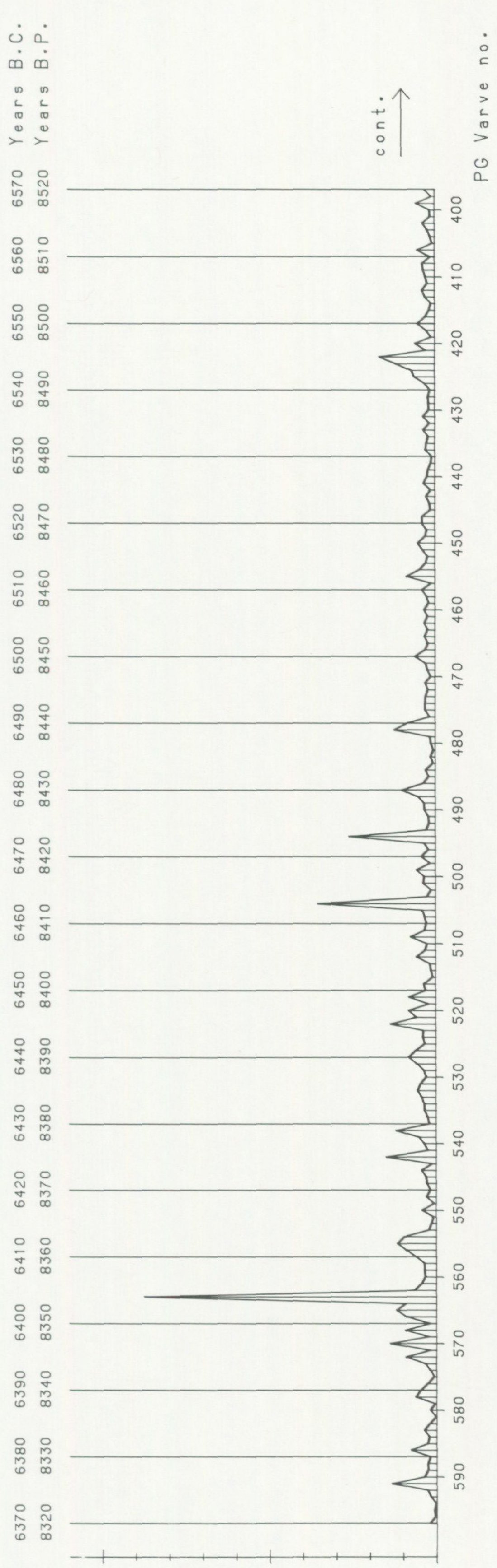

Fig. 36:3. Continuation of the Nämforsen varve graph from the Ångermanälven river in 6570–6370 B.C. (for further explanation, see Fig. 36:1).

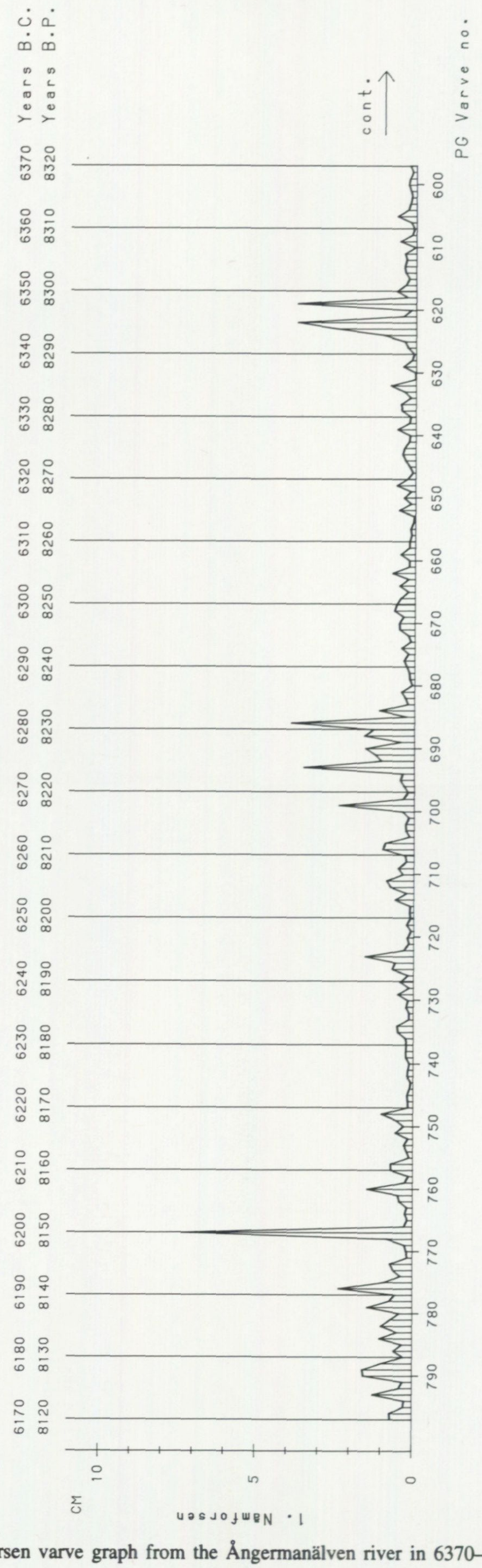

Fig. 36:4. Continuation of the Nämforsen varve graph from the Ångermanälven river in 6370–6170 B.C. (for further explanation, see Fig. 36:1).

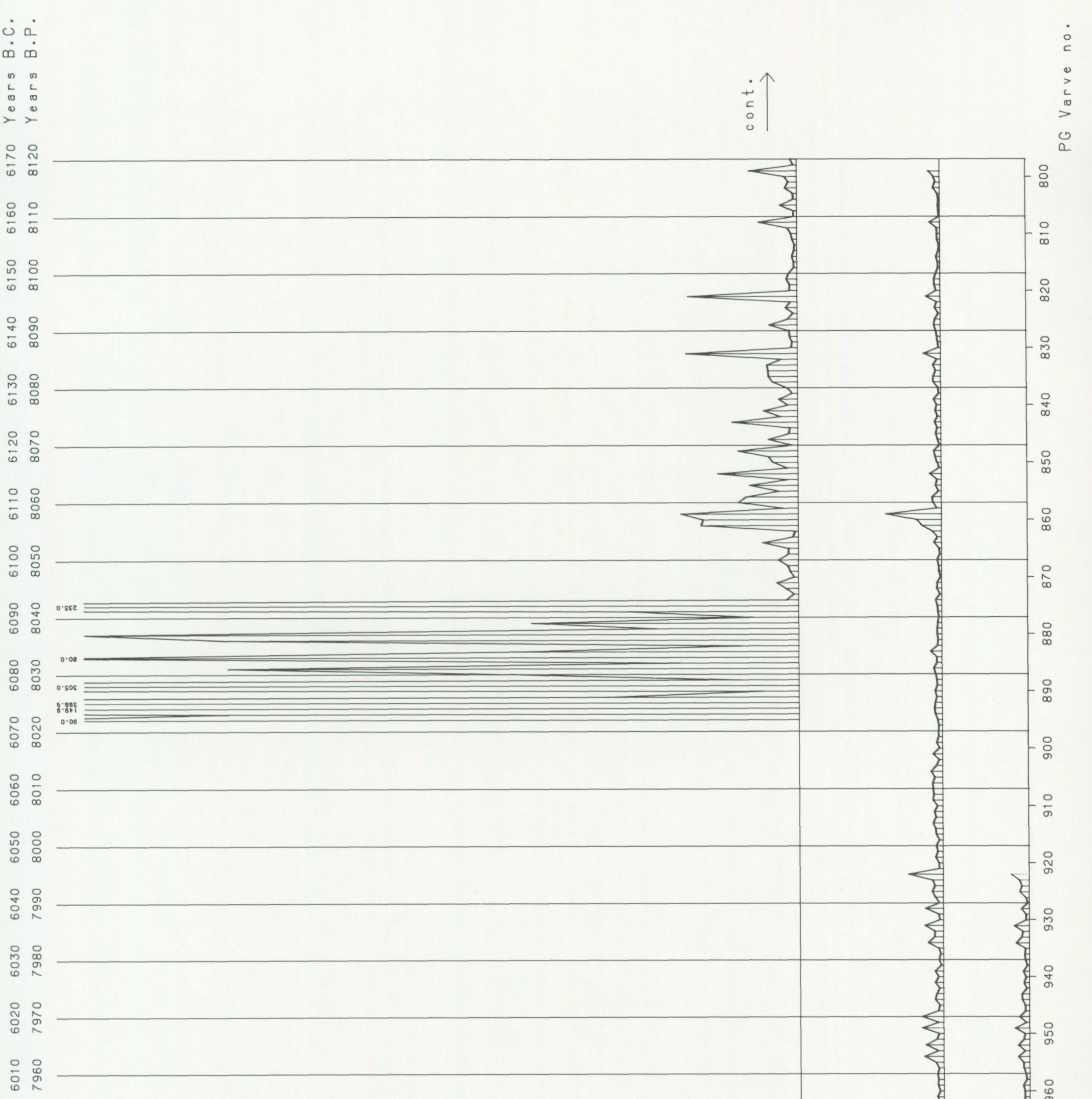

Fig. 36:5. The upper part of the Nämforsen varve graphs and correlations with the Mo and Omnäs varve series further downstream on the Ångermanälven river in 6170–5970 B.C. (for further explanation, see Fig. 36:1).

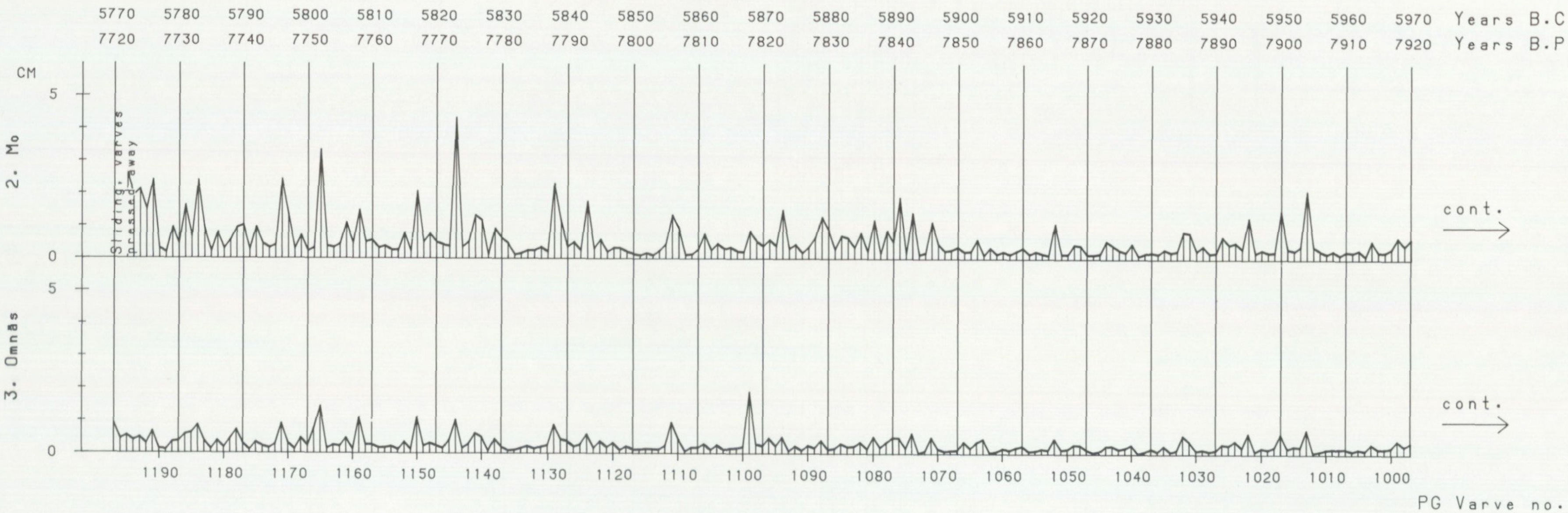

Fig. 36:6. Continuation of the Mo and Omnäs varve graphs from the Ångermanälven river in 5970–5770 B.C. (for further explanation, see Fig. 36:1).

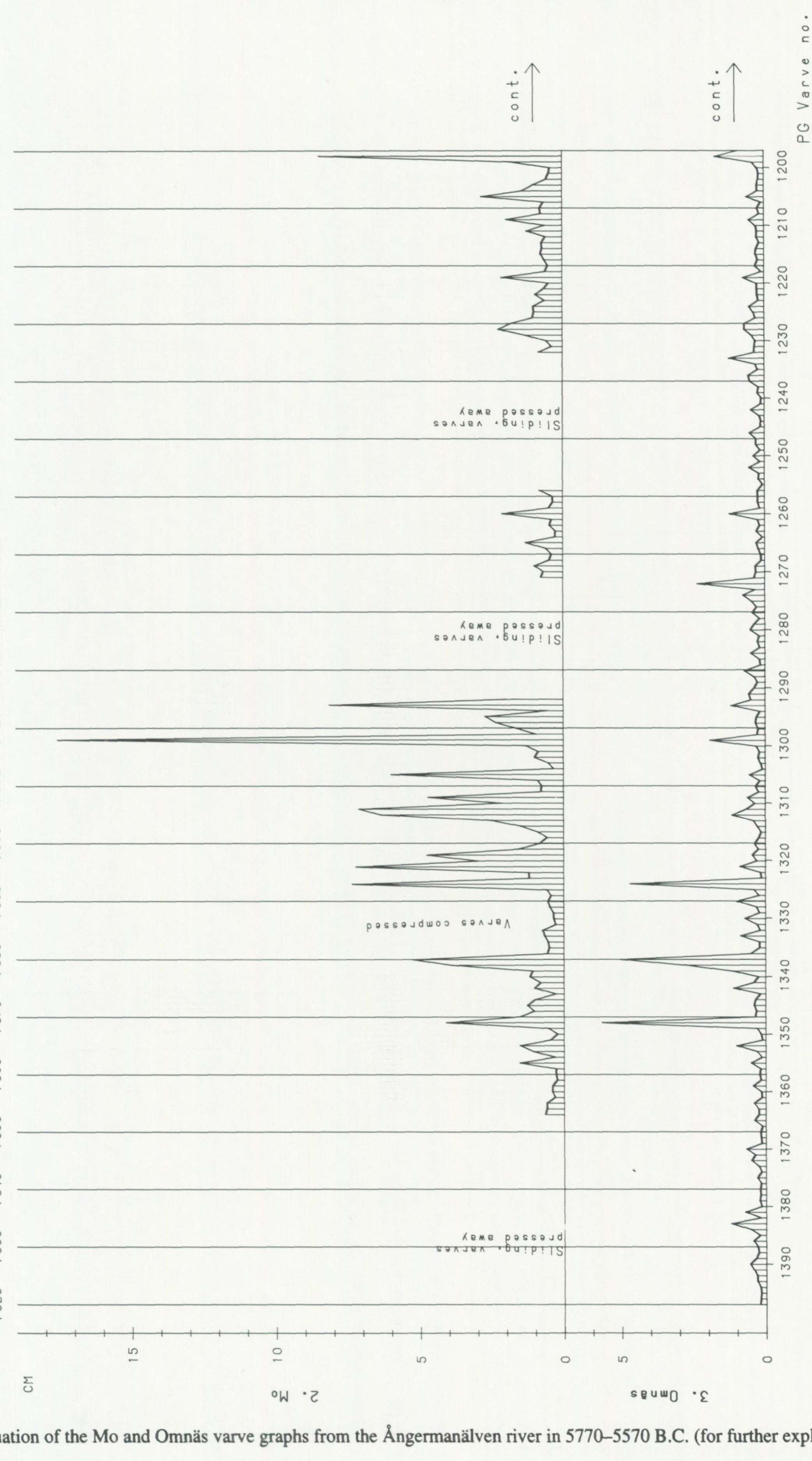

Fig. 36:7. Continuation of the Mo and Omnäs varve graphs from the Ångermanälven river in 5770–5570 B.C. (for further explanation, see Fig. 36:1).

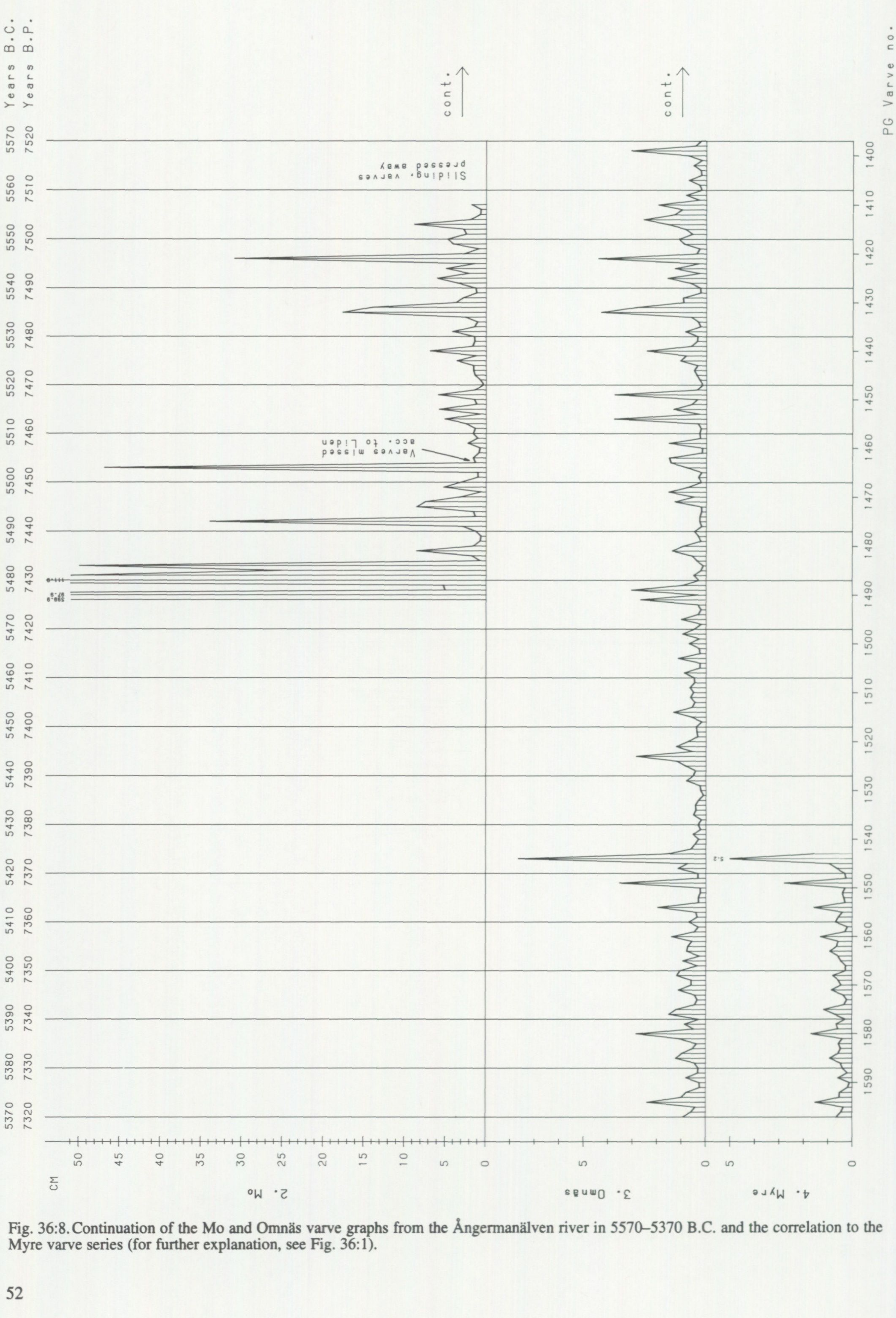

Fig. 36:8. Continuation of the Mo and Omnäs varve graphs from the Ångermanälven river in 5570–5370 B.C. and the correlation to the Myre varve series (for further explanation, see Fig. 36:1).

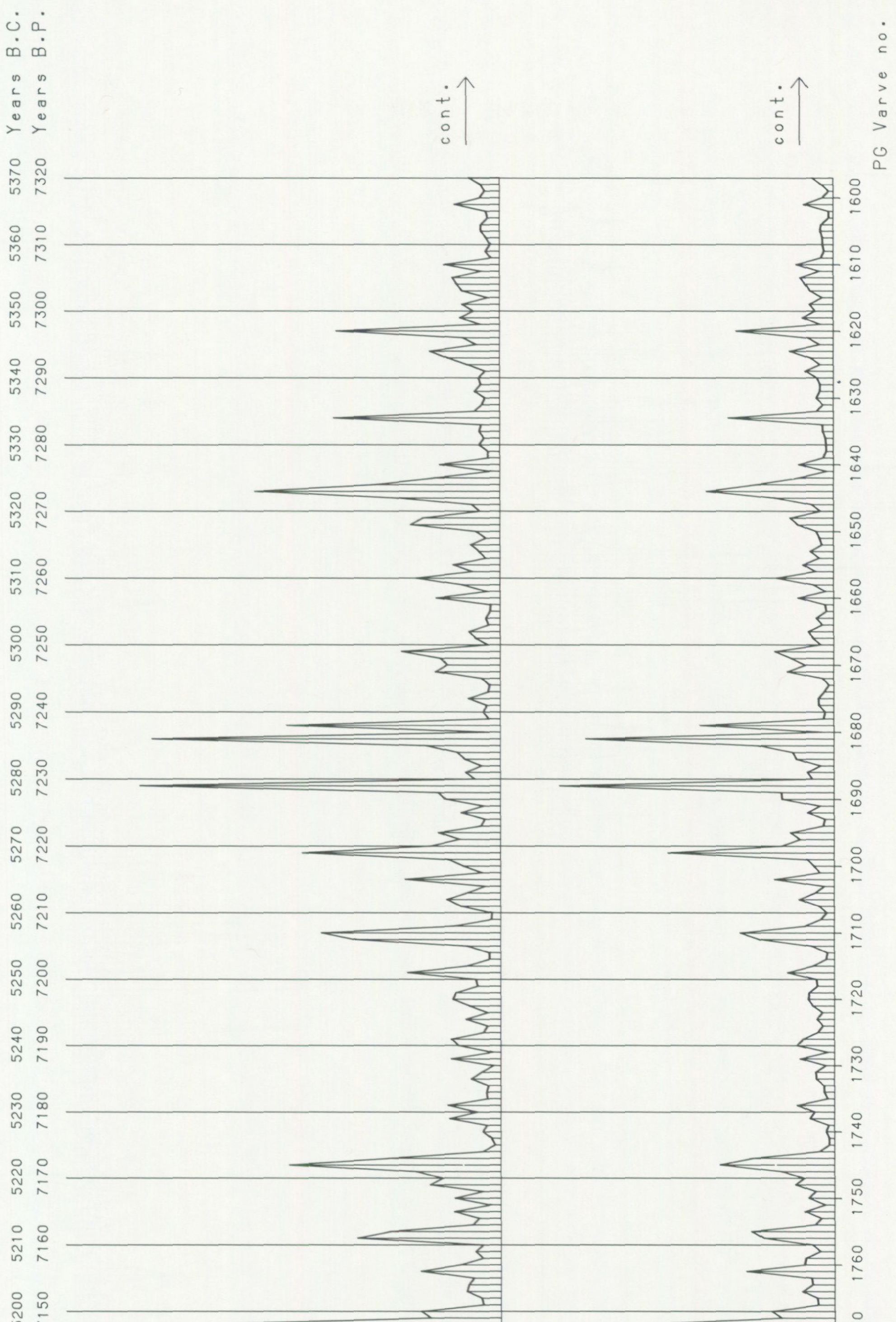

Fig. 36:9 Continuation of the Omnäs and Myre varve graphs from the Ångermanälven river in 5370–5170 B.C. (for further explanation, see Fig. 36:1).

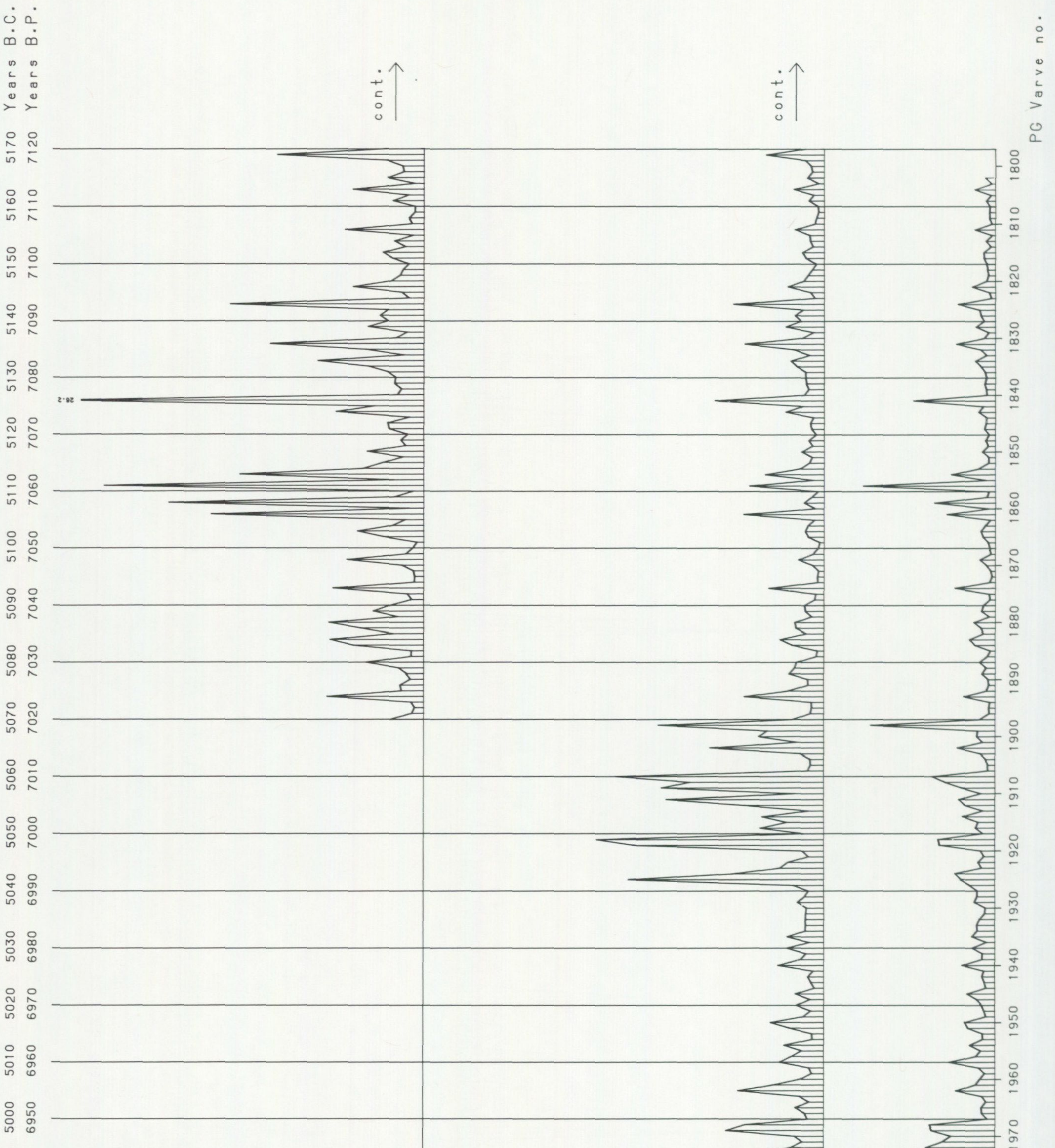

Fig. 36:10. Continuation of the Omnäs and Myre varve graphs from the Ångermanälven river in 5170–4970 B.C. and the correlation to the Vignäsbrännan varve series (for further explanation, see Fig. 36:1).

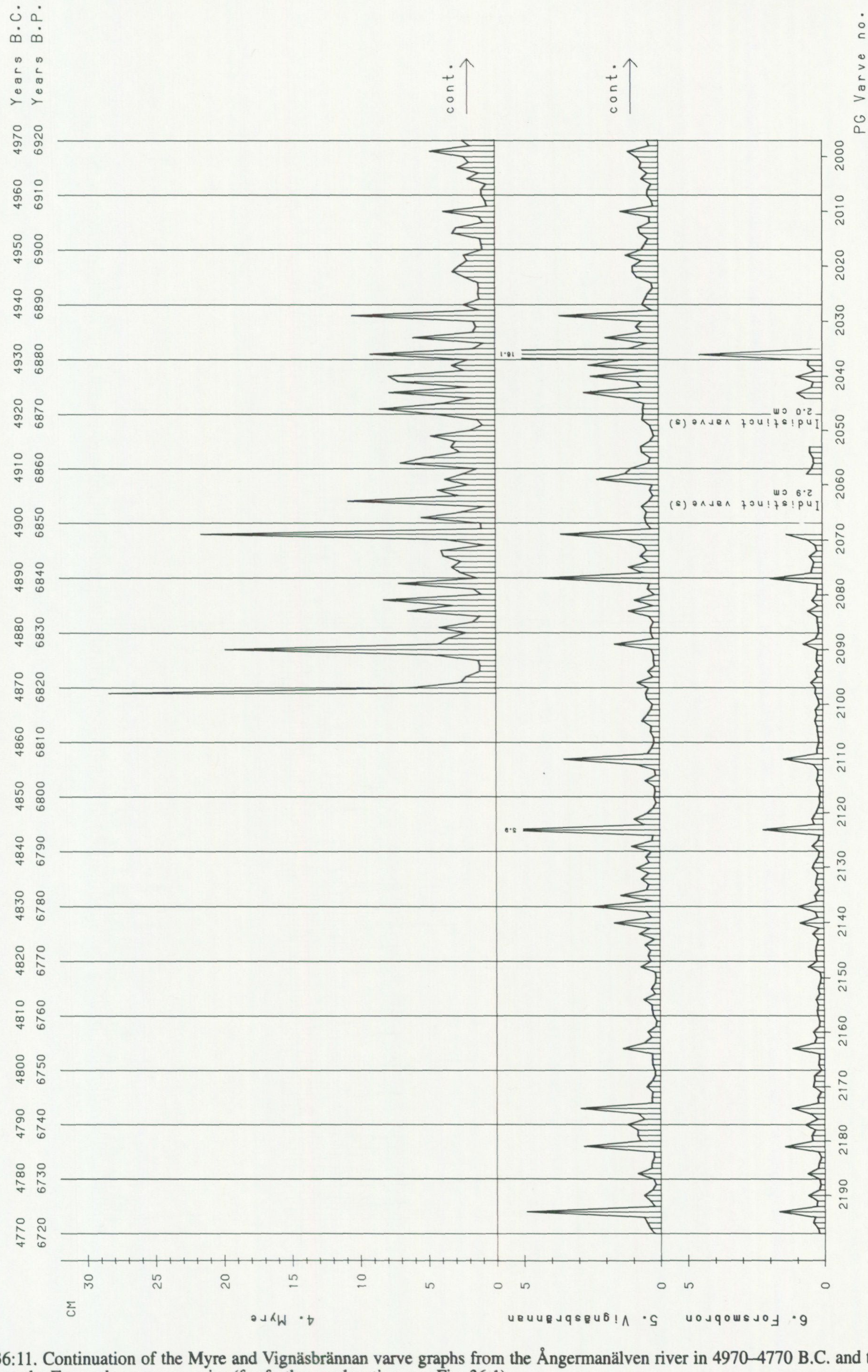

Fig. 36:11. Continuation of the Myre and Vignäsbrännan varve graphs from the Ångermanälven river in 4970–4770 B.C. and the correlation to the Forsmobron varve series (for further explanation, see Fig. 36:1).

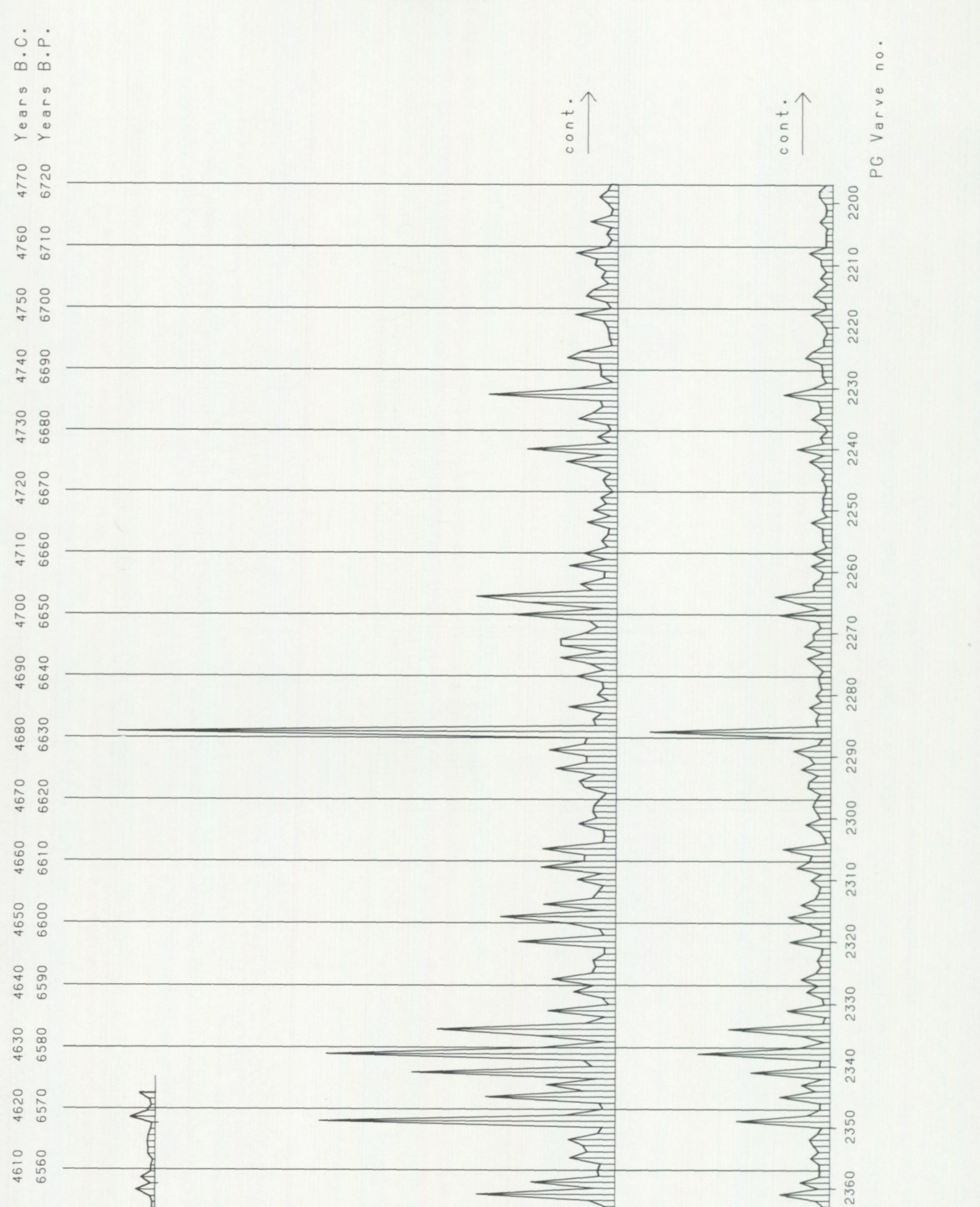

Fig. 36:12. Continuation of the Sand, Vignäsbrännan and Forsmobron varve graphs from the Ångermanälven river in 4770–4570 B.C. (for further explanation, see Fig. 36:1).

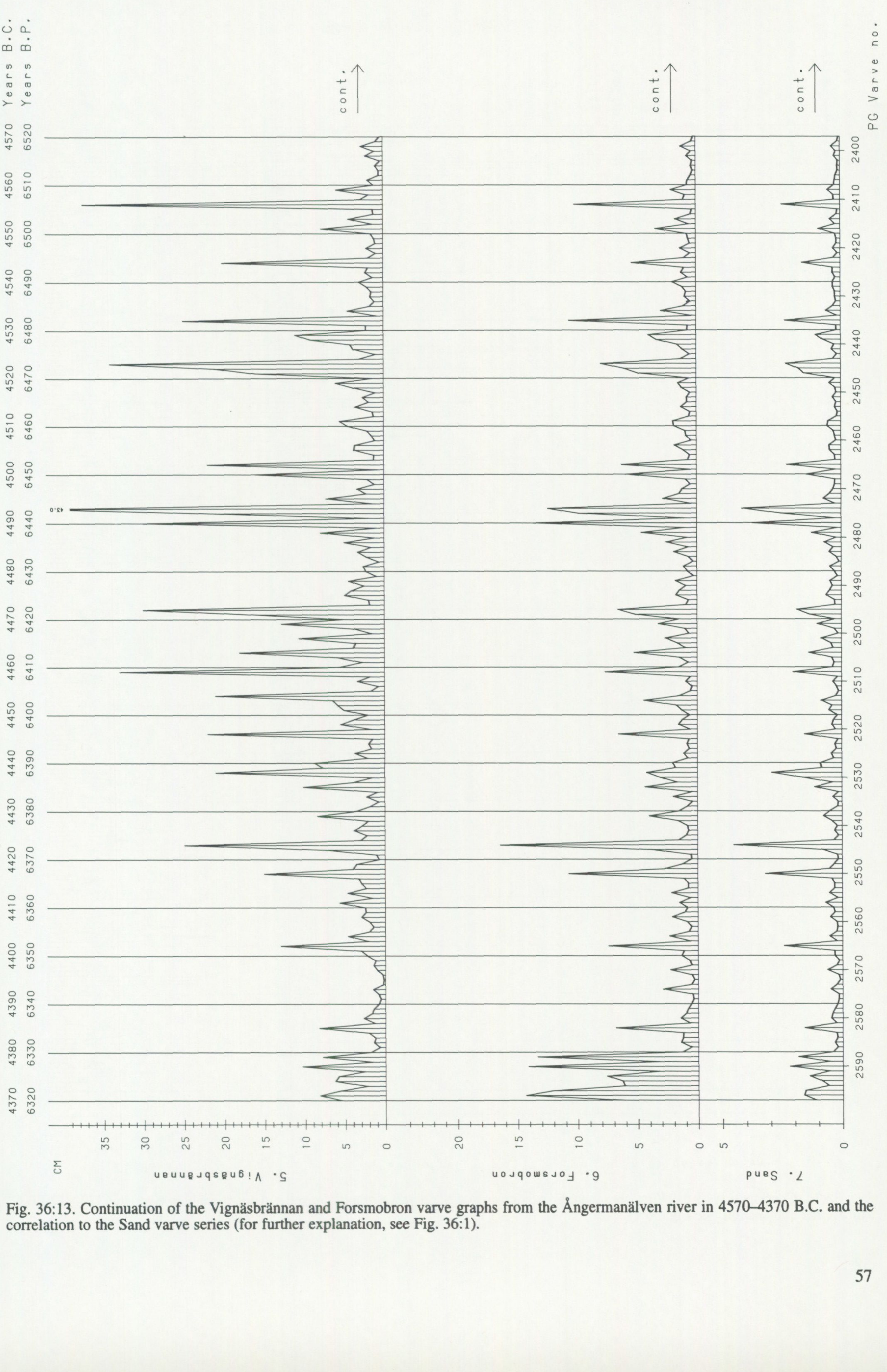

Fig. 36:13. Continuation of the Vignäsbrännan and Forsmobron varve graphs from the Ångermanälven river in 4570–4370 B.C. and the correlation to the Sand varve series (for further explanation, see Fig. 36:1).

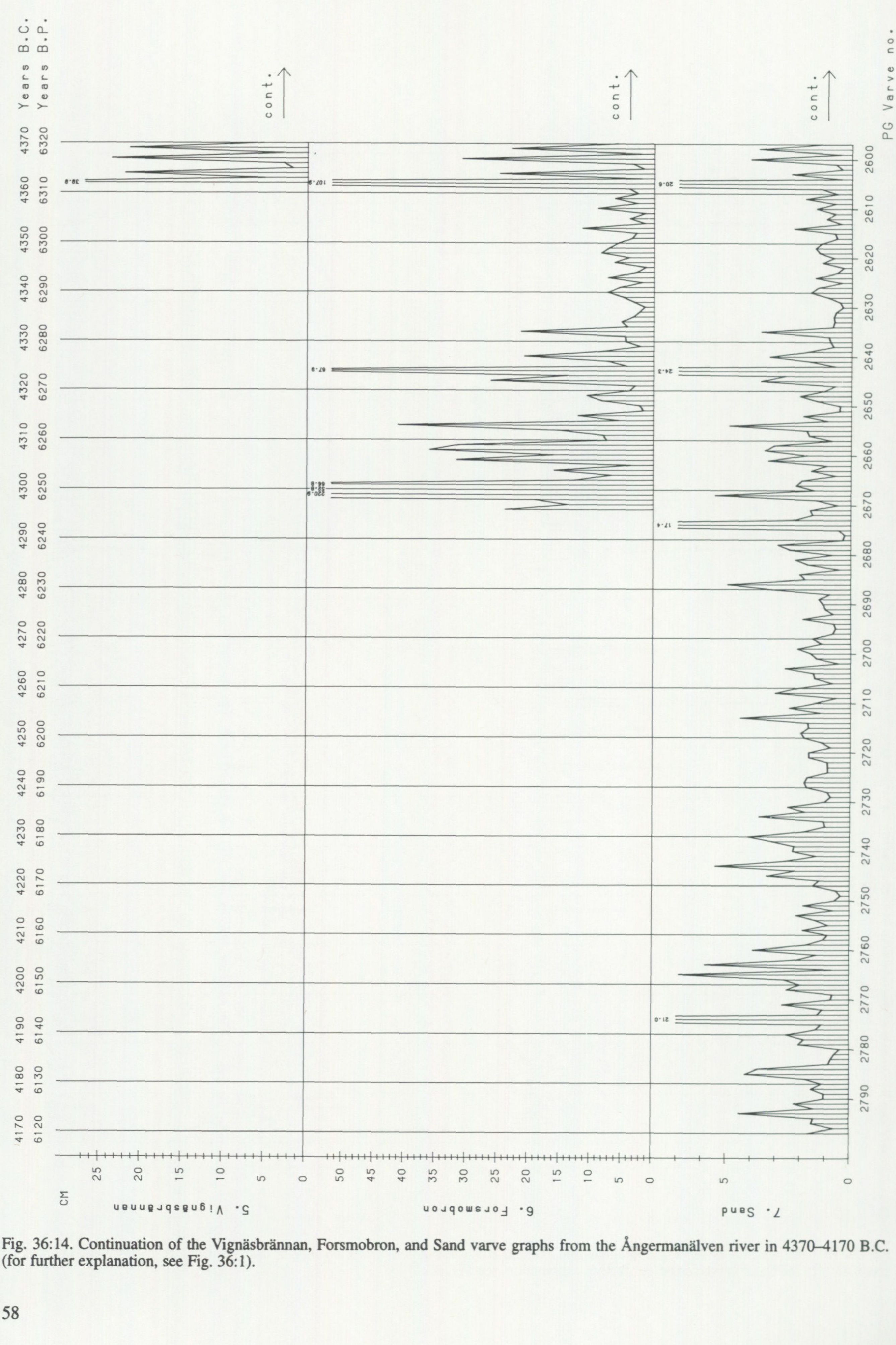

Fig. 36:14. Continuation of the Vignäsbrännan, Forsmobron, and Sand varve graphs from the Ångermanälven river in 4370–4170 B.C. (for further explanation, see Fig. 36:1).

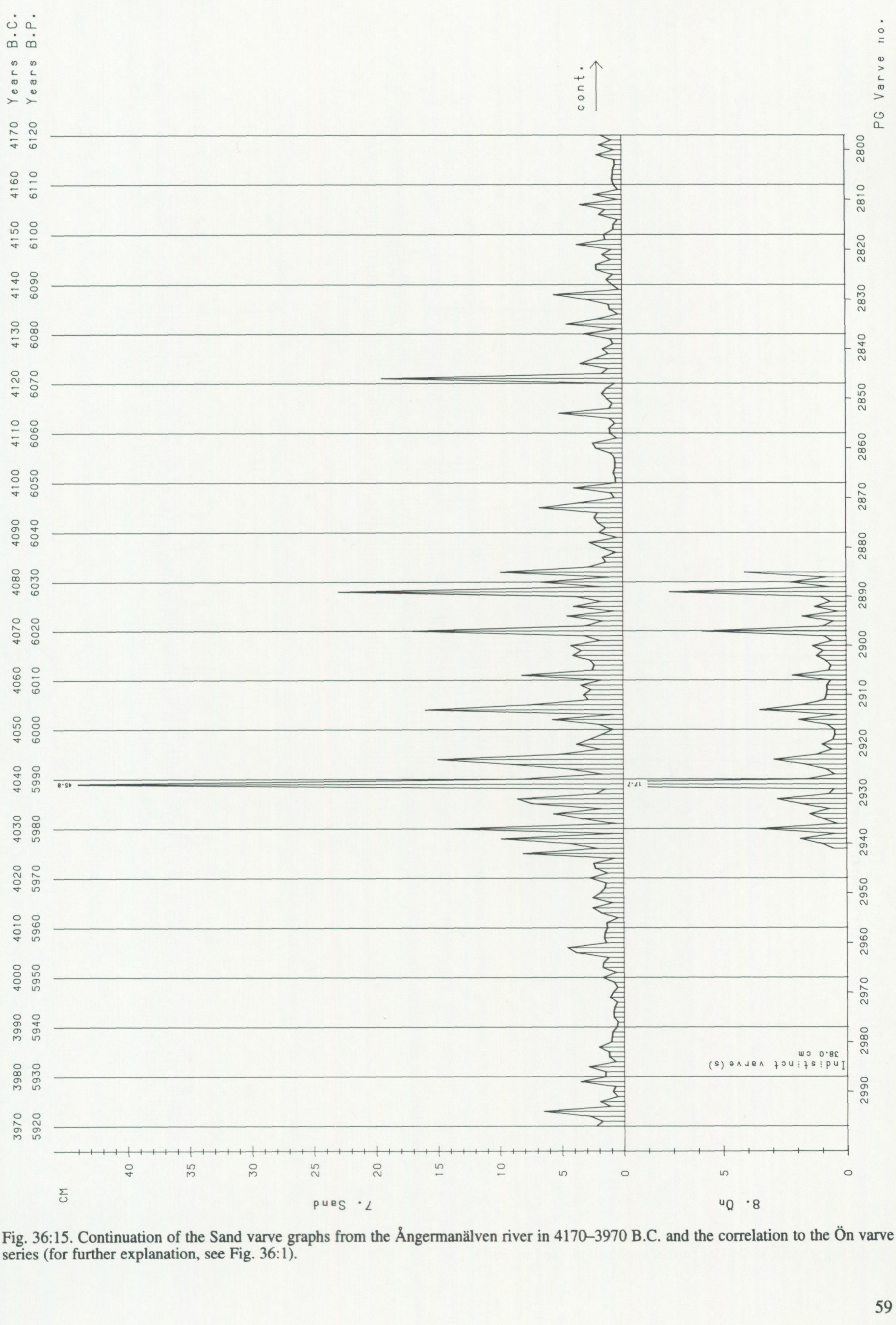

Fig. 36:15. Continuation of the Sand varve graphs from the Ångermanälven river in 4170–3970 B.C. and the correlation to the Ön varve series (for further explanation, see Fig. 36:1).

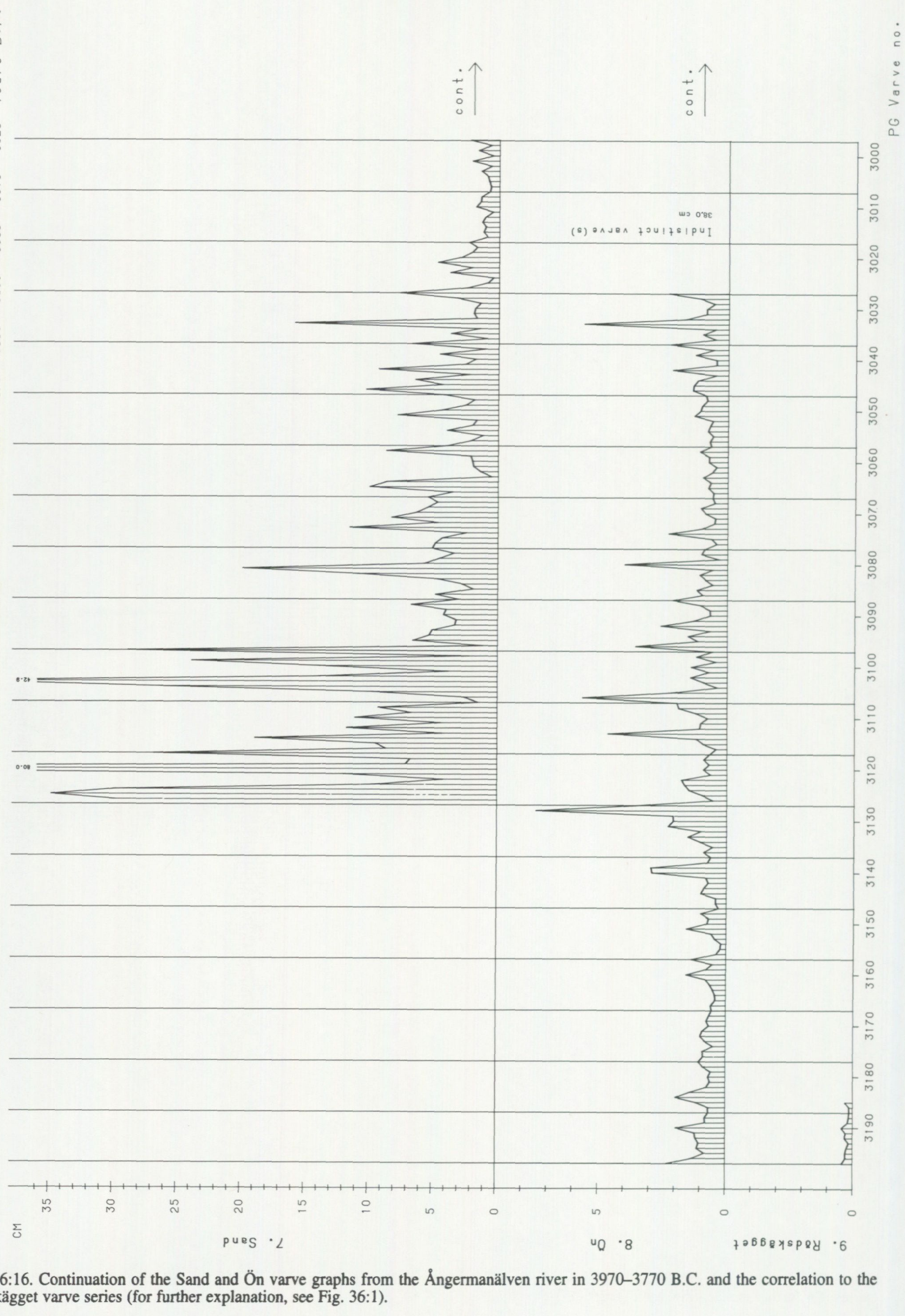

Fig. 36:16. Continuation of the Sand and Ön varve graphs from the Ångermanälven river in 3970–3770 B.C. and the correlation to the Rödskägget varve series (for further explanation, see Fig. 36:1).

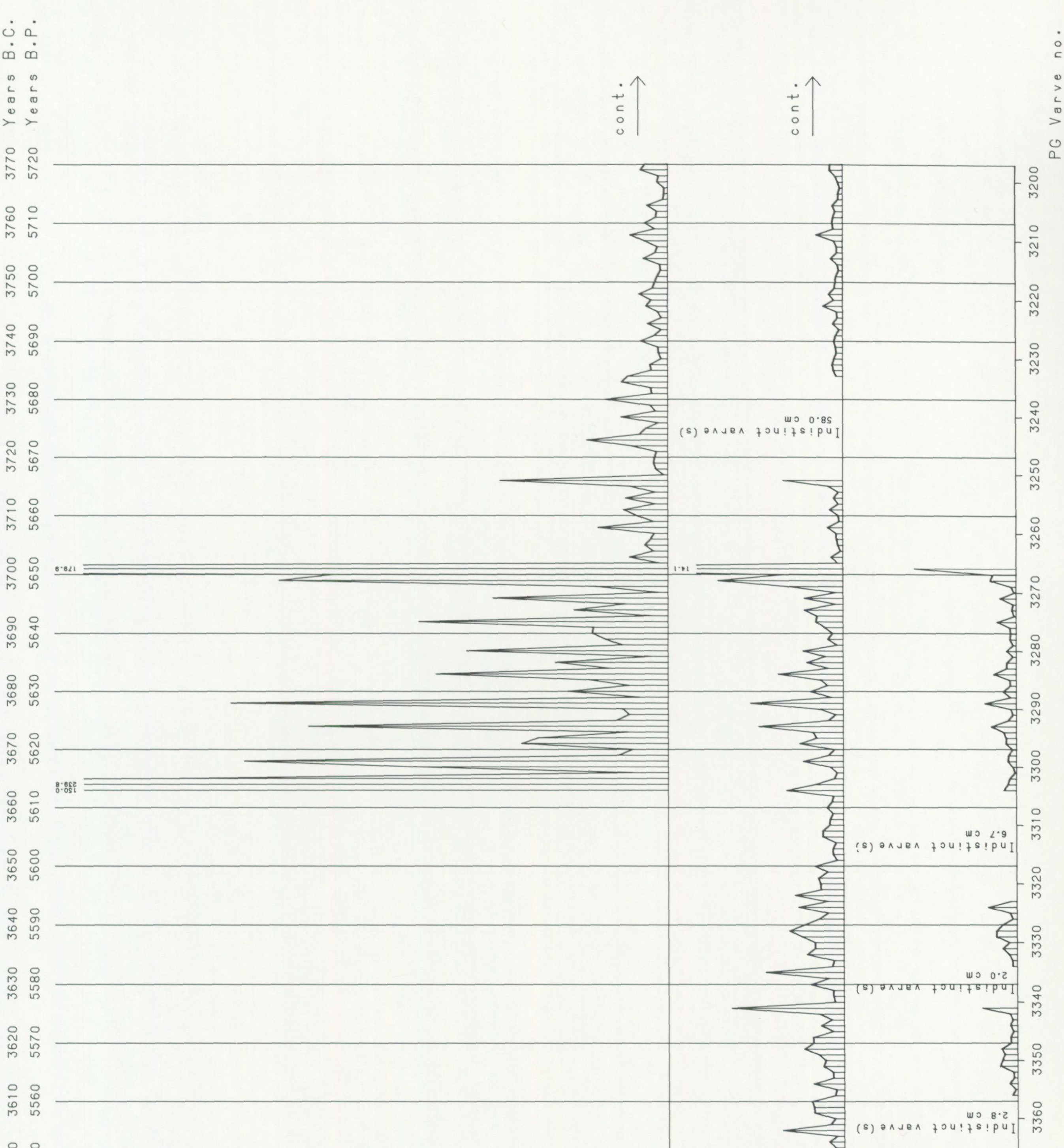

Fig. 36:17. Continuation of the Ön and Rödskägget varve graphs from the Ångermanälven river in 3770–3570 B.C. and the correlation to the Risöviken–Sollefteå varve series (for further explanation, see Fig. 36:1).

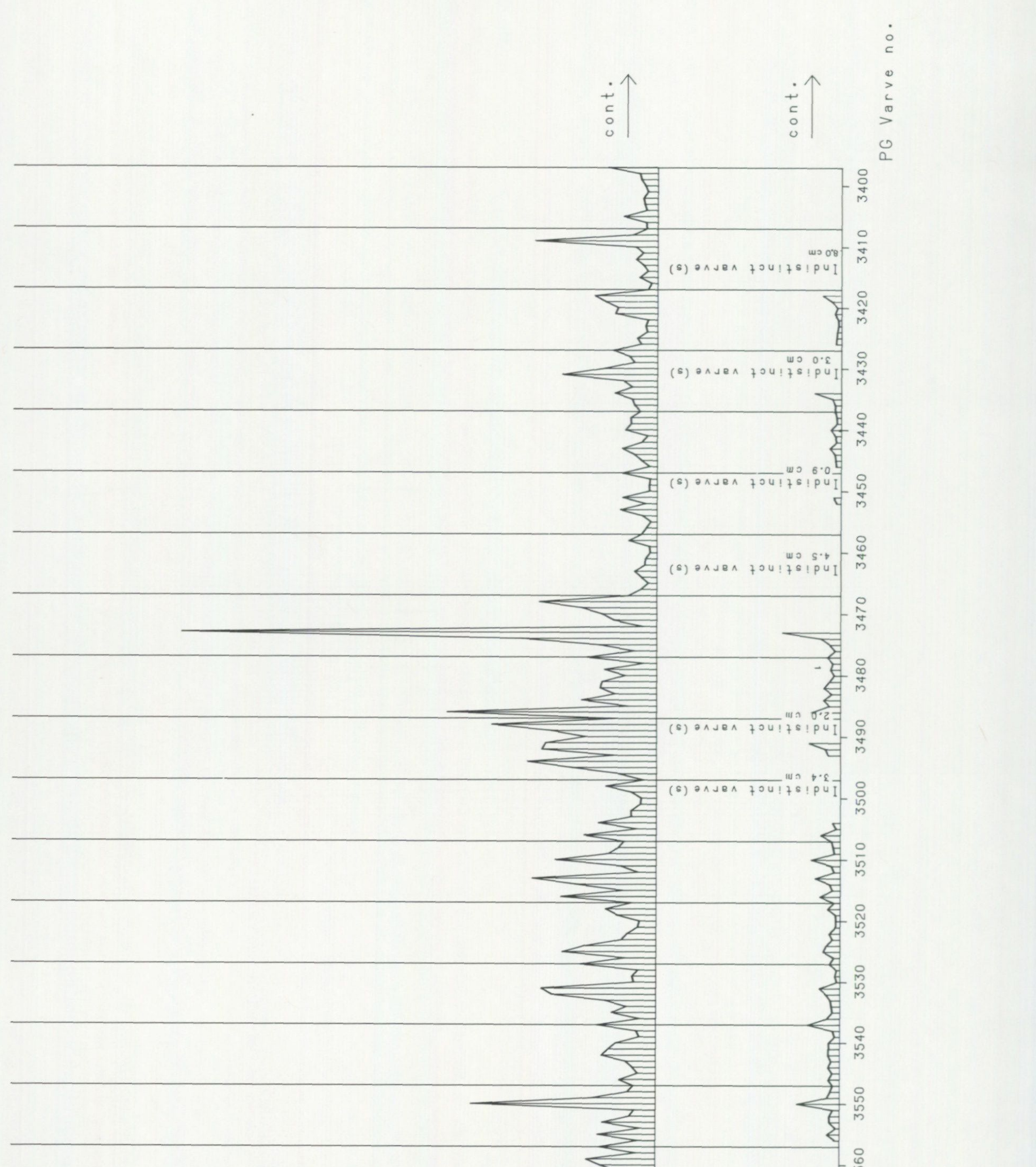

Fig. 36:18. Continuation of the Rödskägget and Risöviken–Sollefteå varve graphs from the Ångermanälven river in 3570–3370 B.C. (for further explanation, see Fig. 36:1).

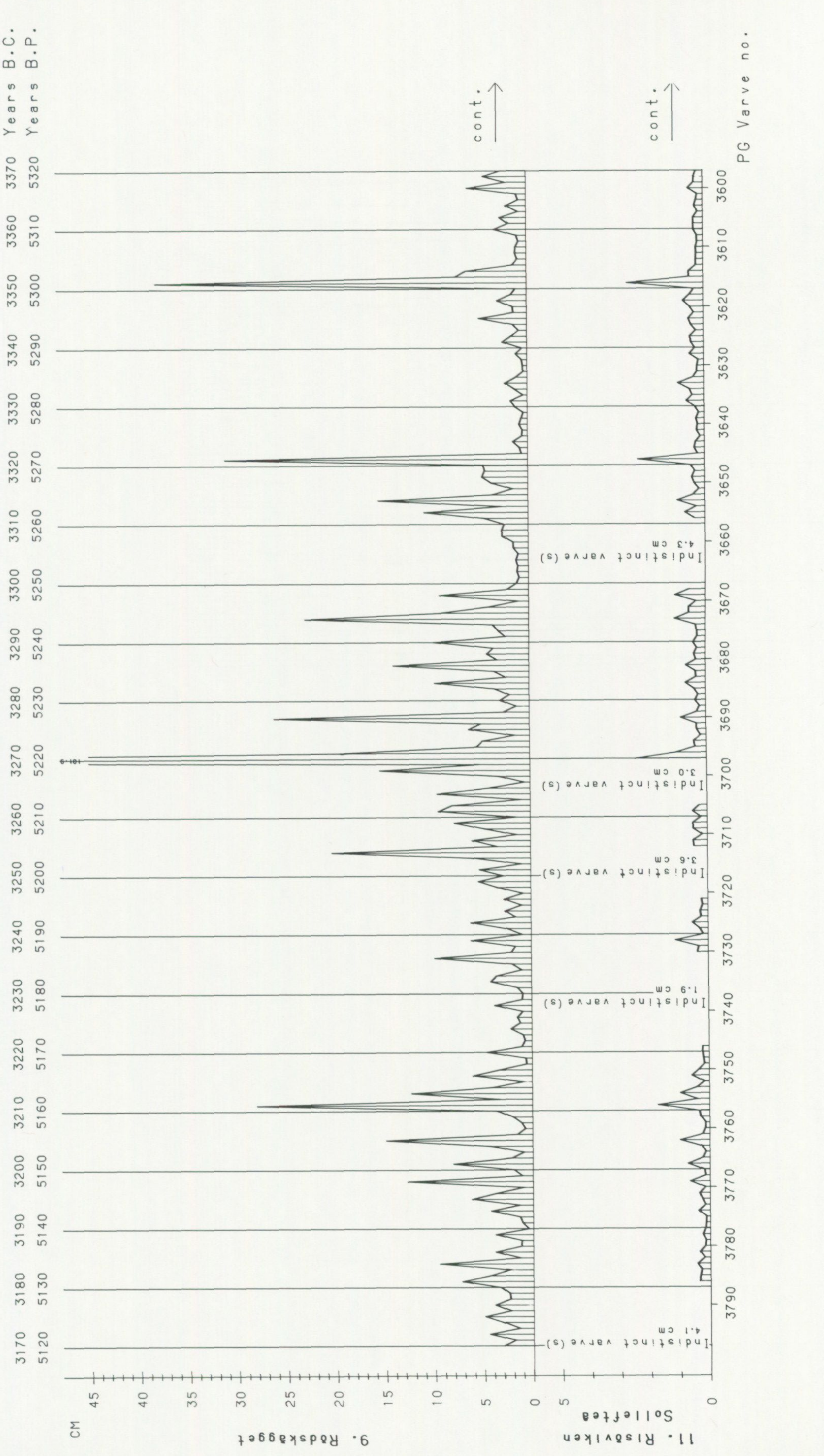

Fig. 36:19. Continuation of the Rödskägget and Risöviken–Sollefteå varve graphs from the Ångermanälven river in 3370–3170 B.C. (for further explanation, see Fig. 36:1).

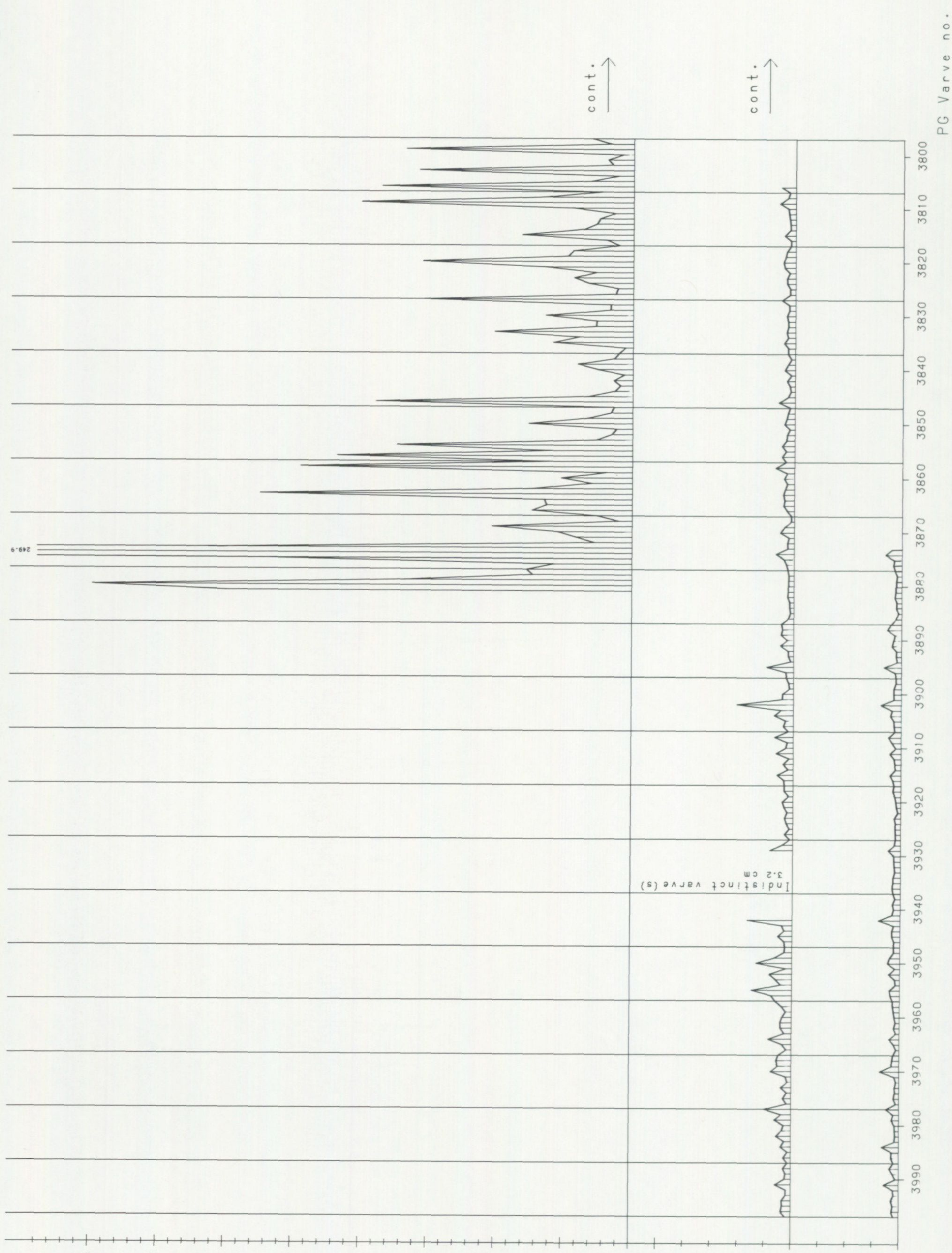

Fig. 36:20. Continuation of the Rödskägget and Risöviken–Sollefteå varve graphs from the Ångermanälven river in 3170–2970 B.C. and the correlation to the Färjstället varve series (for further explanation, see Fig. 36:1).

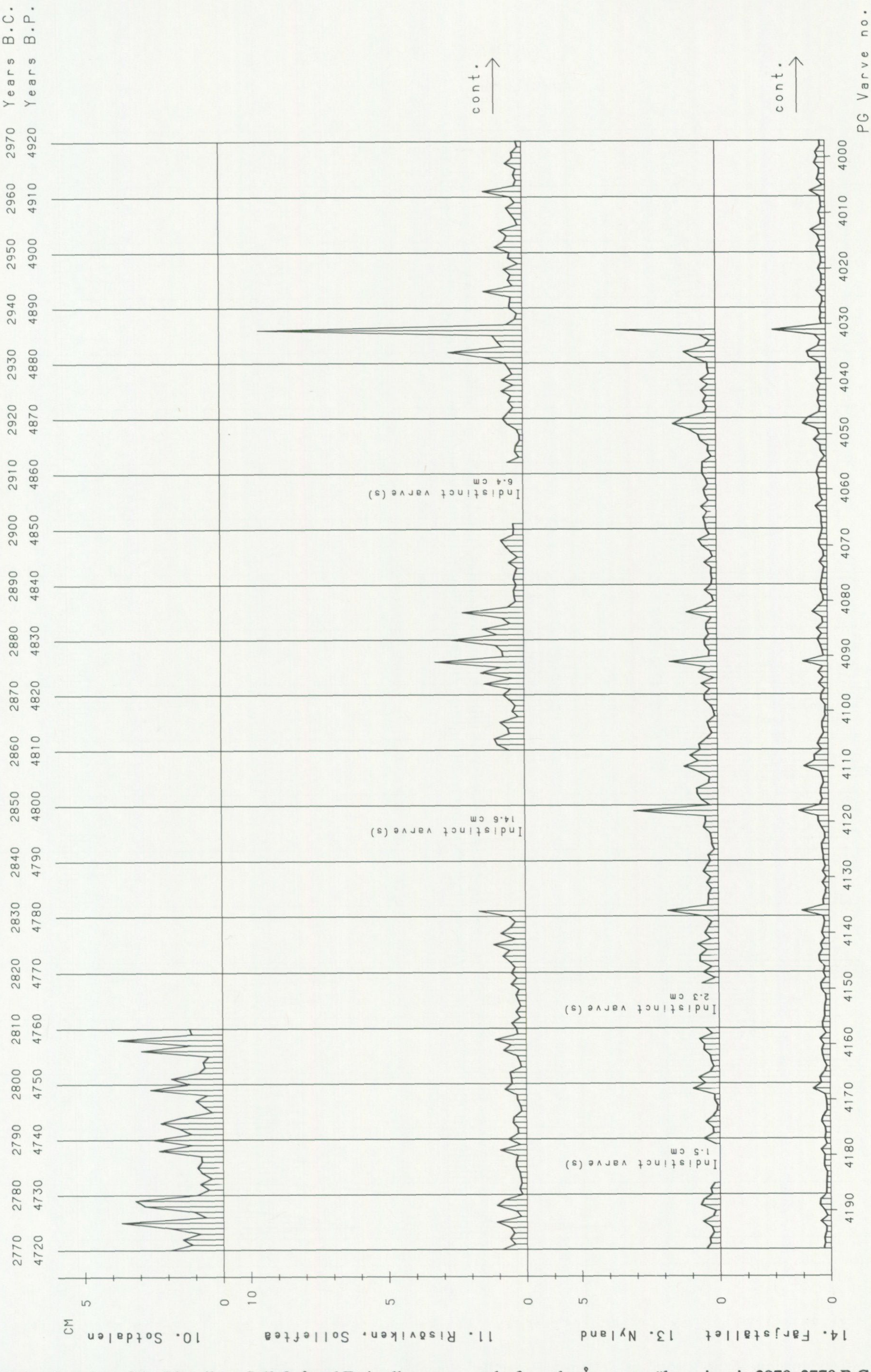

Fig. 36:21. Continuation of the Risöviken–Sollefteå and Färjstället varve graphs from the Ångermanälven river in 2970–2770 B.C. and the correlation to the Sotdalen and Nyland varve series (for further explanation, see Fig. 36:1).

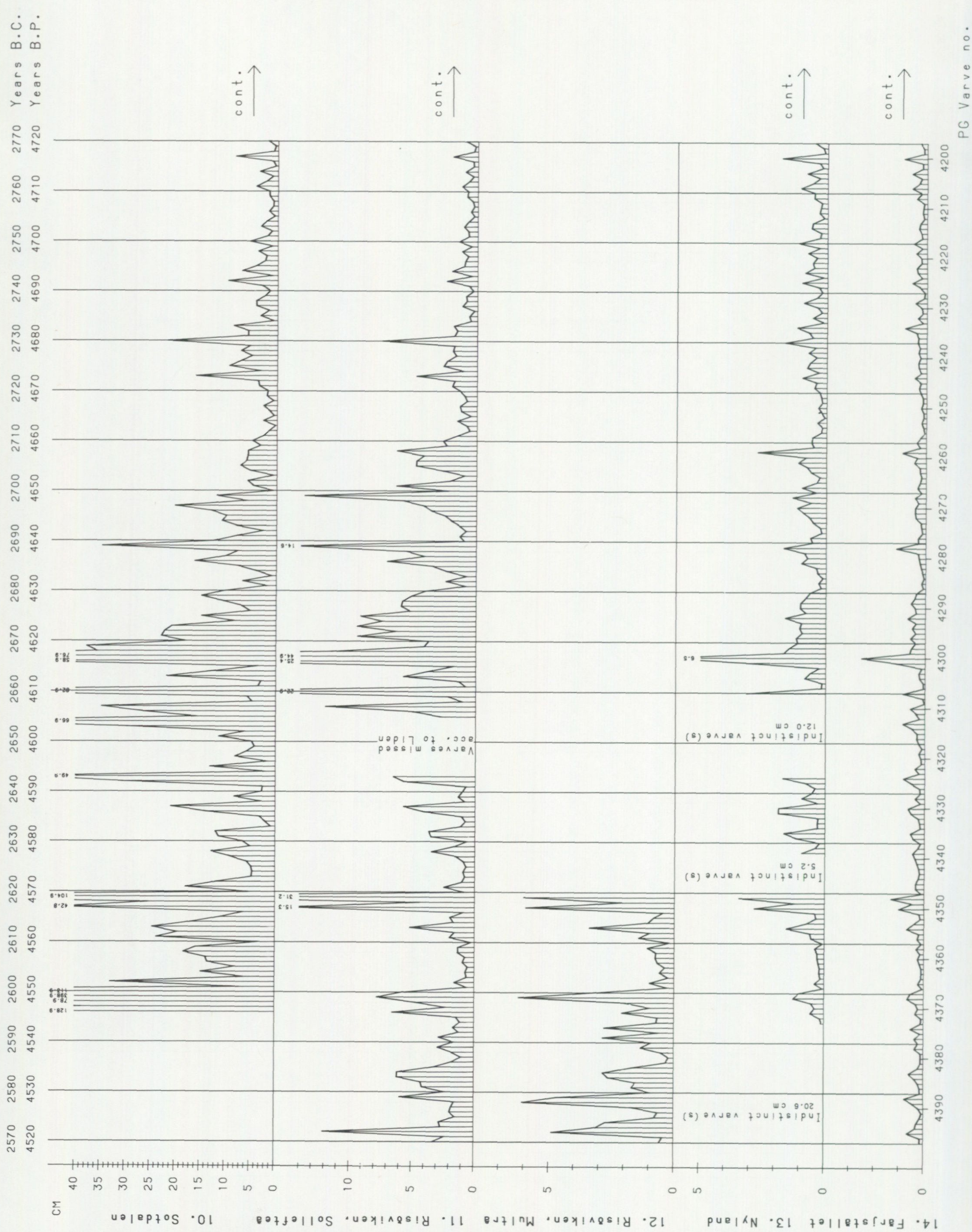

Fig. 36:22. Continuation of the Risöviken–Sollefteå, Färjstället, Sotdalen, and Nyland varve graphs from the Ångermanälven river in 2770–2570 B.C. and the correlation to the Risöviken–Multrå varve series (for further explanation, see Fig. 36:1).

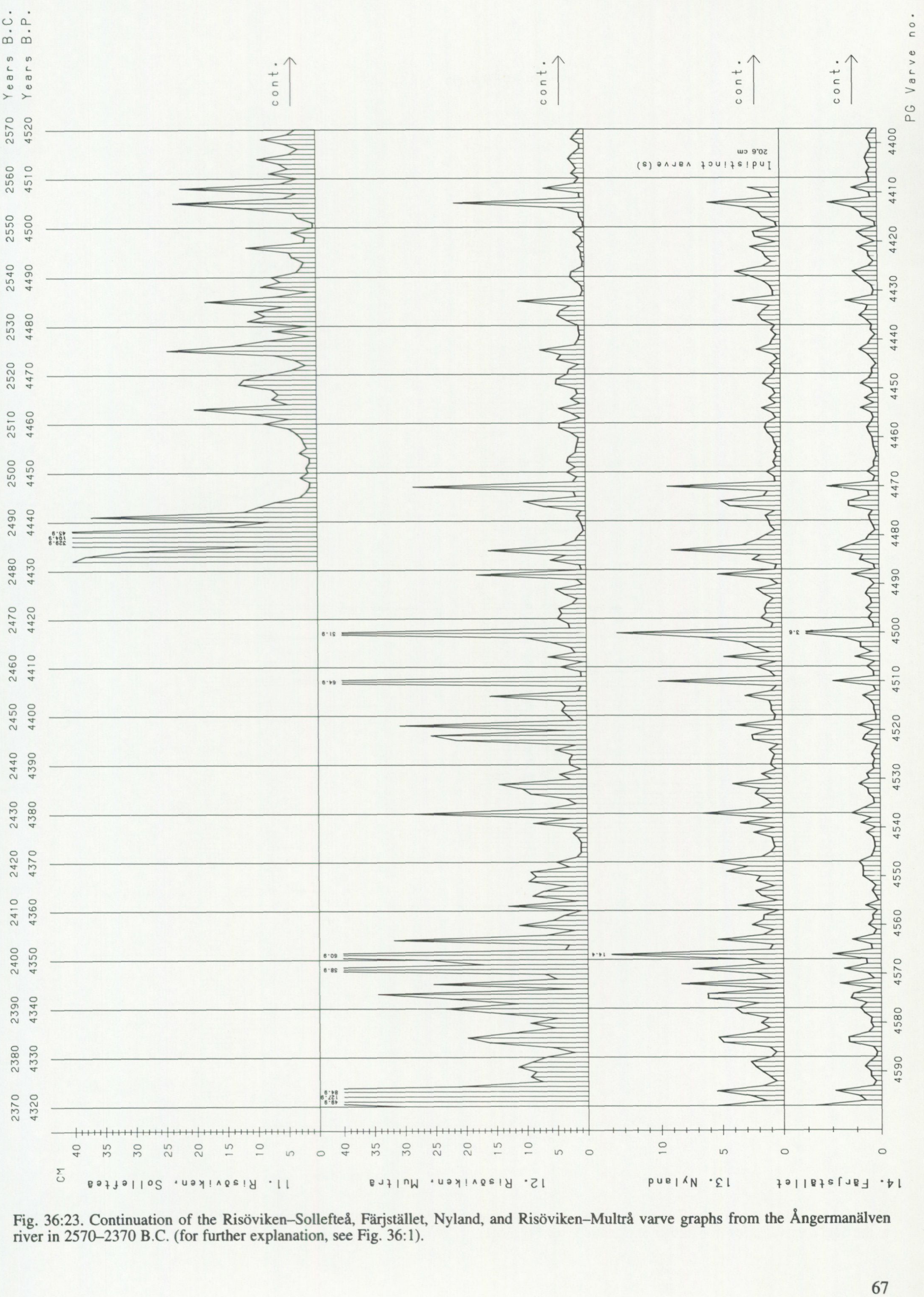

Fig. 36:23. Continuation of the Risöviken–Sollefteå, Färjstället, Nyland, and Risöviken–Multrå varve graphs from the Ångermanälven river in 2570–2370 B.C. (for further explanation, see Fig. 36:1).

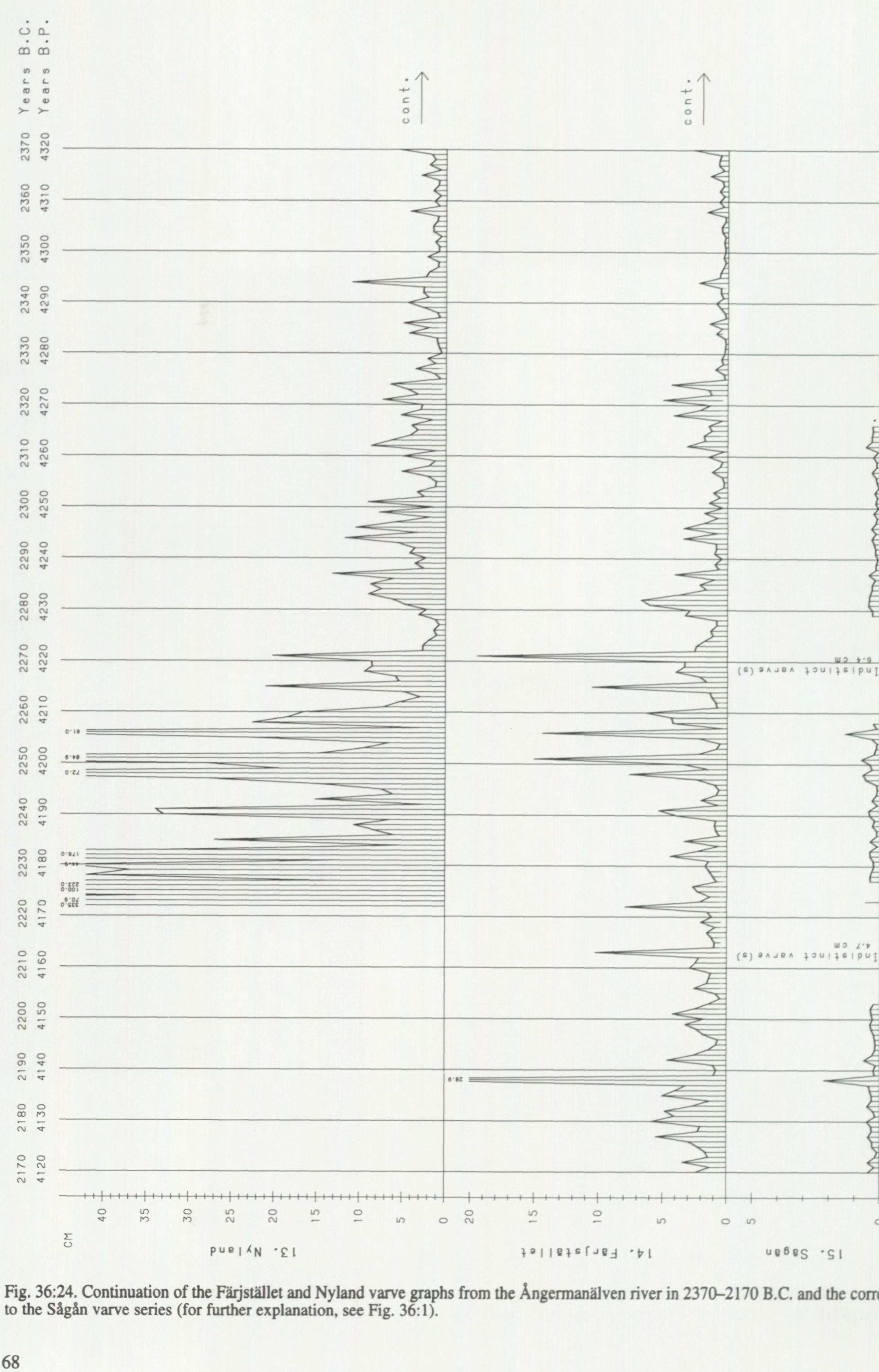

Fig. 36:24. Continuation of the Färjstället and Nyland varve graphs from the Ångermanälven river in 2370–2170 B.C. and the correlation to the Sågån varve series (for further explanation, see Fig. 36:1).

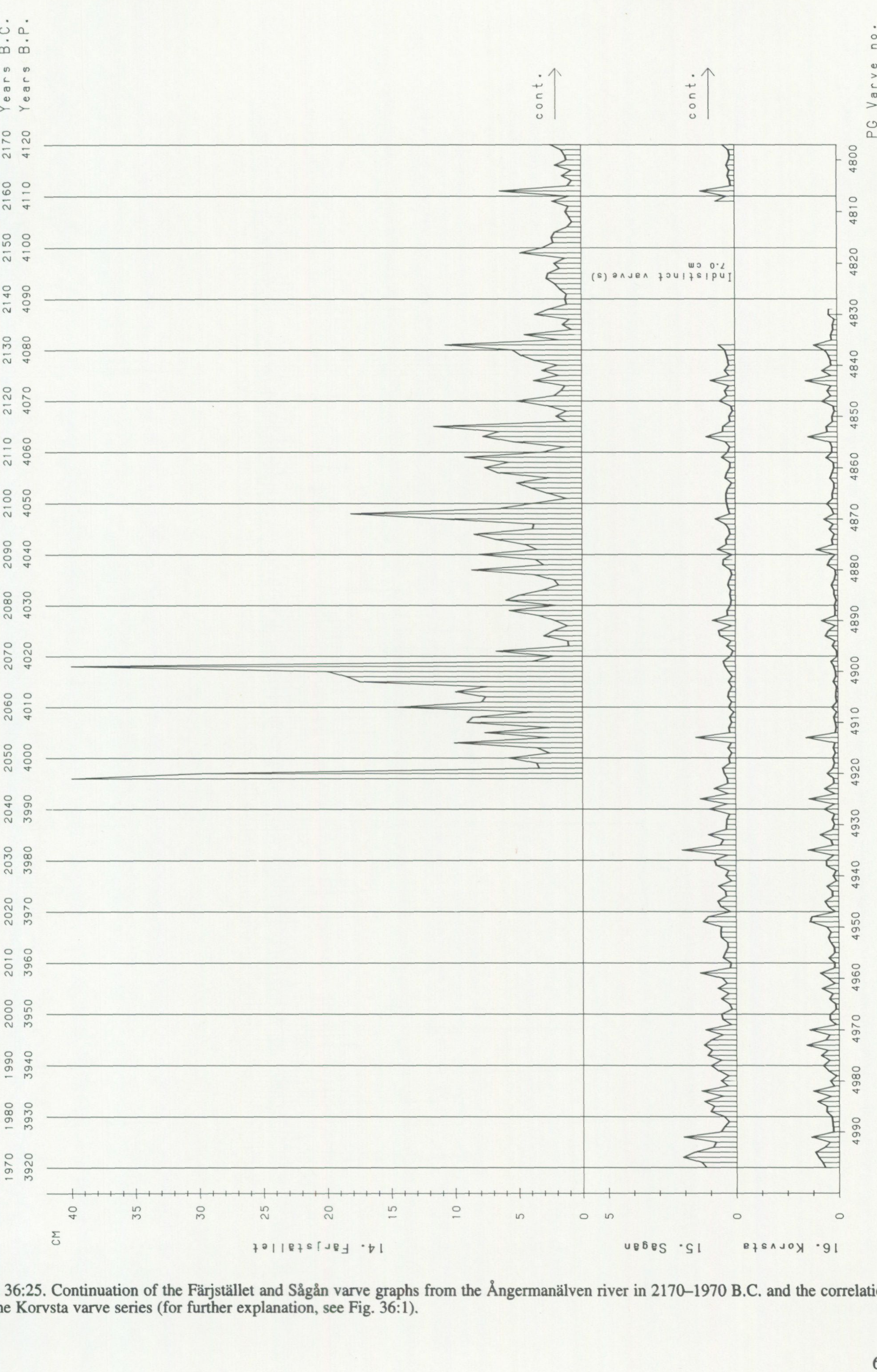

Fig. 36:25. Continuation of the Färjstället and Sågån varve graphs from the Ångermanälven river in 2170–1970 B.C. and the correlation to the Korvsta varve series (for further explanation, see Fig. 36:1).

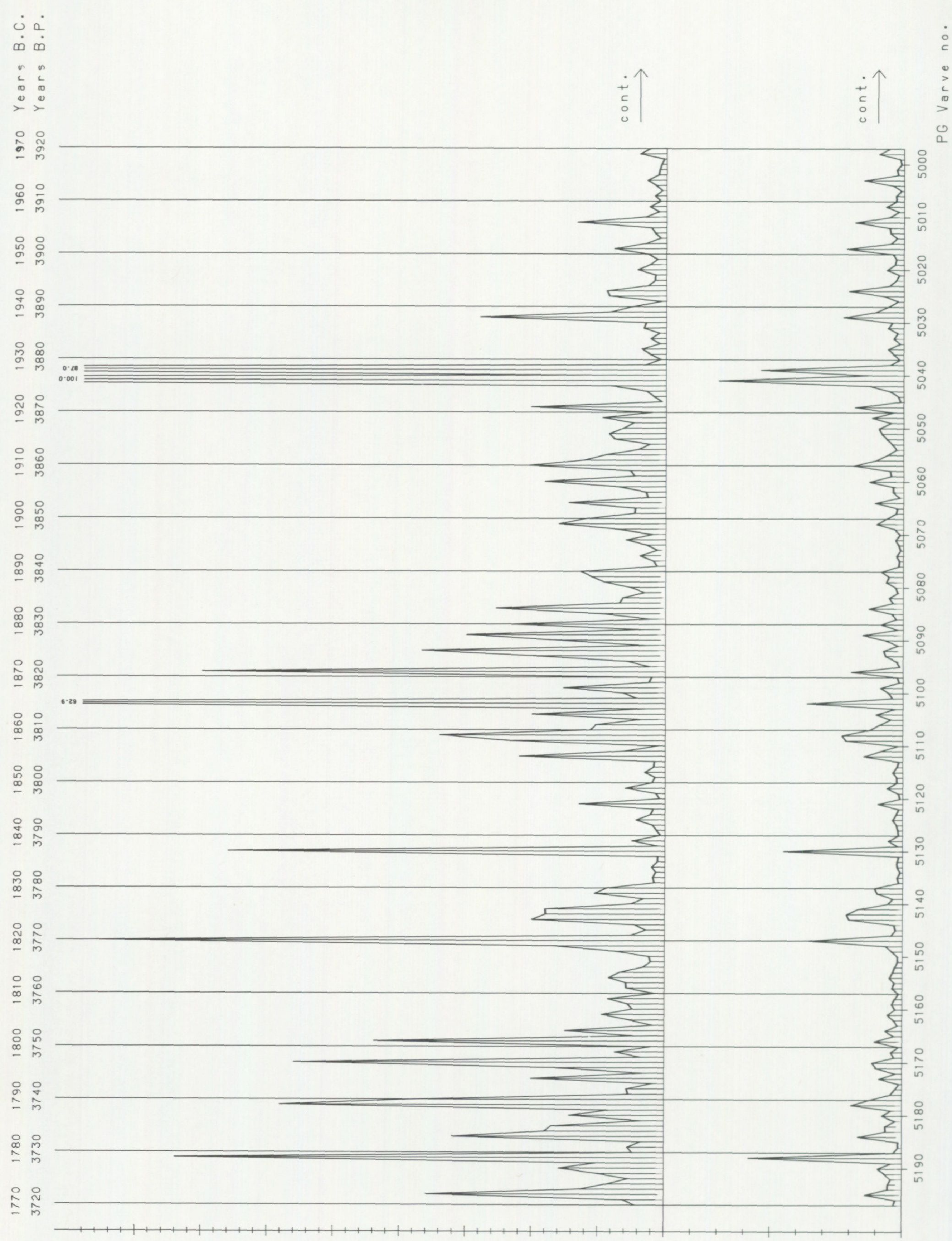

Fig. 36:26. Continuation of the Sågån and Korvsta varve graphs from the Ångermanälven river in 1970–1770 B.C. (for further explanation, see Fig. 36:1).

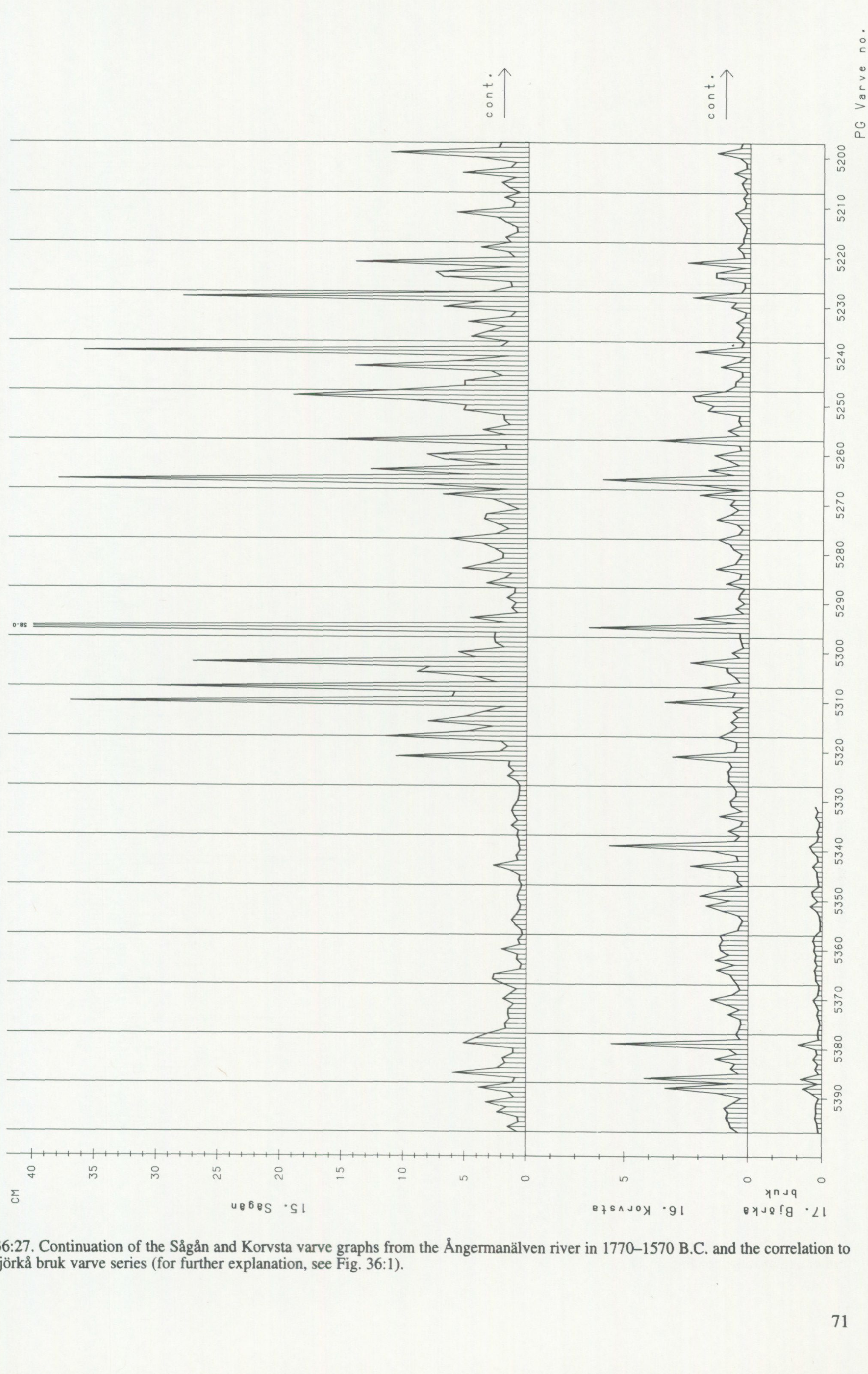

Fig. 36:27. Continuation of the Sågån and Korvsta varve graphs from the Ångermanälven river in 1770–1570 B.C. and the correlation to the Björkå bruk varve series (for further explanation, see Fig. 36:1).

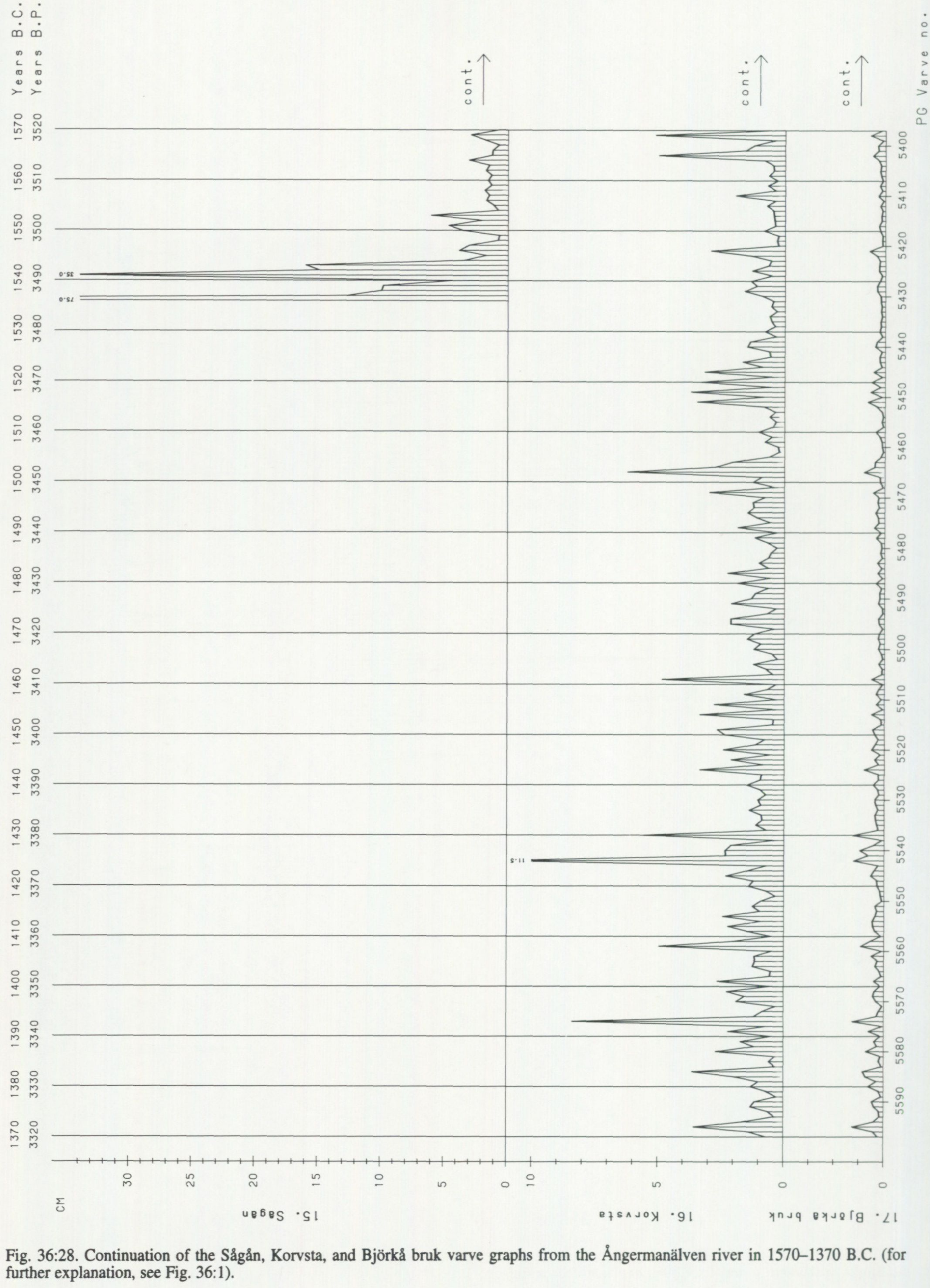

Fig. 36:28. Continuation of the Sågån, Korvsta, and Björkå bruk varve graphs from the Ångermanälven river in 1570–1370 B.C. (for further explanation, see Fig. 36:1).

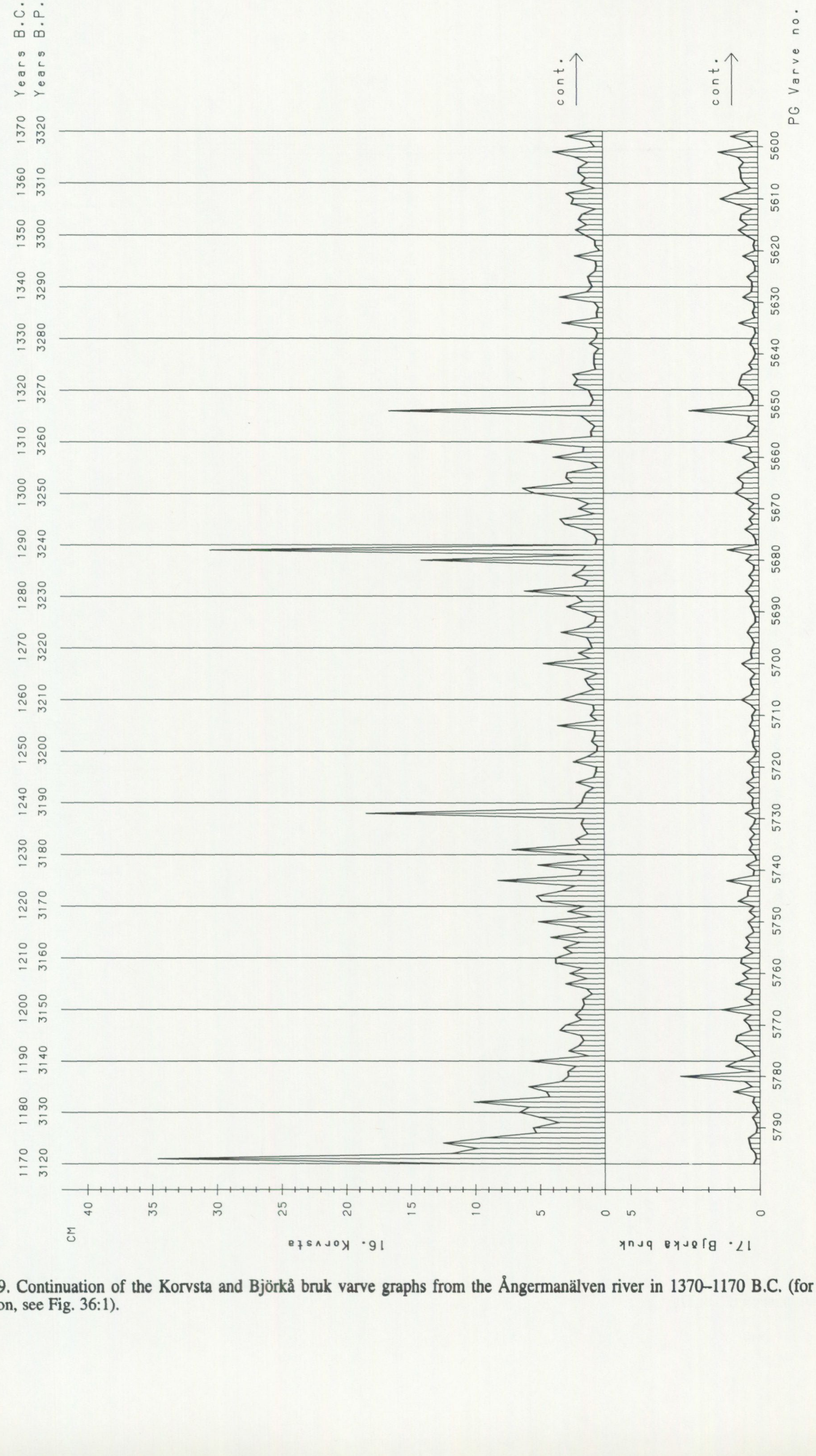

Fig. 36:29. Continuation of the Korvsta and Björkå bruk varve graphs from the Ångermanälven river in 1370–1170 B.C. (for further explanation, see Fig. 36:1).

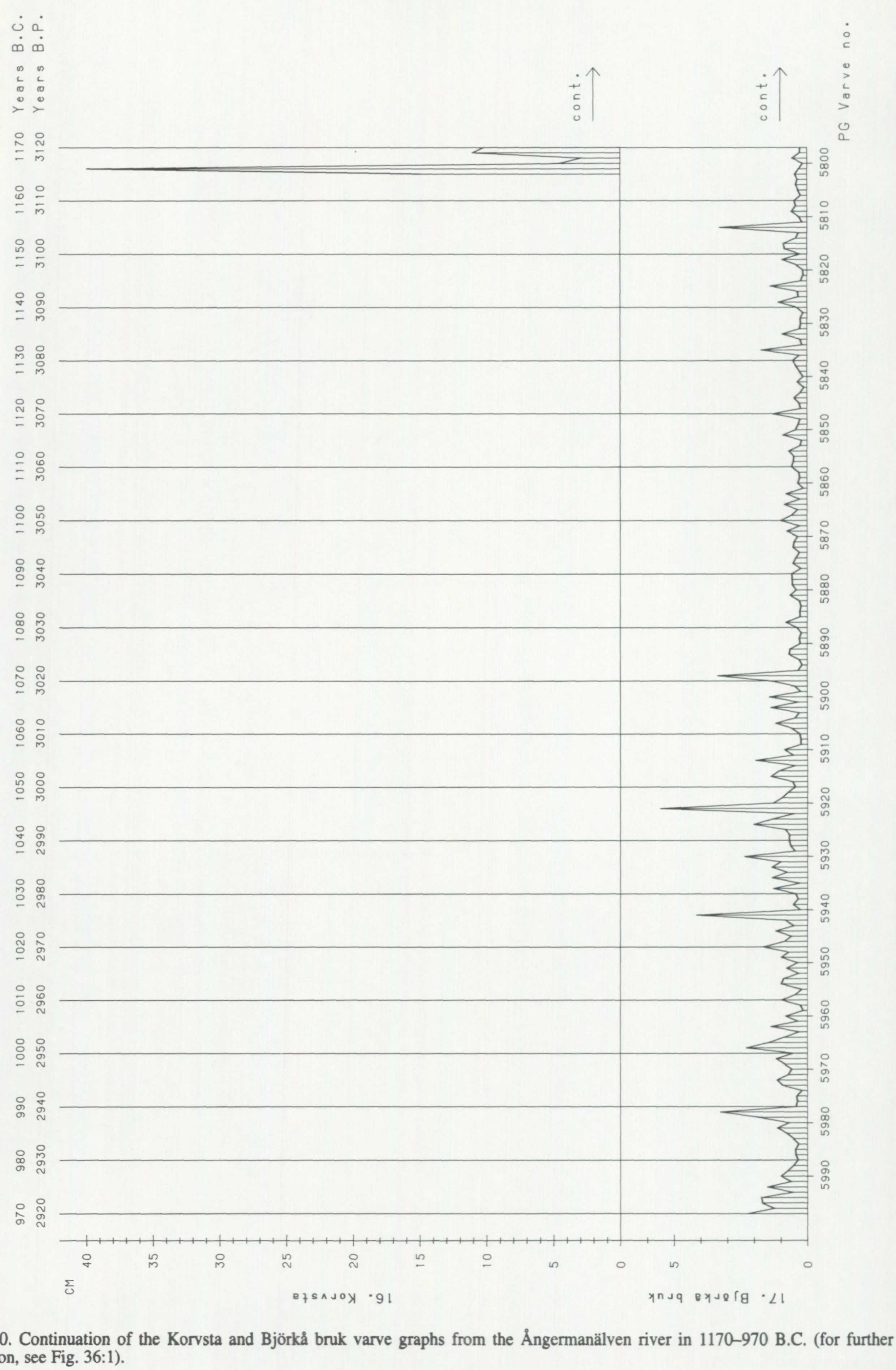

Fig. 36:30. Continuation of the Korvsta and Björkå bruk varve graphs from the Ångermanälven river in 1170–970 B.C. (for further explanation, see Fig. 36:1).

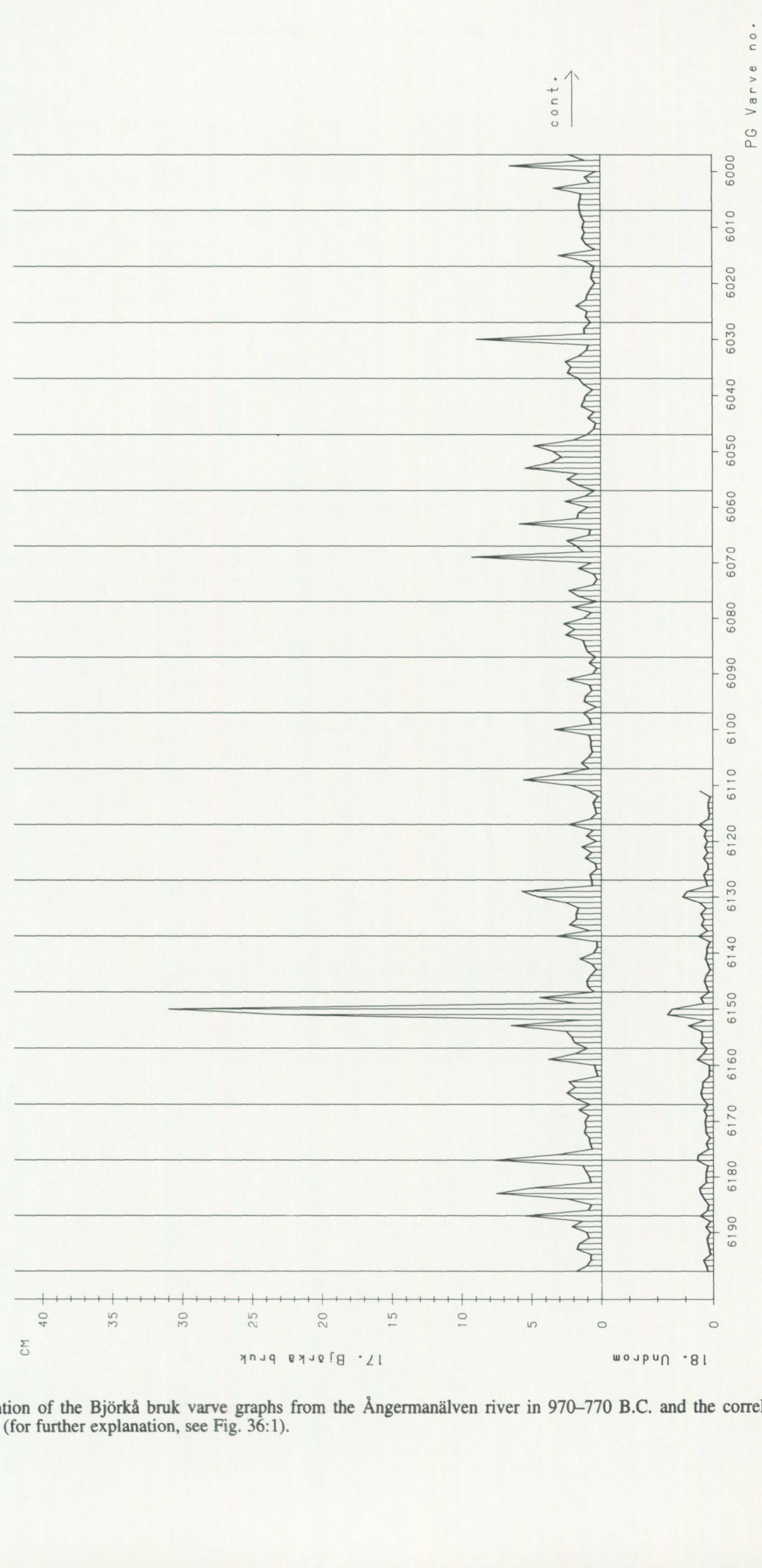

Fig. 36:31. Continuation of the Björkå bruk varve graphs from the Ångermanälven river in 970–770 B.C. and the correlation to the Undrom varve series (for further explanation, see Fig. 36:1).

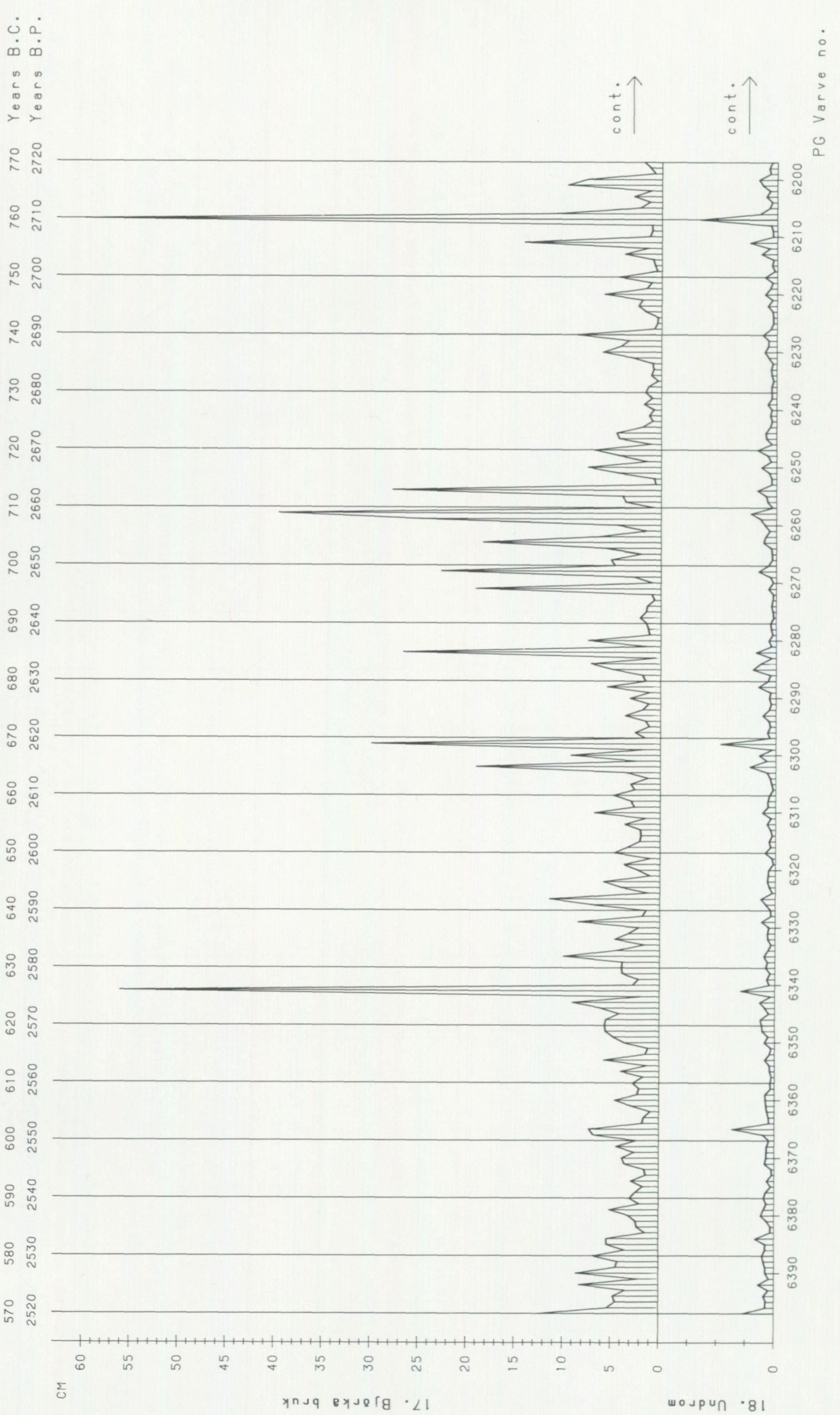

Fig. 36:32. Continuation of the Björkå bruk and Undrom varve graphs from the Ångermanälven river in 770–570 B.C. (for further explanation, see Fig. 36:1).

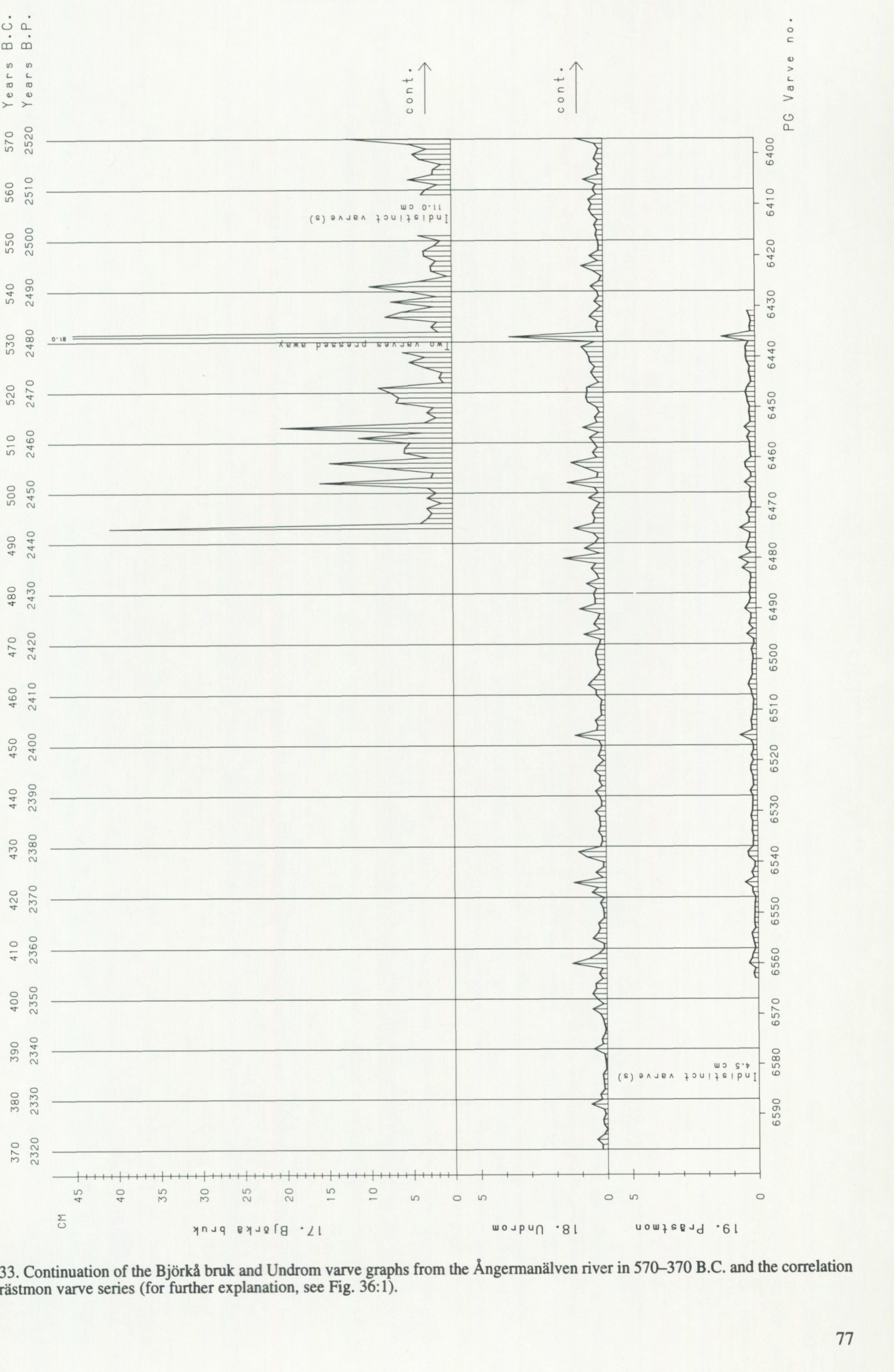

Fig. 36:33. Continuation of the Björkå bruk and Undrom varve graphs from the Ångermanälven river in 570–370 B.C. and the correlation to the Prästmon varve series (for further explanation, see Fig. 36:1).

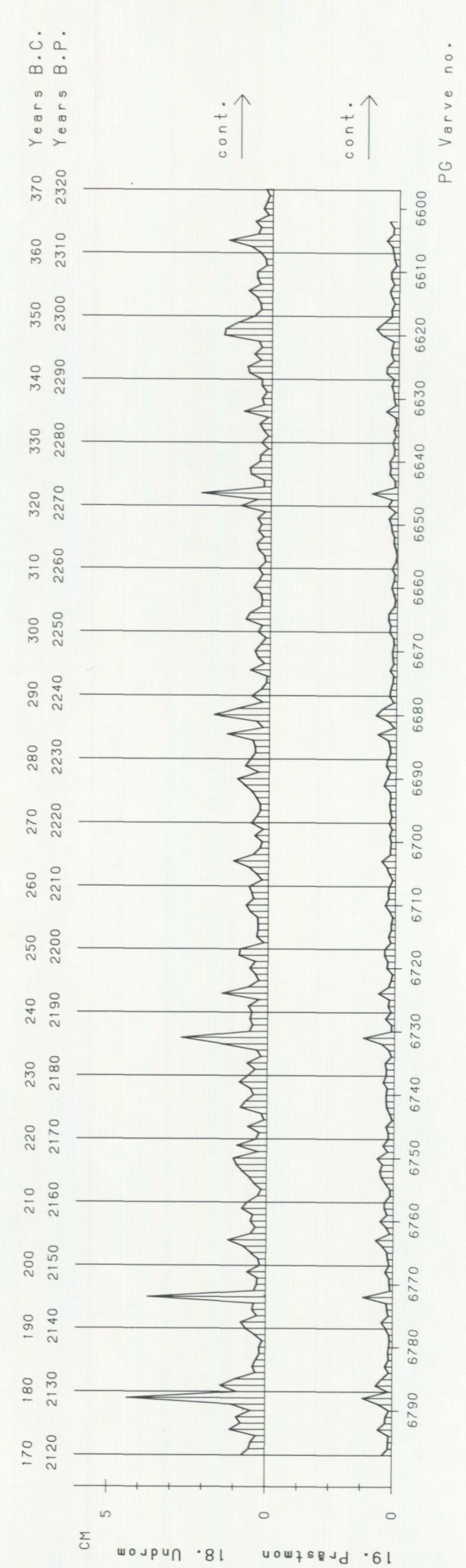

Fig. 36:34. Continuation of the Undrom and Prästmon varve graphs from the Ångermanälven river in 370–170 B.C. (for further explanation, see Fig. 36:1).

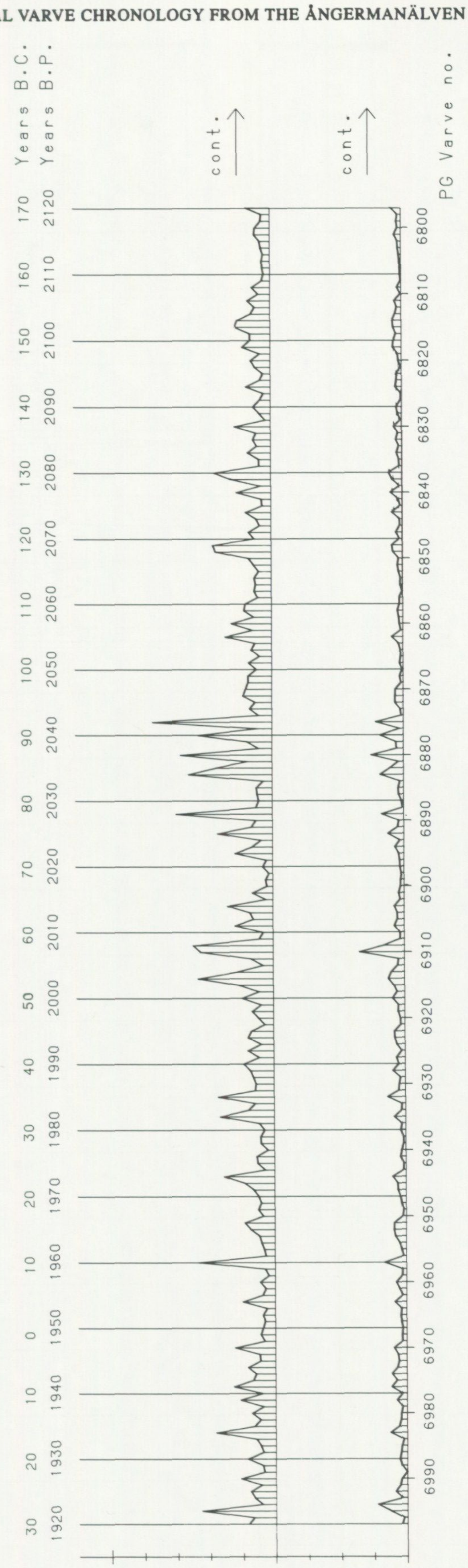

Fig. 36:35. Continuation of the Undrom and Prästmon varve graphs from the Ångermanälven river in 170 B.C.-30 A.D. (for further explanation, see Fig. 36:1).

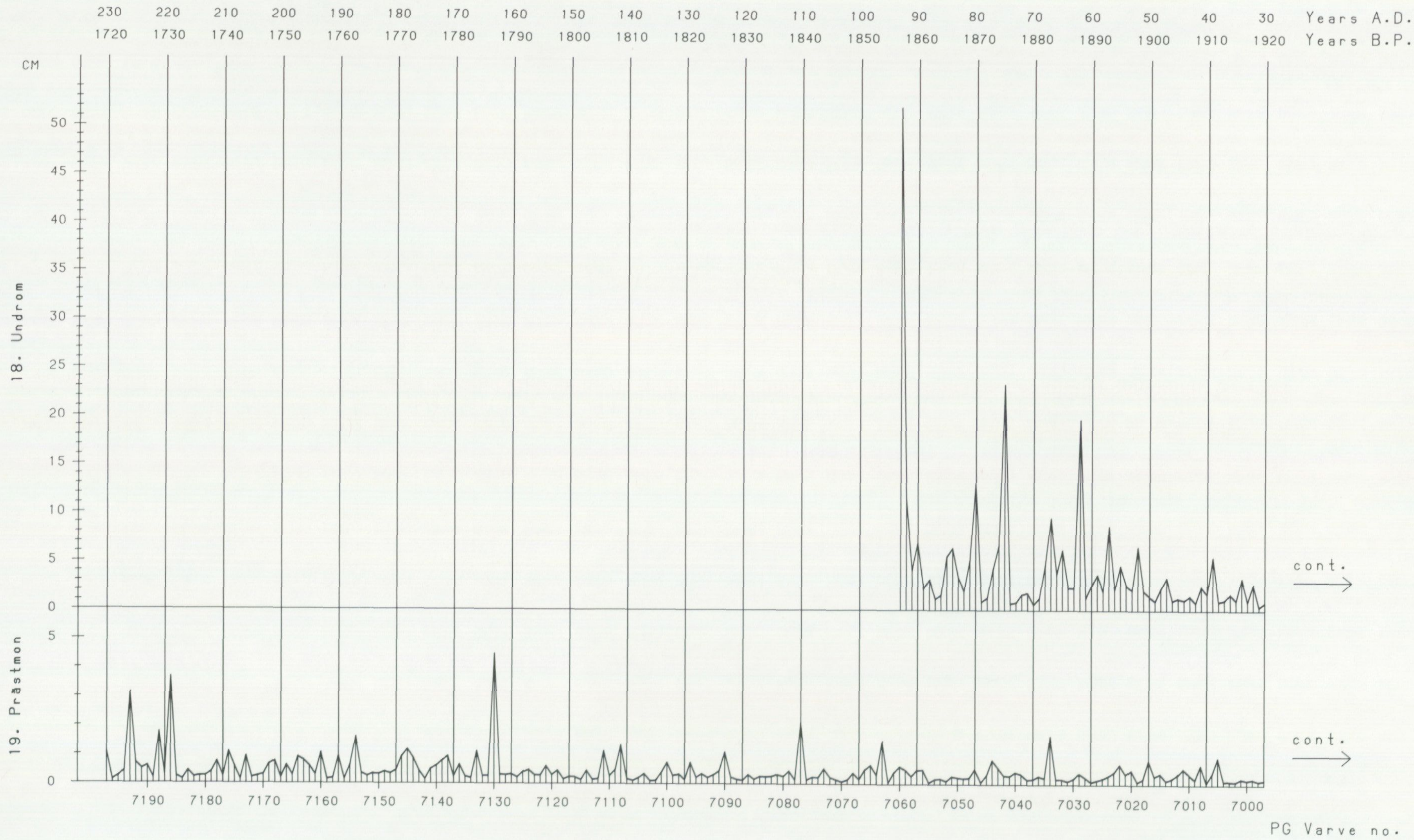

Fig. 36:36. Continuation of the Undrom and Prästmon varve graphs from the Ångermanälven river in 30–230 A.D. (for further explanation, see Fig. 36:1).

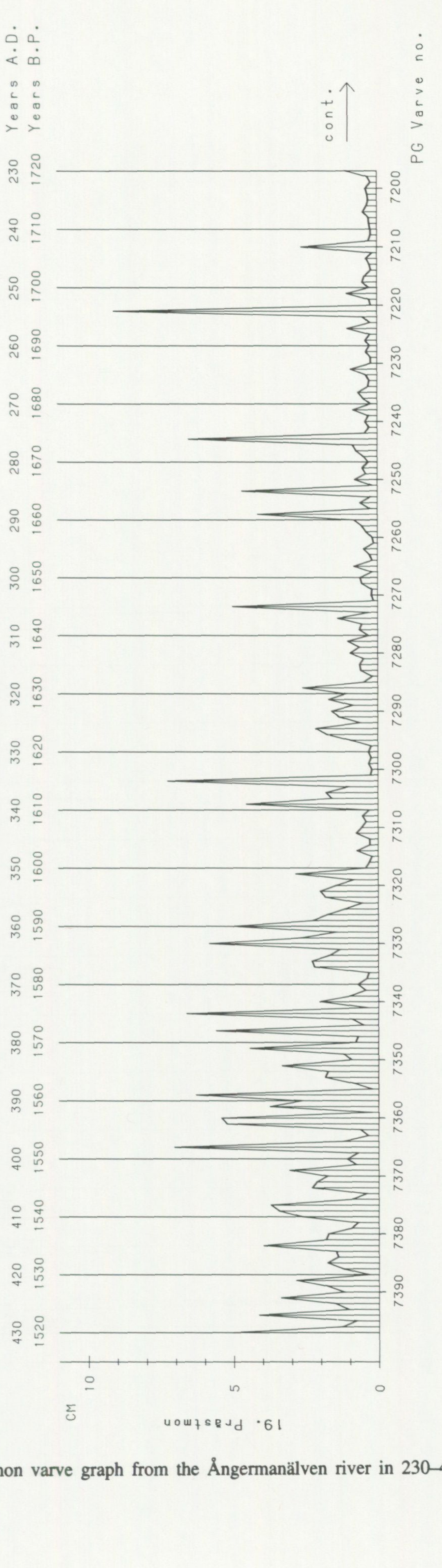

Fig. 36:37. Continuation of the Prästmon varve graph from the Ångermanälven river in 230–430 A.D. (for further explanation, see Fig. 36:1).

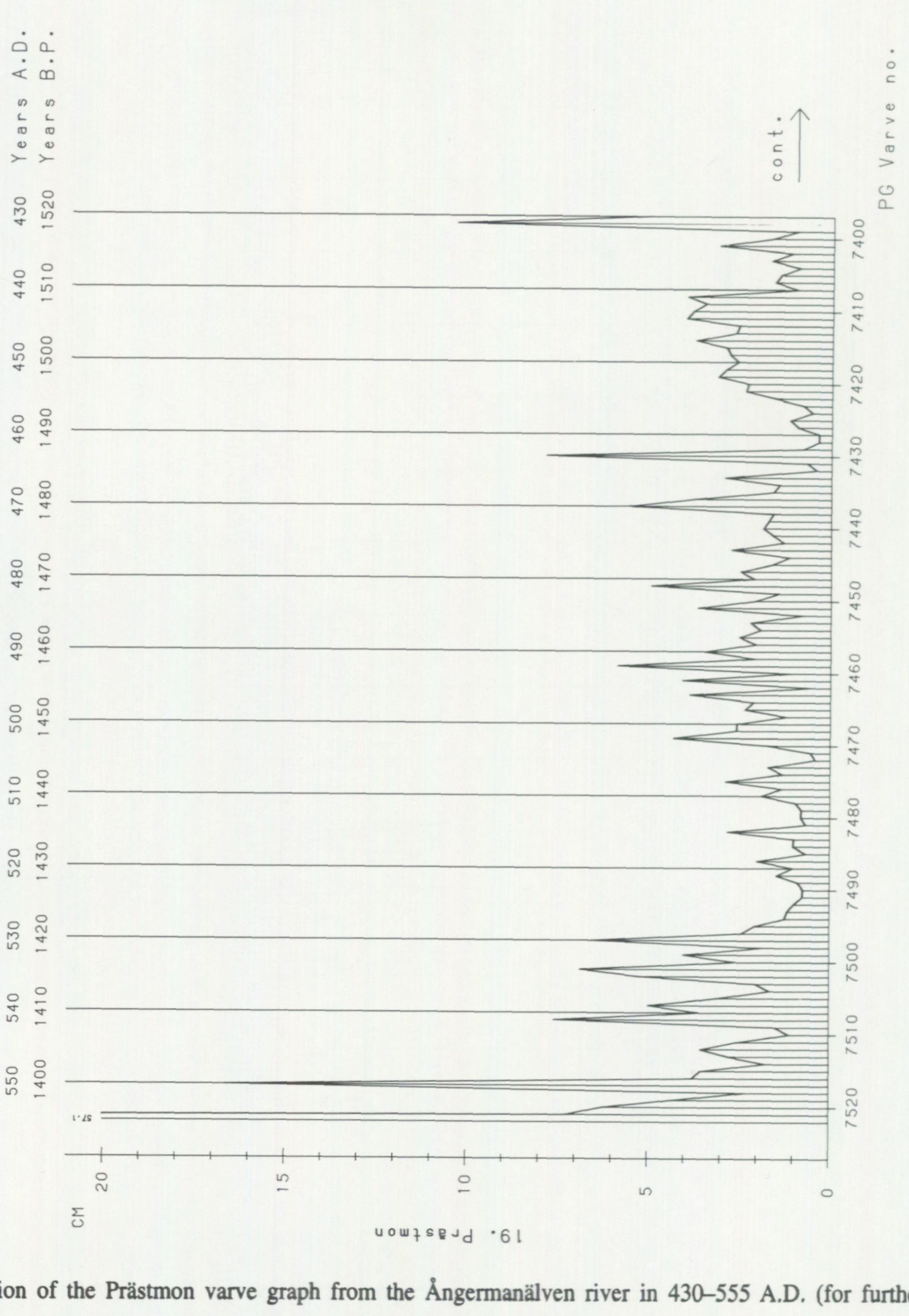

Fig. 36:38. Continuation of the Prästmon varve graph from the Ångermanälven river in 430–555 A.D. (for further explanation, see Fig. 36:1).

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