BULLETIN

DE LA

COMMISSION GÉOLOGIQUE

DE FINLANDE

N:o 60

STUDIES ON THE QUATERNARY VARVE SEDIMENTS IN SOUTHERN FINLAND

BY

MATTI SAURAMO

WITH 22 FIGURES IN THE TEXT, 12 FIGURES, 1 MAP, AND 2 DIAGRAMS ON 10 PLATES

HELSINKI 1923

Fascicules parus du Bulletin de la Commission géologique de Finlande.

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VALTIONEUVOSTON KIRJAPAINO

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CHAPTER VI.

Preface.

The present paper gives an account of continued investigations on the varve sediments in Southern Finland, the first results of wich were published in »Geochronologische Studien über die spätglaziale Zeit in Südfinnland» Bull. Comm. Géol. Finlande N:o 50, also in Fennia, 41, N:o 1, 1918), in the following briefly referred to as »Südfinnland». Since the appearance of this report the chronological research has been extended from the Second Salpausselkä to Northern Satakunta and Häme (Tavastland). At the same time the scope of investigation has been widened, and the stratigraphy and petrography of the varve sediments has been put in the foreground, as appears from the title of the present paper. Studies of this kind have also been applied to parts of the area of the earlier investigation.

The chronology was mainly worked out during the summers of 1917 and 1918. To more detailed studies, especially those concerning the distribution of the varve sediments, I had opportunity of devoting parts of the summers of 1919—1922, and many of the most important localities were studied repeatedly. The laboratory work was carried out during the winter of 1921.

In these studies I have received encouragement and assistance from many different persons. I wish especially to mention with gratitude Professor W. Ramsay, whose great interest and constructive criticism of my work have been very valuable. The translation of my original manuscript written in Finnish was made by Dr. P. Eskola, with whom I have been in close contact, and whose kind collaboration has been of material advantage in the discussion of many problems. Prof. J. G. Granö has given me much valuable advice regarding the disposition of the subject matter. Dr. Benj. Frosterus and Dr. B. Aarnio kindly gave me the aid of their experience in the laboratory work. Professor J. W. Lindeberg assisted me with mathematical calculations concerning sedimentation. To all these gentlemen I express my sincere thanks.

For the field work in 1917 and 1918 I received pecuniary assistance from the Geographical Society of Finland and in 1921 from the Seth

Sohlberg Foundation. This foundation also granted me a bursary for a journey to Sweden in the spring of 1920 which I made for the purpose of these investigations.

All the work since 1919 was done by me while a member of the staff of the Geological Commission of Finland.

Geological Commission of Finland, Helsinki, May 1923.

Matti Sauramo.

Chapter I.

Introduction.

Location and topography of the area. — The present investigation deals, to some extent, with the whole of Southern Finland between the 60th and 63d parallels, but it is specially concerned with the

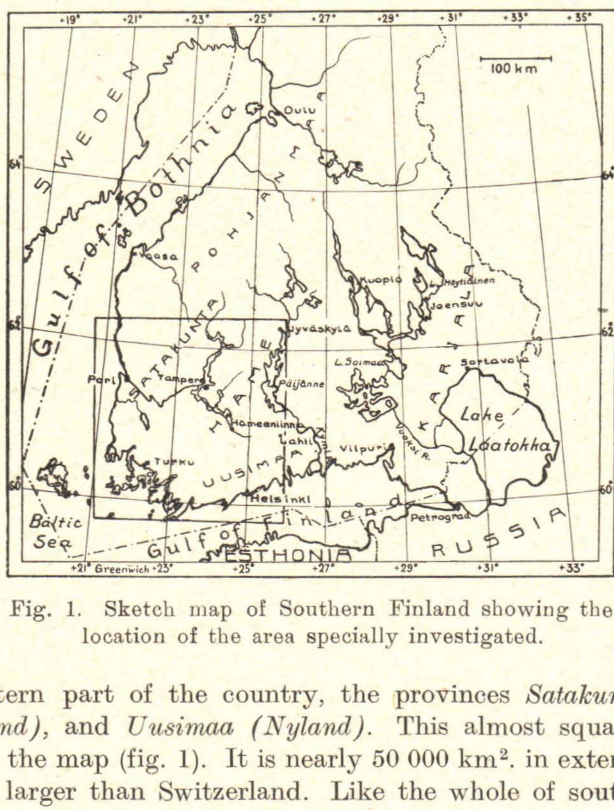

Fig. 1. Sketch map of Southern Finland showing the location of the area specially investigated.

southwestern part of the country, the provinces *Satakunta, Häme (Tavastland),* and *Uusimaa (Nyland).* This almost square area is shown on the map (fig. 1). It is nearly 50 000 km^2. in extent, or considerably larger than Switzerland. Like the whole of southern Finland, it is a part of the large *pre-Cambrian territory of Fennoscandia,* with practically no Paleozoic or Mesozoic formations. Only quaternary deposits, still unconsolidated, occur resting upon the surface of the old crystalline rocks.

In its larger features, southern Finland is a fairly level country. The variations in elevation are shown on the hypsometric map (fig. 13, pag. 132). Large areas elevated above 200 m. only exist near the eastern boundary and in the very gently rising region near the divide between the *Gulf of Bothnia* and the *Gulf of Finland*. From this divide the plain of *Pohjanmaa (East Bothnia)*, about 130 km. broad, inclines uniformly toward the Gulf of Bothnia, in a northwesterly direction, whereas the southern slope toward the Gulf of Finland and *Lake Laatokka (Ladoga)*, forming a belt about 350 km. broad, consists of two faces of different grade: (1) The larger inner part, the *Lake district of Central Finland*, extending to the belt of the recessional moraines[1]) of *Salpausselkä* (»the damming ridge») and (2) the narrower bow-shaped *Coast zone* between the Salpausselkä and the coasts of Lake Laatokka and the sea. The wide lake district is very gently inclined. The big lakes *Saimaa* and *Oriselkä*, bounded by the Salpausselkä, are at an altitude of 76 m, while *Lake Kallavesi* around the town of *Kuopio* is 82 m above sea level. Thus the difference of the water levels between the south shore of L. *Saimaa* and *Kallavesi*, a distance of 200 km, is only 6 m. In the coast zone, on the other hand, there is a difference of 76 m. within 50 km. (L. *Laatokka* is 5 m. above s. l. and the lower part of the Vuoksi river 11 m. above s. l.). The grade is thus much steeper than in the lake district. The existence of these two differently inclined faces is a feature inherent in the surface form of the rock foundation. This appears from the fact that there are rock exposures along the whole length of the Salpausselkä at the same elevations as the recessional moraines. Where the rivers *Vuoksi* and *Kymi* wich form the outlets of the waters from the lake district, cut the Salpausselkä zone, they have eroded their channels in solid rock. The basins of the lake district have also been carved in the rock foundation, and are only to a very small extent ponded by accumulations of quaternary deposits.

In southwestern Finland, northwest of the western end of Salpausselkä, the rise of the level toward the north and east is more uniform, and the difference in inclination between the lake district and the coast zone is not so well marked. In its smaller features

[1]) The term recessional moraine is applied in the sense in which it is used by American geologists (see e. g. Th. C. Chamberlin and R. D. Salisbury, Geology, Vol. III, New York 1906, p. 367). This term having been rarely used in Fennoscandia, it may be emphasized that it applies to deposits formed during halts and not during continuous recession of the land-ice, as the word might suggest. — In Finland, the Salpausselkäs were earlier usually called transversal eskers.

this special area, like other parts of Finland, exhibits much variation and is generally rugged. Numerous, mostly rocky hills rise a few tens of metres, exceptionally a little more than a hundred metres, above the average level, and the depth of the basins is of the same order of magnitude. The extent of the basins is variable, but the number of those conspicuous in the main topographic features is small. Largest of all is the basin of *Lake Päijänne* on the east line of the special area. Its length, in a northerly direction, is nearly 120 km, whereas its breadth is only from 20 to 10 km. Its deepest depression is 15 m. below sea level, though its average depth is much less, like that of all the other basins. The floor of the basin of *Lake Näsijärvi* is 62 m., the water level 95 m. and the average level of the surrounding country about 120 m. above sea level. The depth of *Lake Kyrösjärvi* is about the same, but the basin is shorter. The other basins in the neighbourhood of *Tampere (Tammerfors)* and *Hämeenlinna (Tavastehus)* are shallower, their water level being between 88 and 74 m. above sea level and the depth of the water generally not more than 5 m. Fairly continuous high lands separate the water system of *Tampere-Hämeenlinna* from the basin of *Päijänne* and also from the coast of the Gulf of Bothnia. In the northern part of the latter higher country, in the parish of Parkano, the average elevation is about 200 m. Farther south there is another high tract in the parish of Tammela, reaching an average altitude of 175 m.

All larger topographical features are due to the forms of the rock surface which is exposed in numerous places. The cover of unconsolidated Quaternary deposits has but minor influence upon the land-forms.

Outline of the Glacial deposits.[1]) — The largest part of the Quaternary deposits consists of *unstratified drift*, either as a thin mantle upon the rock surface or as accumulations of ten metres or more thick. *Stratified drift* occurs in the form of eskers (åsar), most of which are longitudinal (i. e. nearly parallel to the motion of the land ice), the longest being continuous through the whole area. Their height above their substratum may attain several tens of metres, even as much as 80 m., as in the *Kangasala—Tampere* esker, and the *Hämeenkangas* esker. The larger recessional moraines, as the *Salpausselkä* etc., also consist mainly of well washed, assorted and stratified materials and have therefore been marked, on the special map (Pl. VIII), with the same designation as the eskers.

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[1]) This outline and the map (Pl. VIII) are based upon the folios published by the Geological Commission of Finland No:s 1—13, 23, 26, and 32 in scale 1: 200,000, and the folios B2 and C2, Quaternary deposits, in scale 1: 400,000.

In the special area, *varve sediments*[1]) are more widely distributed than anywhere else in Finland (see the map fig. 6 p. 75). They are most common in Uusimaa and Southern Häme and in the region of Loimaa—Turku (Åbo), in the southwest. In the lake district, they generally occur near the eskers and on the floors of the basins. In higher regions, there are no varve sediments at all. In the coast region of Satakunta, also, they are very scarce. The thickness of the varve sediments may attain some twenty or thirty metres, but is commonly a few metres only, at least in the case of those of them that are suitable subjects for the present investigation.

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[1]) This term is used, as proposed by G. De Geer (A Geochronology of the last 12,000 years, Compte rendu XI:e Cong. géol. internat. à Stockholm 1910, p. 242, 1912) to designate laminated sediments composed of »*varves*», or periodical laminae.

A varve, as a rule, consists of two parts, a lower *coarser layer* and an upper *finer layer*.

Chapter II.

Methods of Working.

Methods of Connection.

Defects of diagrammatic connection. — The methods of chronological investigation of varve sediments have earlier been set forth in the writings of De Geer, and subsequently in papers by other authors, as in my earlier study (Südfinnland). It would not therefore be necessary to discuss the methods again in this place, but for the reason that De Geer's original method of connection, i. e. of identifying the same varves in different sections by their relative thickness, has not been exclusively applied in the present investigation, but has been supplemented or entirely replaced by other methods, already adopted to some extent in my earlier work. As I have since developed them further and very largely extended their use, it seems proper to explain, before making a special description of the connections, the general principles upon which these methods are based and the reasons that led me to look for them.

By studying the literature on varve sediments we find that all investigations in this field are based on the theory of De Geer and follow the methods wich he has elaborated. It is true that this theory has already passed the stage of a working hypothesis, and can hardly be contradicted as to its main principle, the idea that the varves are annual layers and that their correlation leads to an exact chronology for the last stages of the Ice Age. However, so probable and conclusive as may be the principal deductions from observed facts, no study of the material from a stratigraphical and petrological point of view has yet been undertaken. In my opinion a thorough investigation of this kind is necessary in order to understand the nature of the varve sediments, and to know the limits between which the method applied leads to reliable results. Such a fuller elucidation of these problems will give added confidence in the results, but I also think that everybody who undertakes such an investigation in a sufficiently extensive area, using the methods here advocated, will arrive at the same result as I, namenly that connections based exclusively upon the variation in thickness of the individual varves do not always render reliable results.

Uncertainty and errors may be due to many different circumstances. Sometimes the variation in thickness of the varves is so slight that the variation curve approaches a straight line and no connection can be made. In other cases, when the thickness is variable, the proportions between the thickness of different varves are too inconstant. One and the same series of varves thus appears different in diagrams from different localities, and the variation curve of one section displays no features recognizable in that of the other section. Identification of the varves is then rather a matter of hazard. These cases are not theoretical possibilities or rare exceptions only, but almost as common as »ideal cases» where connection from the diagrams is easy and conclusive. Nor are they restricted to connections between distant localities, but the difficulties may arise even in neighbouring sections. Our area shows many instructive examples of this.

Still worse, even an apparent congruence of graphs does not always warrant reliable connections. As examples of this may be mentioned some of De Geer's connections between Finland and Sweden (Südfinnland p. 34) and between northern America and Sweden[1]), the connections being, as can be proved, erroneous though the agreement among the graphs appears to be good.

Principles of stratigraphic correlation. — The defects of the diagrammatic method, so commonly felt in practice, have led me to look for more reliable methods. A better method must be independent of the variation of thickness of the varves, the inconstancy of which is the main source of trouble, and rely upon other characters, inherent in each individual varve or group of varves and more constant than the relative thickness. Such characters in fact exist among the physical properties of the sediments. Of course, primary properties only must be considered and not secondary ones, such as those due to weathering, or the action of ground water. Those primary properties that may serve for the purpose of connection are: colour of the sediment in the state of natural humidity above the ground water level, coarseness of grain and hygroscopicity, plasticy, arrangement of grains of different coarseness on the varves, i. e. whether the coarser and finer materials are mixed together or arranged in separate layers, and in the latter case, whether these layers of definite coarseness of grain limit each other with sharp lines or by gradual transition.

[1]) E. A. Antevs, The Recession of the last ice sheet in New England, Amer. Geograph. Soc., Research ser. No 11, 1922, p. 48.

These characters may be determined separately in each varve, but this would require very much time and labour. To identify the varves it is not necessary to determine all characters, as they are often recognizable from a few or only one. Another very important circumstance is this: The characters are mostly constant not in a single varve only, but in a number of immediately subsequent varves, whereas some other series of varves may show entirely different characters. In other words, we may separate different *varve series* each of which includes varves physically very similar, but different from the varves of the neighbouring series. These different varve series each of which represents a distinctive *facies* are over wide though limited areas much more constant than the variation in thickness of the individual varves. A fact that renders it very easy to connect varve series is their small number. Even the thickest sections in southwestern Finland, containing several hundred individual varves, do not include more than from three to six varve series. Thus, instead of having hundreds of possibilities, as when connecting individual varves, from diagrams, the number of possibilities is reduced to a few, when whole series of varves are connected. This kind of connection of sedimentary series is exactly the general method of *stratigraphic correlation.*

The stratigraphical correlation of late glacial varve sediments differs from other related problems in so far as their correlation may be carried much farther. It is possible, in any varve series that has been identified in sections of different localities, to identify the individual varves also. This may be done either in the same way as in correlating whole series of varves by direct determination of the characters of individual varves, as many individual varves really show some distinctive characters, or by using the variation of their thickness only, provided this way proves satisfactory. The best results may be achieved by both methods combined.

For exact measuring of the varves and determination of their characters in the laboratory it was found absolutely necessary to collect samples of the whole sections, showing the varve series in undisturbed arrangement. These samples were taken in metal cases, 50 cm. long, 5 cm. broad, and 2 cm. deep. This method has been found very convenient, and the samples are well preserved for ever.

By thus making *first* the correlation of *larger*, and then of *successively smaller* units of sedimentation, the probability of error is reduced as far as possible. Each connection is checked from several sides, being based upon not one but several characters which are in part independent of each other. It is then always possible to tell whether the connection has reached the accuracy of single varves or whether the possible error remains larger, and how large it is. Connection based upon variation in thickness only affords no check of this kind, and the amount of possible error can not be estimated at all.

A restriction of this method is involved by the fact that the physical characters, or facies, may change from place to place. Therefore correlation in this way is practicable in continuously investigated areas only. Sediments from separated areas, as a rule, can not be correlated by a comparision of their physical characters.

An example of correlation. — The application of these general principles will be exemplified by the connections that will be described in the following. A description of a well developed section may, however, be anticipated here in order to give the reader an idea of the general nature of the varve sediments from the point of view of correlation. We chose the exceptionally thick sections near Jokela, (localities 138 and 139 on map Pl. VIII) on the east line of the special area of the present investigation. Their chronological evidence was used in my earlier study, and we shall have in this paper several opportunities of applying these observations to some other interesting problems.

Fig. Pl. and II show the appearance of one among the beautiful clay sections near Jokela in the Kolsa brickyard (loc. 138). It has been opened here to a length of 100 m (fig. 1), but may be followed in other directions several times as far. Fig. 2 Pl. II shows a detail of the same section. The thickness of the sections varies between 2.5 and 4 metres. The varve sediments also continue about 2 m. downward, though this lower portion is not visible in the pictures. The substratum is unstratified drift, in places rock. Four larger uniform series of varves, or *horizons*, may be distinguished in this deposit (Cf. Südfinnland, Plate IV):

The lowest horizon, aSs, (See Pl. IX) is between 100 and 150 cm. thick. The lowest varves are between 10 and 4 cm. thick and composed chiefly of rather coarse materials, as sand and silt. The upper varves are thinner and contain larger amounts of clay.

The second horizon, ISs, is about 125 cm. thick. The varves are between 1.5 and 0.3 cm. thick and, in their natural state of humidity, difficult to distinguish, so that the whole bed appears homogeneous. A closer investigation, however, proves that the material is comparatively coarse, silt and silty clay, its hygroscopicity being 4.8 (see below p. 17). The third varve from the top of this horizon is exceptionally thick and composed in part of sand and gravel (Südfinnland, Pl. IV). It is visible in the pictures. This varve is supposed to have a special significance for the late glacial history of the Baltic Sea.

The third horizon, iSs, lying upon the preceding, is 120 cm. thick and is in its whole thickness visible in both pictures. The varves are sharply marked. This horizon may be divided into three smaller varve series of which the middle one is darkest while the lowest and, still more, the uppermost are lighter. The differences in the tint depend upon the relative thickness of the dark clayey upper parts (the finer layers). They form the main portion of the varves in the middle and lower series. The total varve thickness reaches from 1 to 1.5 cm. The average hygroscopicity is 8.8. In the upper series the varve thickness varies between 0.4 and 0.6 cm. and the dark finer layer is meagre. The low value of hygroscopicity, 3.0, proves clay substances to be present in far smaller amount than in the other series.

The fourth and uppermost horizon, IISs, strikes one even in the pictures by its dark colour and peculiar structure. The varves are from 4 to 2 cm. thick and consist chiefly of the finest clay substance, the hygroscopicity being as high as 12.

These varve series may be easily followed along the sections. It may be seen that their characters are primary and not dependent upon their distance from the surface, or upon the action of ground water, as they maintain their characters and their mutual positions in the central portion of the clay-filled basin, where they are below the ground water level, as well as in the marginal portions above the ground water. At the margins, one of the upper series ends after another until, on the hill slopes, the lowest sandy horizon alone remains. The individual varves also are wholly constant, just like the larger units. Each of them has its own characters by which it may be identified and distinguished from the neighbouring varves: The relative, and, over small distances, even the absolute thickness remains nearly the same; a certain varve may have a thick and dark-coloured clayey finer layer, another a thin and light, while in a third one a thin light band consisting of coarser material may divide the finer layer into two separate portions, and so on. All small details remain surprisingly constant even over long distances. Thus the same horizons and individual varves may be recognized in the section at the Jokela brickyard (loc. 139), about two kilometres south of Kolsa, the locality described above.

When the corresponding varves in both places are correlated down to the bottom, it appears that the southern locality 139 has a greater number of varves than the northern locality 138, and that the surplus varves belong underneath the lowest varve of the latter locality. This proves that the clay varves have that overlapping arrangement postulated by the well known theory of De Geer. Farther north, again more varves from the bottom disappear. Thus, north of the town Lahti, inside the First Salpausselkä, two, and at Leppäkoski, at the outer margin of the Second Salpausselkä, three of the lowest varve series have dropped out, and the sediments there start with that series which is uppermost in Jokela. By considering the position of the varve series, we arrive at the conclusion set forth in my earlier paper (Südfinnland) that the proximal margin of the uppermost varve series of Jokela lies at the Inner, or Second, Salpausselkä, (hence the designation IISs), that of the middle series in the area between the two Salpausselkäs (»inter-Salpausselkä», iSs) that of the lower dark series at the Outer, or First, Salpausselkä (ISs), and finally that of the lowest, coarse grained series between the First Salpausselkä and Jokela (»ante-Salpausselkä», aSs).

The Jokela sections also illustrate the fact that the correlation of varves and varve series is rendered the more conclusive and easy, the thicker the sections are. I therefore endeavoured to use large sections whenever it was practicable. The skeleton of the whole stratigraphy and chronology consists of such sections. They need not be situated close to each other, in order to afford a reliable connection, provided the number of varves in them is large enough and that the characters of the varves are constant. For local investigation, even smaller sections are serviceable and are then connected with their larger neighbouring sections. If, on the other hand, the characters, or the facies, of the varve series begin to change from place to place, as is the case in certain parts of our area, it is necessary to have observations made closer to each other, even if the sections are large, in order to follow the gradual changes.

Characteristics of the Varve Sediments.

Coarseness of grain is the most important character of sediments. Many others, as colour, plasticity, and water content, depend directly upon it. Two ways of exact determination of the grain are practicable; they differ entirely from each other and their results are expressed in different units. Being thus supplementary to each other, they may suitably be used simultaneously. One way is (1) to make a mechanical analysis and the other (2) to determine the hygroscopicity.

(1). The mechanical analyses are carried out as follows: The sample is well mixed and carefully ground. 100 grm. of it are weighed up, boiled with water during several hours, and thereafter treated with ammonia to remove the organic substances possibly existing and cementing the particles. The grains of differend sizes are then separated with the aid of Atterberg's sedimentation apparatus[1]) which

[1]) A. Atterberg, Die mechanische Bodenanalyse und die Klassifikation der Mineralböden Schwedens, Intern. Mitt. f. Bodenkunde Bd. II, 1912, pp. 319—323.

imitates natural sedimentation. The clay is first allowed to settle during 16 hours from a water column 20 cm. high (or during 8 hours from 10 cm.). Particles smaller than 0.002 mm. in diameter remain suspended in water. These are now removed together with the water and separated. The precipitate is again mixed with water and the treatment is repeated several times, until all particles of that size have been separated. Perfect separation of the finest portion sometimes requires a time of more than a month. The remaining coarser portion is allowed to settle during $7\frac{1}{2}$ minutes from a water column 10 cm. high, whereby the particles smaller than 0.02 mm. in diameter remain suspended. The last settling lasts 30 seconds from a 10 cm. water column, whereby grains of less than 0.1 mm. in diameter are separated from still coarser materials. The separation was never carried farther, because the amount of coarser material in the sediments investigated was always so small that the continued treatment of the residue would not have given any useful results.

The mechanical analysis thus implies a separation of the material into groups of different coarseness, and the percentage amounts of these groups are determined. This method is useful for the determination of coarser material, but, as particles smaller than 0.002 mm. in diameter cannot be separated farther, at least not in any sufficiently short time, such determinations do not give any true idea of the coarseness of the grain of clayey sediments in which the finest materials are most characteristic.

(2). The mechanical analysis may be supplemented by the *determination of hygroscopcity*, developed in the last years and so far little used. Hygroscopicity is, according to the definition of Mitscherlich[1]), the amount of water covering the surface of the particles of soil as one single layer of molecules. The weight of a molecule of water is, according to Nernst, $8.3 \times 18 \times 10^{-22}$ mg. Supposing that the water molecules have the shape of cubes and that they cover the surface of the particles as a continuous layer, the area of 1 mg. of soil may be calculated from the following equation:

$$F = \frac{Wh}{\sqrt[3]{8.3 \times 18 \times 10^{-22}}} \, mm^2$$

or, if the hygroscopicity Wh be expressed per cent in 1 gram:

$$F = Wh \times 40.6 \text{ m}^2.$$

[1]) E. A. Mitscherlich, Bodenkunde für Land- und Forstwirte, Berlin 1913, p. 70.

According to the investigations of Vageler[1]), however, the soil particles do not absorb one but 200 layers of molecules of water. The absolute area of the soil consequently should be really one two hundreth part of what the above equation gives, and the correct equation should be:

$$F = Wh \times 0.203 \ m^2.$$

Odén[2]) has furthermore demonstrated that the amount of hygroscopic water is not only dependent upon the total surface area of the soil particles, but also on the chemical nature and constitution of the soil. But when these characters are constant, the hygroscopicity and the surface area of the particles determined by other methods are fairly proportional. Therefore the method of determining the hygroscopicity is well applicable to clays which are all chemically very closely similar to each other, as they are in the area investigated.

The difference in the methods of calculating the absolute surface area of the soil particles does not matter much for our present problem, as the *hygroscopicity is, in any case, inversely proportional to the coarseness of grain, or increases as the grain decreases.*

In practice, the determination of hygroscopicity has been carried out in the following way: About 20 grm. of the material are ground fine and kept for 5 hours in a steam bath in vacuum with phosphorus pentoxide. The sample is thus made completely dry. It is then weighed and placed under reduced air pressure over a 10 per cent aqueous solution of sulphuric acid, and kept so, once renewing the acid, for 5 or 6 days. The material has now taken up its maximum amount of water and is weighed once more. The difference between this and the first weighing gives the amount of water absorbed, which is expressed as a percentage of dry substance. The figure thus found expresses the *relative hygroscopicity* and is inversely proportional to the coarseness of grain. Coarse grained sediments have low hygroscopicity, fine-grained have high. In the Finnish varve sediments the variation ranges between 0 and 17.

Determinations of hygroscopicity give account of the average coarseness of the soil. In particular, they indicate the amount of the finest particles, the colloidal substances which are characteristic of the fine-grained soils. Compared with the crude method of mechanical analysis which often gives indefinite results, the determination of

[1]) Vageler, Fühlings Landw. Zeit. 1912, p. 18.

[2]) Sven Odén, Note on the hygrospicity of clay and the quantity of water absorbed per surface unit, Transactions of the Faraday Society, vol. XVII, 1921. p. 11.

hygroscopicity is very sensitive, and its results are good characteristics for the study of the mode of origin of the sediments.

The coarseness may also be estimated from some other character depending upon the coarseness:

(1.) The coarseness of sediments appears, to a certain degree, from the amount of shrinking when the material is dried and loses its natural moistness. Coarser sediments hardly shrink at all, whereas fine stiff clays may show a linear shrinking of from 4 to 13 per cent. Thus the different parts of a varve shrink differently, the finer layers more and the coarser less. In clay samples preserved in metal cases, therefore, the homogeneous layers may fall apart from each other, and the coarser layers protrude over the shortened finer layers. Or it may happen that the varves bend, the finer layers pointing to the concave side.

(2.) The degree of coarseness of grain may also be estimated from the colour, coarser materials, as a rule, being lighter, and finer materials darker, the darkness apparently increasing with the fineness. The finest, very dark grey clays have a peculiar intense lustre on cut surfaces.

(3.) A crude estimation of the degree of coarseness between wide limits may finally be made by testing with the finger. In coarse material, the particles fall apart, a little finer powder feels floury, but the very finest material is hard, or *stiff.*

The variation in coarseness in sections through sedimentary beds may, therefore, be very satisfactorily established by exact quantitative determinations in a few varves of each series, and by comparing with them the varves not studied exactly, by the cruder methods just described.

Colour. The colour of sediments in part depends upon secondary changes, as weathering, precipitation of iron oxides and humus etc. Such phenomena have not been considered in this study. In part the colour is connected with the degree of coarseness, as mentioned above. It is then a primary character; variation due to this cause is that of lightness or darkness. Increasing darkness with increasing fineness — or more probably with increasing amount of the finest material — can only be noticed in very fine clays showing colloidal characters and having a hygroscopicty higher than 8.

The increase of light absorption with decrease of grain in clays of extreme fineness is an empirical fact. Now, the experimental and theoretical investigation of white paint pigments[1]) has proved that

[1]) H. E. Merwin, Optical properties and theory of color of pigments and paints. Proceedings of the Amer. Soc. for testing materials, XVII, part II, 1917.

V. M. Goldschmidt. De hvite farver i naturen og tekniken, Tidskrift for Kemi no. 23 og 24, 1919.

the diffuse reflection of light and hence the whiteness of paints is at its optimum when the diameter of single pigment grains is between 5 and 1 μ, while still finer pigments appear greyish, owing to the fact that particles whose diameter is smaller than the wave-lengths of light do not effect ordinary reflection. As colloidal clay substances are known to have grain diameters much smaller than the order of magnitude of light waves, it seems very probable that the darkness of such fine clays is due to this cause. The optical phenomena in clays, however, are complicated and other factors may play an additional rôle.

Some clays have true colours of their own (reddish, violet, or brownish). These, combined with the variation in darkness, may lend the sediments various shades. Disseminated carbon sometimes gives the sediment a dark, dull, non-lustrous hue.

Plasticity is the formability of clays. It may be determined, according to Atterberg[1]), by its (1) flow limit, i. e. the amount of water (per cent of dry material) present when the clay just declines to flow when moved and (2) rolling limit, i. e. the amount of water present when the material rolled as slender rods just begins to break. The difference between the two figures indicates the extension of formability and has been defined as the expression of plasticity. It may rise, in very fine clays of the areas investigated, to 40.

Chemical composition of the varve sediments in Southern Finland is very uniform all over the area, as appears from the investigations of Benj. Frosterus and B. Aarnio, published in the reports issued by the Geological Commission of Finland. Some representative analyses of primary sediments unaffected by surface weathering are quoted below.

	1	2	3	4	5	6	7	8
SiO_2	54.90	52.80	62.70	56.90	78.65	44.90	48.40	57.00
Al_2O_3	16.21	17.56	14.65	17.10	8.30	17.85	18.29	17.50
Fe_2O_3	8.94	11.06	6.55	7.68	3.52	10.30	12.13	8.95
MgO	2.89	4.00	2.19	2.74	0.78	3.71	4.13	3.03
CaO	4.72	2.50	2.14	1.60	8.96	1.48	1.70	1.45
Na_2O	4.55[2])	4.64[2])	3.36	2.22	2.73	1.92	2.19	1.72
K_2O			2.87	3.76	2.74	2.44	3.67	4.66
TiO_2	—	—	0.82	—	—	—	—	—
P_2O^5	—	—	0.30	1.18	—	0.11	—	—
SO_3	—	—	0.20	0.58	—	0.02	—	trace
Cl	—	—	—	—	—	—	—	trace

[1]) A. Atterberg, Mineraljordarnas klassifikation efter deras konsistensformer, Kungl. Landbruksakademins Handl. och Tidskrift. 1915, p. 497—532.

[2]) From difference.

CO_2	1.06	—	—	—	—	—	—	—
Absorbed water ..		3.12	—	—	—	—	—	—
Loss on ignition	7.52	4.34	4.97	6.77	1.59	17.28	10.87	6.02
	100.00	100.00	100.75	100.53	100.27	100.01	100.87	100.33

1. Lime-bearing varve clay, glacial?, Haraldsby, Aland. Analyst W. Y. A. Hall. Benj. Frosterus, Det finska lermaterialet som geologisk och teknisk produkt, Geol. Komm. Finland, Geotekniska Meddel. N:o 6, 1909, p. 16.

2. Varve sediment, glacial, Puolimatka, Tampere, Analyst W. Y. A. Hall. Benj. Frosterus, op. cit. p. 16.

3. Varve clay, Särkjärvi, Karjalohja. Analyst B. Aarnio. B. Aarnio, Agrogeologisia karttoja N:o 1, 1916, p. 15.

4. Varve sediment, stiff clay, and

5. varve sediment, silt, Gumnäs-Odnäs militieboställe, Pojo. Analyst B. Aarnio. Benj. Frosterus, Agrogeologiska kartor N:o 2, 1916, p. 31, 29.

6. Varve sediment, stiff clay, Ruotsula Valkeala (near Kymi river). Analyst B. Aarnio. B. Aarnio, Vanhat kauramaat, Suomen Geol. Komm. Geotekn. Tiedonantoja N:o 29, 1921, p. 11.

7. Varve sediment, stiff clay, Mustiala, Tammela. Analyst B. Aarnio. B. Aarnio, Agrogeologisia karttoja N:o 3, 1921, p. 13.

8. Varve sediment, stiff clay, locality 59 Loimaa. Analyst E. Ståhlberg, made for the present investigation.

The differences noticeable in the primary sediments are parallel to differences in coarseness.[1]) The coarsest sediments are rich in quartz and feldspar and may contain as much as 80 per cent SiO_2, whereas the finest clays may contain only 44 per cent SiO_2. The latter are richest in alumina containing up to 20 per cent Al_2O_3, and also richest in ferric oxide, potash, and magnesia. An analogous correspondence between chemical composition and coarseness has also been noted in the Swedish varve sediments by Tamm.[2])

The Finnish varve sediments are invariably free from carbonates, except those of Aland which contain about one per cent CO_2.

Classification of Varve Sediments.

The basis of classification. — Each kind of sediment is composed of materials of different coarseness, but a certain class dominates

[1]) Cf. Benj. Frosterus, and B. Aarnio, op. cit.

[2]) Olof Tamm, Markstudier i det nordsvenska barrskogsområdet, Medd. från Statens skogsförsöksanstalt, häft. 17, 1920, p. 89.

and gives the sediment its main characters. It may therefore serve as a basis of classification for the varve sediments, as for the other soils. The classes of coarseness accepted for International use by the Session of the International Commission for the Mechanical and Physical Study of Soils, in Berlin, Oct. 31st 1913[1]) are as follows:

1. >20 cm.
2. 20—2 cm.
3. 2—0.2 mm.
4. 0.2—0.02 mm.
5. 0.02—0.002 mm.
6. $<$ 0.002 mm.

A grouping according to the dominant class of coarseness, using these divisions, leads to a classification very convenient for the present purpose, as the different groups may, as a rule, be distinguished by an ocular examination, and quantitative determinations are not always necessary. This classification shows resemblance to some others proposed in America[2]), with regard to finer sediments especially to Udden's classification[3]).

The English terms are those generally used for the corresponding groups.[4]) In the case of the finest sediments, however, the clays in a restricted sense, it seemed appropriate to use, as a basis of farther division, not the direct coarseness, but other more easily determinable characters depending thereon. Instead of »coarse clay» and »fine clay», they may be called *silty clay* and *stiff clay*.

The classification applied thus assumes the following aspect:

1. *Gravel.* Diameter of the pebbles more than 2 mm.
2. *Sand.* Diameter of grains between 2 and 0.1 mm.
   a. *Coarse sand.* Between 2 and 0.5.
   b. *Medium sand.* 0.5—0.2.
   c. *Fine sand* (Swedish *mo*). Between 0.2 and 0.1 mm.

3. *Silt* (Swedish »mo» and »mjäla»). Dusty soil, chiefly composed of grains between 0.02 and 0.002 mm. in diameter, not plastic, does not contain appreciable amounts of clay. Hygroscopicity from 1 to 3.

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[1]) Intern. Mitt. f. Bodenkunde Bd. IV, 1914, p. 3.

[2]) Chester K. Wenthworth, A scale of grade and class terms for clastic sediments, Jour. Geol. Vol. XXX, 1922, pp. 377—392.

[3]) J. A. Udden, Mechanical composition of clastic sediments, Bull. Geol. Soc. Amer., Vol. XXV, 1914, pp. 657—658.

[4]) I am greatly indebted to Professor C. H. Wentworth of the state University of Iowa, U. S. A., for valuable advice concerning terminology.

4. *Clay.* Plastic soil whose physical characters are controlled by the presence of material of the fineness of colloidal substances.

   a. *Silty clay.* Feels floury in dry surface, being easy to powder. Plasticity from 8 to 15. Hygroscopicity from 4 to 8. Linear shrinking from 0 to 4 per cent.

   b. *Stiff clay* (Swedish styvlera). Feels stiff and hard, and not floury, in dry condition. Cut surface lustrous. Plasticity more than 20. Hygroscopicity more than 8, linear shrinking from 4 to 13 per cent.

   In the finest and, at the same time, stiffest clays, plasticity may be as high as over 35, and hygroscopicity more than 10.

Chapter III.

The Observations.

Remarks on the maps and plates. — The method of investigation outlined in the preceding chapter involves a minute study of sections in the sediments, and it is necessary first to present the whole material of observation.

In the following description of the sections investigated, as well as in the maps and plates, the localities are designated throughout by the same numbers.

The most important and representative sections (marked by D after the names of localities) are represented by diagrams indicating the variation in thickness of the varves (Plate X). These diagrams have been made in the same way as in previous geochronological works, except that the finer layers, or »winter layers», when well developed, have been indicated separately and marked black.

In the diagrams, corresponding varves have been placed on the same vertical line. The diagrams are arranged in a manner which accords as far as possible with the geographical distribution of the sections, in the following way: The sections farthest southwest of the principal line along which most of the sections studied are situated, which runs from southern Häme in a northwesterly direction toward the town Ikaalinen, are placed on the lower half of the plate, while the sections northeast of the line are placed on the upper half.

The starting point of the chronology has been placed, as in the earlier study, at the first varve above those formed during the period of the Second Salpausselkä. Thus the corresponding year is year O, and the subsequent years are + years, the sign +, as a rule, having been omitted. Every tenth varve in each diagram has been united by a vertical line with corresponding varves in the other graphs.

Each diagram expresses the variation in the varve thickness in the section from the bottom upward (in the diagrams from the right to the left). As pointed out in the preceding chapter, the conformity or, still more, lack of conformity of the graphs does not always indicate, whether they have been placed correctly or not, or, in other words, whether the connection is right or wrong. Other characters of the varves must be determined to make the connections reliable. The graphs, however, give account of several other features which will be discussed later on, and the arrangement of the graphs in the form of plates has the advantage of affording a synoptical view of the stratification of the sediments.

Description of the sections. — In the following the more important localities, as 1 Leppäkoski and 2 Högfors, and a few others, will

Fig. 2. Section in varve clay. Loc. 1 Leppäkoski, the Sipilä brickyard. 1918, Photo M. Sauramo.

be described in detail, while the observations made in the other sections will be listed as briefly as possible.

1. Leppäkoski. D. Railway station about 2 km. southeast of recessional moraines belonging to the series of the Second Salpausselkä. Three large brickyards: Leppäkoski south of Puujoki river, and Sipilä (See fig. 2) and Rauhaniemi north of this river. Investigations were carried out especially in the two last-named places, and the sketch-map (fig. 3) gives a general view of them. Sections made in laminated late glacial sediments have in all a length of several kilometres, and the distance between the points farthest from each other in the sections of Rauhaniemi and Sipilä is 800 m. The clay field is about 88 m. above sea level. The depth of the section varies between 2.5 and 4 metres, but the total thickness of the clay deposits is more than 10 m. Except for a few local disturbances, the strata have been

Fig. 3. Map showing the brickyards of Leppäkoski, 1921. 1 varve sediments; 2 eskers; 3 isohypses, equidistance 4.2 m.; 3 boundary lines between farms; 5 edges of the clay pits; 6 line showing the position of the cross section ABC DEFG, fig. 3 and 4; 7 levelling points; 8 railroad; 9 small railroad of the brickyards; 10 highroad.

preserved in their original positions; in the uppermost parts which belong to sediments later than those whose chronology is considered in this paper, there is, however, some contortion of the beds. Leppäkoski is one of best clay sections investigated and affords the best material not only for the study of stratigraphy and chronology but also for the investigation of the structure of a most typical varve sediment.

The cross section of the sediments at Leppäkoski (figg. 3 and 4) gives an idea of the different varve series present.[1]) The substratum consists of stratified drift which, on both sides, rises as small hills. The surface of this basement of the clay deposit is somewhat uneven. The cross section shows a ridge of drift under the clay. The stratified sediments include three larger varve series which may be designated, from the bottom upward, with numbers 1, 2, and 3.

1. The lowest series is exposed at the surface on both flanks of the valley, near the drift ridges, but is covered by other series in the central parts of the valley. At the ridge under the clay mentioned above, it is nearer the surface. This series is from 5 to 8 m. thick, and its individual varves measure from 15 to 1.2 cm., being much thicker than usual. The number of the varves is exactly 200. The coarser layer constitutes by far the largest part of the varve. It consists of sand and silt and has a sharp boundary against the finer layer which consists of finest clay substance, of a dark violet colour which gives the whole sediment a dark tint. Hygroscopicity in the uppermost varves is 7.40. The whole Leppäkoski lowest series is bounded in the northwest by the Second Salpausselkä, or belongs to horizon IISs (except a few of the lowest varves).

2. The second series occurs in the largest part of the valley between the two eskers, but in its central part it is covered by still younger sediments (see the cross section). It is about 2 m. thick and light

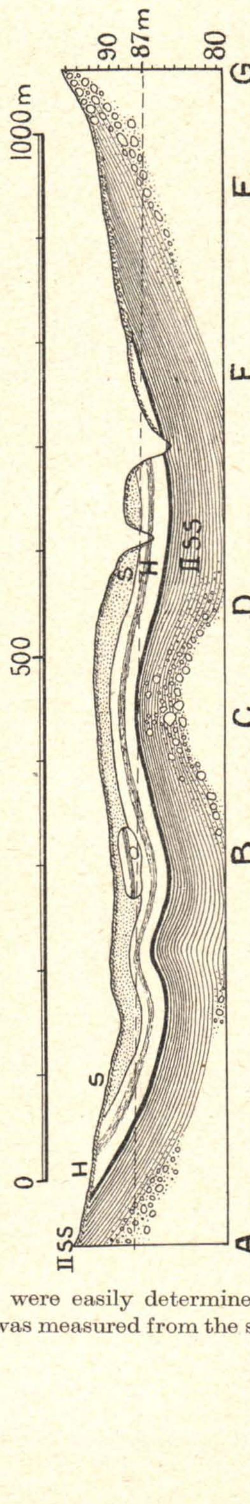

Fig. 4. Cross section through the varve sediments along the line ABCDEFG (see the map fig. 3). The designations IISs, H, and S refer to the horizons of sediments.

[1]) This cross section through clay deposits, more than one kilometre long, has been studied, for the most part, in the walls of the clay pit and in excavations on its floor. The rest was drawn from borings made by Mr. Luther, civil engineer, in the clay area at regular rectangular intervals of 40 m. The different varve series were easily determined from the bore samples, and the depth of each series was measured from the surface.

gray in colour, owing to the thick, light coarser layers which mainly consist of silt. In comparison with these layers the very much thinner finer layers, consisting of fine clay, are rather inconspicuous. The proportion between the finer and coarser layers of the varves, and the colour of the sediment, is not, however, the same throughout this series. Varves 100—180 in its central part have somewhat darker, finer layers, and hence the sediment, as a whole, has here a darker, tint. These dark layers are perfectly dull, unlike the finer layers of the common kind of sediment which is rich in the finest clay and always more or less lustrous.

According to chemical analyses made by Mr. Lönnroth in the Laboratory of the Geological Commission, a bulk sample of these varves contains 0.29 per cent carbon, and the finer layers alone 0.60 per cent. In the lighter lower varves the corresponding figures are 0.28 and 0.35. The total quantity of carbon is therefore about the same[1]) in the light and dark clays, but in the latter it is mainly concentrated in the finer layers, giving them a dark hue. When this dark material is suspended in water, there appears upon the surface a dark, foamy layer never observed under other circumstances. Examined under the microscope this substance appears to contain dull black opaque particles between 0.01 and 0.06 mm. in diameter. When treated with concentrated sulphuric acid and potassium bichromate these particles evolve gas bubbles. — It is not possible to say anything about the origin of this carbonaceous substance, except that it clearly appears as a primary constituent of those varves in which it occurs.

The variation in varve thickness remains remarkably constant in all parts of the sections, although the variation is small, as may be seen from the diagram in Plate X. The first 200 varves are on an average 0.8 cm. thick, the thickest being 1.6 cm. The next 100 varves vary between 0.5 and 0.4 cm. and the uppermost varves are about 0.1 cm. The number of these last mentioned thin varves is approximately 230. Exact counting is rendered difficult by the presence of two bands of fine and very plastic non-laminated clay in the upper part of this series.

The average coarseness of the material of this series appears from determinations of hygroscopicity, made on three different groups of varves. The results are as follows:

	Hygroscopicity
Varves 75—90[2])	3.35
» 150—200	4.5
» 400—	4.49

[1]) This is approximately the normal amount of carbon present in all the varve clays. It is probably present in the form of humus.

[2]) The numbers by which the varves have been designated are, if not stated otherwise, those given to them in the diagrams (Plate X).

This result indicates that the average coarseness decreases, or at least that the relative amount of the finest material increases upward in the section. The relative proportion of the different classes of coarseness, on the other hand, appears from the mechanical analyses made on the two first-named samples

		Varves 75—90	Varves 150—200
1.	> 0.2 mm.	0.04	1.3
2.	0.2—0.02 mm.	3.1	7.3
3.	0.02—0.002 mm.	67.3	46.0
4.	< 0.002 mm.	28.8	45.3

According to these analyses, the portions of finer grain are more abundant in the upper than in the lower part of this series, which agrees whith the results determined by hygroscopicity. The upper part contains, moreover, a *larger amount* of the coarsest material than the lower.

Plasticity in this horizon is very small, owing to the comparative coarseness of the material, being in the lower part less than 1 and even in the upper parts only between 2 and 3.

The clay varves of the series described have been designated as *horizon H*, or the *Häme clay,* their proximal lines being situated in the province of Häme. At Leppäkoski this horizon is very uniform, except for the two dark bands mentioned above. In many other sections which will be described later there occur three different kinds, and therefore horizon H has been divided into three subhorizons: H_1, H_2, and H_3. The boundary varves between these minor groups are varves 291 and 463.

3. The uppermost series at Leppäkoski only occurs in the deepest part of the clay basin, and its margins are exposed on the surface. Its whole thickness is about 1.50 m., the individual varves measuring between 0.3 and 0.2 cm. The material is clearly coarser than that of horizon H and often shows diagonal bedding. The varves have commonly been contorted into small waves, and sometimes thin lenses of sand occur between them (see fig. 5 Pl. IV). The number of the varves has not been determined exactly, as, owing to the small disturbances mentioned, they are not conclusive for chronological study in this place. The sediments of the lower part of this horizon may be designated as *horizon S*, or the *Satakunta clay,* their main distribution and the proximal lines of their varves being in the province of Satakunta.

The last described horizon is locally covered by later clay sediments of a thickness of more than 0.5 m. They are entirely nonlaminated and have not been considered at all in this study.

The normal order of horizons and varves is as described above. In places, however, disturbances have been encountered, as in the south end of the large pit opened in the fall of 1921. This place is visible in fig. 4 at B. The sequence is normal from the bottom to the upper part of horizon H, so that the two above-mentioned dark bands are visible. But above those varves there follows a repeated succession of varves of horizons H and S. The two dark bands appear once more, making it very easy to note the disturbance. The varves are almost horizontal and nearly parallel to the normal series, and they may be traced about ten metres in a horizontal direction. They apparently belong to a block of clay that has moved from some other place in the close vicinity and been placed upon the clay strata at the same time as parts of the latter were removed. The transportation was probably made by some rather big iceberg that dragged over the place during the formation of horizon S.

Connection. The excellent sections at Leppäkoski have a central significance for the late glacial chronology of southern Finland. Their evidence was used in my earlier study Südfinnland, p. 19—20 and in the area now under special consideration they afford a very convenient starting point. A number of clay sections in the vicinity have been connected immediately with the Leppäkoski section; among them are the important sections of 2 Högfors, 4 Pusula, 14 Tuulos, 15 Hauho, 24 Lepaa, 31 Lammasmäki, 32 Iittala, and many others, in fact all the sections in the area except a few localities in the northern part, as the varves spreading out from this tract were not counted in the Leppäkoski sections, although they exist there.

In this place it is also useful to pay attention to the connection of the different parts of the Leppäkoski sections, as this has much interest for the methods adopted. Those long sections well exposed in the walls of the clay pits offer an unusual opportunity of testing the constancy of the characters of clay varves, as it is possible to trace a definite varve over the whole length of the sections without interruption. Fig. 3 Pl. III shows samples of varve series of horizon H taken from two pits in Sipilä and Rauhaniemi, 800 metres apart, connected. Corresponding varves, every tenth marked with its number, have been united by lines. Although photography cannot reproduce differences between dark and light which are very distinct to the eye, and although, on the other hand, a photograph shows many confusing features, as patches and bands due to separation of iron oxide, the pictures give a very good idea of the perfect constancy of the varves even in the smallest details. The reader may compare varves 110—120 in both sections, or the similarity of all features in varves 104—109, and he will be convinced of the possibility of reliable connections on the basis of the structure of clay varves as well as by means of the variation of their thickness.

2. Högfors. D. Brickyard on the south shore of Lake Pyhäjärvi. This lake is situated 75 m. above sea level. The bottom of the strata has not been reached in the deepest part of the section which is below the lake level; in the neighbouring slope of an esker the whole series rises to higher levels. The thickness of the section is 3 m., and more than 300 varves have been counted. Two series may be discriminated:

1. The lower series comprises 292 varves (0—291) with a total thickness of more than 2 m., the thickness of the individual varves varying from 4 to 0.4 cm. The structure of the varves differs from that of those in the corresponding series of Leppäkoski in so far as the finer layers are well developed, of dark brown colour or almost black and lustrous when dry. This finer layer has sharp boundaries against the next upper varve as well as against the underlying coarser layer of the same varve. The proportional thickness of the finer and coarser layers in the varves changes gradually within the series, the coarser layer being predominant in the lower part and the finer layer in the upper part. This gradation is not continuous, however. Varves 125—140 consist almost entirely of dark, lustrous and stiff finer layers and are therefore difficult to distinguish from each other. The varves of the upper part, again, are more distinct, because they have better developed coarser layers. The material, on the whole, is much finer than in section 1 Leppäkoski. This appears still better from the determinations of hygroscopicity, which was found to be, in varves 60—80, 3.9 and, in varves 110—130, 11.5.

2. The upper series consists of dark and very stiff clay, in which the varves are not distinguishable except for a thin portion of its lower part. They are much thicker than the upper varves of the lower series. Farther up the clay is quite homogeneous.

Connection. Högfors is connected directly with loc. 1 Leppäkoski, as seen from the diagrams, Pl. X. The agreement among the graphs is rather good, in places, especially in the first part, and so also above varve 160, until the Leppäkoski varves become too much alike. Other parts of the diagrams have less similarity, e. g. varves 115—135. This connection relies not only upon the diagrams, but also on other characters of the clays, compared in metal cases. The photograph (fig. 4, Pl. III) represents a series of clay varves from both localities connected. Notwithstanding a distance of 45 kilometres and the necessary limitations of photographic reproduction of clay sections, the picture shows a very great similarity between the varve series from those two places. Some varves having special features have been designated by ×. By comparing the corresponding varves it may be noted, moreover, that the relative thickness is not by any means always constant. Thus varves 86—94 are »meagre» in Högfors, but as »fat» as the lower varves in loc. 1 Leppäkoski. According to the connection the lowest varves, from 0 downward, belong to horizon IISs. Their number, so far as may be estimated from the coarseness and thickness of the strata, is at least 10, but hardly more than 20. The other varves belong to horizon H, series 1 being equivalent to H_1, and series 2 to the lower part of subhorizon H_2 (see p. 29).

3. *Pusula Ikkala.* Altitude 45—50 m. Substratum hard drift. The varves, more than 50 in number, are from 5 to 1.5 cm. thick, but not well distinguishable from each other owing to numerous bands of different colour. The finer layers are comparatively thick, reddish and lustrous. The material contains large amounts of finest clay and also sand and silt, which constitute the main part of the material in the lower part of the section.

Connection. Direct connection with loc. 1 Leppäkoski, by diagrams, and by diagrams and structure with section 4 Pusula Ikkala, 2 km. from this locality. According to both connections the lowest varve is — 3, or the locality belongs to the zone of the Second Salpausselkä.

In the neighbourhood of the brickyard there are clay sections in which the varve series continues farther upward than in locality 3, but no bottom was exposed. Their clay is identical with that in the middle part of 2 Högfors. The varves may be connected with part of horizon H_1.

4. *Pusula Ikkala. D.* Altitude about 70 m. Thickness of the section 4 m. Substratum drift and sand. Two kinds of varve sediment, the lower series 1 distinctly laminated, and the upper series 2 nearly homogeneous.

1. Thickness from the bottom 2.5 m. 299 varves counted (— 7 — 291). Their thickness varies from 25 to 0.1 cm. The sediment is similar to that in loc. 2 Högfors, except that varves 125—140, which are there hard to distinguish, are very distinct in this place, the finer layers being well developed. Varves 75, 184, 195, and 196 are remarkable for their thick dark violet finer layers.

2. Dark, stiff and very fine clay in which varves may be distinguished in a few places only. They seem to be about 0.5 cm. thick.

Connection. This section is connected by diagrams and by structure with localities 3, 2, and 1. The correlation of series 1 and 2 with series 1 and 2 of 2 Högfors is confirmed by the agreement of the diagrams, when placed as they are on the plate of diagrams. Series 1 ends in both localities in the same varve, 291. Thus placed the diagram shows, also, a marked similarity to the diagram of loc. 1 Leppäkoski. Series 1, from the eigth varve upward, thus belongs to H_1, and series 2 to H_2. The seven lowest varves still belong to

IISs. The first of them is — 7, or the locality belongs to the zone of the Second Salpausselkä.

5. Pusula Marttila. Clay pit on the southeast side of a great esker, in a gently inclined clay plain at an altitude of 70—75 m. Thickness of the section 1.5 m. Substratum sand. 125 varves counted (41—165). The lower varves thick, between 25 and 5 cm., composed almost exclusively of sand; the upper varves 10 cm. on an average. The structure is exactly the same as in loc. 2 Högfors and 4 Ikkala with reddish finer layers.

Connection by diagrams with loc. 1 Leppäkoski and also with 4 Ikkala. The clay belongs to subhorizon H, the lowest varve being 41.

6. Somerniemi. D. Section 2 m. thick. Altitude 83 m. Substratum sand and drift. 84 varves counted. Two series of stratified sediment.

1. 120 cm.; 78 varves (214—291) from 6 to 1 cm. thick, with material similar to that from Leppäkoski of horizon H_1, having thick, light coarser layers consisting of fine sand and silt, and thin finer layers.

2. 80 cm.; dark, stiff, very fine and plastic clay with thick finer layers and thin coarser layers. The varves are thick, mostly between 2 and 3 cm. Only a few lower varves, however, may be distinguished with certainty, as the clay in the upper part is quite homogeneous.

Connection. This section has been connected by diagrams with loc. 2 Högfors. The congruence of the curves is very satisfactory, and the characters of the corresponding varves thus connected agree perfectly. Similar agreement was found with section 4 Ikkala and many others which will be described later. The connection is therefore wholly reliable, in spite of the small number of varves. The bottom varve is 214.

7. Somerniemi Jakkula. Clay pit on the shore of Lake Oinasjärvi, about 3 km. southeast of locality 6, south of a recessional moraine. Altitude 73 m. The section is about 2.5 m. deep, but the bottom was not found. The stratigraphy in the lower portion has been greatly disturbed by faults and contortion. Among the superposed undisturbed layers the lower, more than 60 in number, belong to series H_1 above which there follows H_2 clay, very like that in loc. 6.

8. Somero. Clay pit, altitude about 100 m. Substratum unstratified drift, the section 1.5 m. deep. Two series of varves.

1. 20 cm.: 13 varves (279—291): from 3 to 1 cm. The material is similar to that in series 1 of sections 6 and 7 Somerniemi, though with a larger amount of silt.

2. The clay of the upper series is similar to that of series 2 in Somerniemi. 14 varves in the lower part are from 4 to 5 cm. thick,

and consist of black and reddish stiff finer layers and thinner coarser layers of silt or fine sand. This coarser band disappears entirely in the upper part of the section, and the clay is therefore homogeneous, first reddish and finally dark gray. The plasticity of this clay reaches as high a value as 40.

Connection. The characters of the sediment are clearly the same as in loc. 6 Somerniemi. The lower series belongs to subhorizon H_1, and the upper series to H_2. The bottom varve is 279.

9. *Perniö.* Section made near a rock exposure in the clay plain. Altitude 12 m. Substratum rock. The number of varves counted 90. The clay is rather distinctly laminated, the thickness of the varves between 20 and 10 cm. The finer layers are comparatively thick, with red and black bands.

Connection. This section has been connected by diagrams with loc. 1 Leppäkoski and others. The lowest varve is 100.

10. Loppi. The village of Topeno. Altitude about 100 m. The late glacial sediments here consist of silt, and sand, but no ordinary clay, and they are not distinctly laminated. They occur, however, in the manner of clay in depressions and not, like ordinary sand, on the slopes of eskers. Such sediments are rather widely distributed, occurring also near the highroad between Topeno and Renko.

11. Lastujärvi. Clay section, 1.5 m. deep, on the shore of the small lake Lastujärvi, which is 105 m. above sea level. Substratum coarse sand upon which has been deposited sand in which no varves can be distinguished, owing to the poor development of the finer layers. In the upper parts the varve structure becomes more distinct. This material is gray in colour and of the same degree of coarseness as horizon H in Leppäkoski.

Connection. The section of Lastujärvi may be easily correlated with horizon H in Leppäkoski. A well developed dark series, including varves 100—180, is visible. The variation of the varves also is clearly similar. The lowest varve that may be determined is 10, but some poorly developed varves may exist below it. No trace of horizon IISs.

12. Vanaja. D. Small clay pit, about 2.5 m. deep. Altitude about 85 m. Substratum unstratified drift. More than 100 varves counted (38—149). The lowest varves very thick, 30—10 cm. and, consisting almost exclusively of sand, not well distinguishable. Going upward the varves maintain a constant thickness, between 0.4 and 0.2 cm. The character of the material in the higher part is similar to that of horizon H in Leppäkoski.

Connection. The varves in Vanaja belong to horizon H; the connection has been described and illustrated by a photograph in Südfinnland, pp. 10—11. The bottom varve 38.

13. Harviala. Clay pit northwest of the Harviala estate and railway station. Altitude 85 m. The character of the material is exactly the same as in loc. 12. The same dark series (100—140) visible. The lowest varves not distinguished.

Connection with Leppäkoski and Vanaja on the basis of the dark varve series. The section has about ten varves lower than the Vanaja section, so that the bottom varve should be between 20 and 30.

14. Tuulos Syrjäntaka. Altitude 95 m. The depth of the sections 3 m. Substratum sand and drift. The lowest varves are from 30 to 0.5 cm. thick, while the upper varves have a uniform thickness of about 0.2 cm. There is, however, a single layer of sand 40 cm thick. resting upon the 231:th varve counted from the bottom of the section (or varve 291 in the chronological scale). This coarse layer is overlain by a series of varves of a total thickness of 30 or 40 cm. The varve sediment is rather coarse in grain, in the lower part consisting of sand, and in the upper part of silt and silty clay. The thin varves are light coloured and lack the ordinary dark finer layers. In varves 100—140 the finer layers are a little darker, though dull, apparently due to the presence of carbonaceous matter, as in loc. 1 Leppäkoski. In the upper part of the section, the coarser material is again more abundant, forming numerous bands, from 0.2 to 0.5 cm. thick, between the varves.

Connection. This section may be easily connected with Leppäkoski and other localities by means of the characters of the sediments. The dark varve series (100—140) which was described from loc. 1 Leppäkoski, 12 Vanaja, and 13 Harviala, is present here also. The variation of the varve thickness also shows a satisfactory agreement with that in Leppäkoski. The bottom varve is 60.

15. Hauho. D.[1]) Clay pit in the village of Hyömäki. Altitude 94 m. Section 2.5 m. deep. More than 450 varves counted. Six different varve series may be distinguished.

1. 1.5 m., 206 varves (106—311); from 40 to 0.2 cm., consisting of coarser and finer sand, silt and silty clay. A few sandy varves occur, as 169 and 295. Hygroscopicity in varves 145—170 was found to be 3.64, in varves 220—250 it is 4.79.

2. 8 cm., 41 varves (312—352) from 0.3 to 0.2 cm., consisting mainly of very fine dark and lustrous stiff clay. A few varves in this series, however, are quite similar to those in the lower part of series 1.

3. 3 cm.; 32 varves (353—384) like those in the upper part of series 1.

4. 12 cm.; 79 varves (385—463); from 0.8 to 0.2 cm. Characters like those of series 2. Hygroscopicity 11.14. Among the dark, thick varves there are a few thinner, light varves like those in series 1 and

[1]) By a mistake, the parts of sections 15 Hauho and 24 Lepaa from the bottom to varve 300 have changed places in the plate of diagrams.

3. In the upper part of the series, all varves gradually assume this character, effecting a gradual transition into series.

5. 11 cm.; 44 varves (464—507); from 0.4 to 0.2 cm., exactly like those of series 1 (upper part) and 3. Hygroscopicity is 5.71.

6. 50 cm.; more than 50 varves (508—), reaching the weathered surface zone. They are much thicker than in any of the former series (except the lowest varves of series 1). The great thickness, on average 1.5 cm., is chiefly due to fat, dark finer layers, though the coarser layer also is thicker than the whole varves of the lower parts of the section. A high hyrogscopicity, 10.96, proves that the average material of this series is very fine.

Connection. Hauho was connected directly with loc. 1 Leppäkoski by means of the characters of the sediments. In this section may be recognized the same dull gray layers as in varves 100—140 in Leppäkoski. It is also possible to identify several individual varves from their distinctive features which are identical in both sections. The diagrams, too, show a good agreement in the lower part of the sections.

The Hauho section includes all the varve series which have been met with in the area north of the Second Salpausselkä, but it is not one of the sections which have served as starting points in the stratigraphic divisions. Its structure being different from that of these sections, the different series (facies) do not, as such, strictly correspond to the horizons separated elsewhere. Thus, according to the connection, series 1 up to varve 291 belongs to H_1, and the rest of this series and series 2, 3 and 4 belong to H_2. Series 5 coincides with subhorizon H_3, and series 6 with horizon S.

The bottom varve is 106.

16. Pälkäne Kukkonen. Clay pit on cultivated fields, 1.5 m. deep. Altitude 100 m. Substratum drift. 4 different series:

1. 90 cm.; about 230 varves (174—403), from 2 to 0.3 cm. Exactly similar to the lowest part of the former section (Hauho).

2. 8 cm.; 40 varves (404—443), from 0.5 to 0.2 cm. This series is similar to series 2 and 4 in the Hauho locality (15), though the finer layers are less well developed. See fig. 6 (b) Pl. IV.

3. 11 cm.; 64 varves (444—507), from 0.2 to 0.1 cm. Exactly like series 5 in Hauho.

4. About 45 cm. sediment with distinguishable varves, (508—); from 1.7 to 0.5 cm. Their characters are the same as those of series 6 in Hauho.

Connection with Hauho and others by means of the characters of the varve series. Series 4 = 6 in Hauho (horizon S); series 3, 2 and 1 belong to H, series 2 being a part of subhorizon H_2. The lowest varves being somewhat indistinct, the varves could not be counted exactly. The bottom varve is between 170 and 175.

17. Luopioinen Aitoo. Clay pit about 4 km. east of loc 16. Altitude about 95 m. Nearly 175 cm. distincly stratified clay overlain by gray, nonlaminated clay. This section resembles very much the preceding locality (see fig. 6 (c) Pl. IV): The series are the same and even the thickness of the different parts nearly identical. The varves corresponding to series 2 in 16 Pälkäne have still less well developed finer layers.

Connection with loc. 16 Pälkäne is easy. When samples of these sections are placed along side, the corresponding varves and varve series may at once be recognized (see fig. 6 b and c Pl. IV). Horizon S in both sections is very striking. The lowest series have the same defect as in Pälkäne, and therefore it could only be determined that the bottom varve is between 130 and 140, but not more exactly.

18. Luopioinen Holja, about 6 km. east of the former. Altitude about 100 m. 1.5 m. stratified sediments, resting upon unstratified drift. 2 different series:

1. 60 cm.; about 355 varves (153—507), from 0.5 to 0.1 cm., consisting of silt and silty clay.

2. 15 cm., 15 varves (508—522), from 2 to 0.5 cm., with thick coarser layers consisting of silt, and thin finer layers.

Connection with the two former localities was based on the characters; series 2 = S, series 1 belongs to H. Bottom varve about 150.

19. Asikkala Pulkkila. On the shore of the south end of Lake Päijänne. Clay pits at an altitude of about 90 m. Sections from 1 to 2 m. thick, with 100—150 varves from 0.5 to 0.2 cm. The material is fine sand an silt, the finer layers being very thin and only a little darker than the coarser layers.

Connection. The clay in these sections belongs clearly to horizon H, being very different from the stiff and dark clay IISs in Anianpelto, 8 km. from this place, on the south side of the Second Salpausselkä (No. 60, Südfinnland, p. 20). Owing to the small variation in thickness of the varves, and the absence of characteristic features, they could not be connected exactly with Leppäkoski.

20. Padasjoki Maakeski. Clay pit on the shore of Lake Päijänne, altitude about 85 m., 2 m. deep, upon rock. 130 varves counted. The material of the lower thick varves is sand, and that of the upper thinner varves silt and silty clay.

Connection. As this section does not include horizon S which is so very conspicuous in many other sections with its thick varves, nor any other recognizable varve series, it cannot be connected exactly. From the diagrams the bottom varve should be 50, but in the absence of other criteria the connection is not quite safe.

21. Padasjoki. Drainage channel in the Church village. Section 1.5 m. deep. Altitude 90 m. Substratum coarse sand. More than 430 varves counted. 2 different series were distinguished:

1. 130 cm.; about 407 varves (100—507), from 3 to 0.1 cm., consisting of sand, silt and silty clay.

2. 10 cm.; 30 varves (508—537) similar to those in the lower series, but their thickness is 0.6 or 0.4 cm.

Connection. By comparing the sequence and structure of the strata with those in the sections of 16 Pälkäne and 18 Luopioinen it may be realized that series 2 corresponds with horizon S, while series 1 belongs to horizon H. As the varves in the lowest series could not be distinguished from each other with certainty, the bottom varve was not determined exactly. It is about 100.

22. Sysmä Otamo Korteinen. D. Clay pit on the east side of Lake Päijänne, at an altitude of 30 m. Substratum unstratified drift. Section in stratified clay 1.5 m. deep, with about 430 varves in all. Two series:

1. 120 cm., 388 varves (120—507), thickness from 3 to 0.1 cm. The material in the lower part is silt, in the upper part silty clay.

2. 30 cm., about 40 varves counted, (508—). They are from 0.3 to 0.8 cm. thick and consist of silty clay.

Connection. This section is similar to those in 18 Luopioinen and 21 Padasjoki. Series 2 is identical with the upper series of Luopioinen belonging to horizon S. Thus connected, the variation diagram, regarding the lower varves, agrees with those of the 15 Hauho and 1 Leppäkoski sections. The bottom varve is 120.

23. Sysmä Church village Rantala. 5 km. west of the former locality, on a level with Lake Päijänne, 78 m. Substratum unstratified drift. This section is like the former.

Connection did not encounter any difficulty, either from diagrams or by comparing the characters of the varves. The bottom varve is 133.

24. Lepaa. D.[1]) Parish of Tyrväntö, 15 km. northwest of the town Hämeenlinna (Tavastehus). Several clay pits about 1 km. south of the Lepaa Gardening College. Substratum rock and drift. Altitude about 85 m. Another section investigated in the garden of the college. In the former locality the upper part of the clay sediments show some sliding, the strata resting upon inclined surface of rock. Therefore the nondisturbed lower series only could be used. Two series:

1. 75 cm.; 195 varves (103—297), 5—0.2 cm. The light coarser components are prevalent, the finer layers being thin and only a little darker. Thus the structure is similar to that of series 1 of 15 Hauho. One more sandy varve (No. 295) was observed.

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[1]) See footnote p. 35.

2. More than 85 varves, (298—); from 0.15 to 0.3 cm., consisting mainly of very fine dark and stiff clay. Varves 351—382, however, are much like those of series 1.

Connection was based upon the structure and the diagrams. In the lower varves it is easy to find similarities to loc. 1 Leppäkoski as well as to 15 Hauho. The agreement among the diagrams appears from Plate X. According to this connection series 1 to varve 291 belongs to H_1, the rest of this series and series 2 to H_2. Varves 350—385 in the latter series have their equivalent varves in series 3 of Hauho. The bottom varve is 103.

25. Hattula Katinala. Brickyard on the shore of Lake Vanajavesi. Altitude about 80. Depth of the pit 2 m. The bottom not reached. The lower part is similar to series 1 in loc. 24 Lepaa and 15 Hauho (subhorizon H_1), while the upper part has a regular lamination and is dark like series 2 (subhorizon H_2).

26. Hattula Katinala. Clay pit near the railroad. Substratum drift, altitude 90 m. The varves, 50 in number, are from 5 to 1 cm. thick and consist of sand and silt. The lowest of them have been contorted and thrust together. The connection of the varves did not therefore appear practicable. From their characters, however, they seem to belong to subhorizon H_1.

27. Hattula Vuorentaka. Southwest of the large Parola esker. A 50 m. long and 1.5 m. deep section was exposed during drainage work in the summer of 1921. The clay belongs, from its structure, to subhorizon H_1, but there was a break at a certain varve, continuous all through the section. Some varves have been thrust together and contorted. Above and below this level the varves have a regular sequence.

28. Hattula Inkala. Clay pit. The clay clearly belongs to subhorizon H_1, but the sequence of strata in the lower part has been disturbed.

29. Renko. Clay pit near the farm Palavainen near the Renko river. Altitude 106 m. The material is similar to the portions belonging to subhorizon H_1 in the preceding sections, but much coarser. There is sand and silt between the varves, and the finer layers are but very little finer and darker than the coarser layers. The small number of the varves prevents connection with other sections.

30. Hattula Pelkola. Clay pit 1.5 km. southwest of the Pelkola estate. Altitude 86 m. This section is, in all respects, similar to section 26 Katinala. The varves belong, judging from their characters, to subhorizon H_1, but a more exact determination of their age was prevented by the small number of the varves.

31. Hattula Lammasmäki. D. Brickyard south of the Lammasmäki farm. Altitude 86 m. The section is 2.5 m. deep, the series of strata is complete, and the lamination exceedingly beautiful and distinct. 5 different series distinguishable.

1. 100 cm.; 157 varves (135—291), from 6 to 0.1 cm. The material of the lower varves is sand, higher up chiefly silt and silty clay. The average coarseness in varves 200—230 appears from the hygroscopi-

city which was found to be 4.67. This varve series is in all respects perfectly similar to series 1 of loc. 24 Lepaa.

2. 23 cm.; 99 varves (292—390) whose average thickness, 0.2 cm., is a little more than that of the upper varves in series 1. Structure of the varves is different from that of the subjacent series, the finer layers, more than a half of the total thickness, being black and composed of stiff clay. The boundary between the light coarser and the dark finer layers is very sharp and the contrast in their colour makes the lamination exceedingly pronounced. Varves 344—372 have smaller finer portions than the other varves. A few varves, as 294 and 295, have no finer layers at all, being similar to the varves of series 1. As the structure indicates, the grain is much finer than in series 1; a determination of hygroscopicity gave the result 8.81 proving the same.

3. 27 cm.; 73 varves (392—463). Average thickness 0.35, cm., the thickest varves being 0.8 cm. and the thinnest, in the upper part, 0.2 cm. thick. The structure is similar to that in the next lower series, but the dominant parts of the varves are the finer layers, consisting of stiff clay, lustrous in cut surface, while the coarser layer is only a thin band, often almost invisible. It is therefore sometimes difficult to determine the varve boundary. The material consists chiefly of finest clay, as appears from the high hygroscopicity, 14.92, found in a bulk sample of this series. This is one of the highest figures found. In the uppermost part of the series, where the finer layers as well as the whole varves become thinner, there appear some varves without any fat finer layers at all, being similar to the varves of series 1. (See the diagram Pl. X and fig. 8 (b) Pl. V).

According to a chemical analysis, a bulk sample of this series contains 0.62 per cent carbon. This amount is approximately the same as that found in the dull-grey finer layers in loc. 1 Leppäkoski (see p. 28), but the colour is different. This difference is probably due to the fact that the carbon does not here occur as distinct black particles, which apparently give the Leppäkoski clay its dull hue, and the darkness of the Lammasmäki clay may simply be a consequence of the fineness of material.

4. 12 cm.; 44 varves (464—507). Two kinds of varves, some, as 469, 472 and 502, being similar to those of series 3, while all others are exactly like those of series 1 with a thickness of about 0.15 cm. (see fig. 8 (b) Pl. V). In their coarseness they also show resemblance to series 1, as appears from the hygroscopicity, which was found to be 6.52. The exceptional thickness of the fat, dark varves is due to the finer layers, as visible from the diagram.

5. 80 cm., reaching the weathered surface; 53 varves (508—560), from 2 to 0.5 cm. Their finer layers are thick, the coarser layers, in the lower part, very thin but increasing upward (see the diagram). The main part is very stiff clay.

Connection has been based upon the structure of the strata as well as upon the diagrams. In the first place, series 5 corresponds with the uppermost part in the sections of 15 Hauho and 16 Pälkäne (horizon S).

The dark series, 2 and 3, represent subhorizon H_2 and find their analogues in series 2 + 3 + 4 in Hauho. Between these varves and the upper S-clay there exists everywhere subhorizon H_3 with its meagre varves. The lowest series are alike in all the sections mentioned. The boundaries of the series (facies) do not coincide, except the lower boundary of the uppermost series (S). When the diagrams are placed according to this connection, the Lammasmäki section is found to agree very well with sections 1 Leppäkoski and 2 Högfors. A reliable connection with Leppäkoski being of great chronological importance, the diagrammatic connection has been checked by a direct comparison of the sediments, and its reliability has thus been verified. The Lammasmäki section has therefore been connected with the starting point of the chronology, Leppäkoski, directly, as well as via loc. 2 Högfors, 24 Lepaa and 15 Hauho.

The Leppäkoski section in its upper portion, from varve 260 upward, being unsatisfactory, the Lammasmäki section carries the chronology further, as the sections that will be described below may be easily and definitely connected with it.

The Lammasmäki section also belongs to those sections upon which the division of the sediment into horizons has been based. The uppermost varve (291) of series 1 marks the end of subhorizon H_1. Series 2 and 3 form subhorizon H_2, and series 4 subhorizon H_3. Varve 508 marks here, as in the sections loc. 15 Hauho, 16 and 17 Pälkäne, and 18 Luopioinen, the start of horizon S which will subsequently serve as a useful guide in the connection of clay sections.

The bottom varve at Lammasmäki has been assumed to be 135, but it is possible that there are a few varves below this in the sand.

32. Iittala. D. Pit made specially for this investigation 1 km. northwest of the Iittala railway station near the highroad, 2.5 m. deep. Altitude 94 m. At the bottom, sand and drift. The stratigraphy is normal and distinct, the varve series the same as in the former locality from which the Iittala section is at a distance of 7 km. These two sections, situated at the opposite margins of the same lake basin, are alike as twins (see fig. 8 Pl. V) and exemplify the regularity of stratification under uniform conditions. 5 different series.

1. 70 cm.; 104 varves (188—291). The characters of the varves, and the gradual changes in these characters, are similar to those in series 1 of Lammasmäki. Hygroscopicity in a sample from varves 240—260 was found to be 3.71. Mechanical analysis 1 (see below).

2. 23 cm.; 99 varves (292—390). The description of series 2 of Lammasmäki holds good here to the smallest details. A general difference may be noted in a somewhat better development of the finer layers in all the varves. Mechanical analysis 2 (see below).

3. 36 cm.; 73 varves (391—463), from 1 to 0.3 cm., correspond with series 3 in Lammasmäki. The boundaries of the varves cannot be well distinguished in the lower part of this series; to this difficulty is due the fact that the graph, in this part, does not show the same agreement with the Lammasmäki diagram as in the upper part. Hygroscopicity was found to be 14.8. Mechanical analysis 3 (see below).

4. 12 cm.; 44 varves (464—508). Differs but very little from series 4 of Lammasmäki, and in the same direction as series 2. Varves 469, 472 and 489 are here a little thicker and darker than in the former. Hygroscopicity 7.3.

5. 100 cm., reaching the weathered surface, 53 varves (508—560) counted. The varves are appreciably thicker than in the corresponding series in Lammasmäki, chiefly owing to the finer layers, the difference thus pointing in the same direction as in the lower parts of the section. Hygroscopicity in varves 540—550 was found to be 14.71 and, in varves 560—570, 9.47. Mechanical analysis 4 was made on a sample from varves 540—560.

Mechanical Analyses.

	1	2	3	4
Grain	%	%	%	%
> 0.2 mm.	0.8	2.2	6.5	7.0
0.2—0.02 mm.	5.6	8.2	7.0	11.9
0.02—0.002 mm.	60.0	19.8	20.7	17.0
< 0.002 mm.	33.0	69.5	65.0	63.0

Connection appears from the description of the Lammasmäki section. Reproductions of photographs of series 3, 4, and 5, placed along side, may be given to illustrate the similarity (fig. 8 Pl. V). The Iittala section may also be connected by diagrams with the sections 2 Högfors and 1 Leppäkoski.

According to the connection, the sediments at Iittala start with varve 188. Each series belongs respectively to the same horizon as in Lammasmäki.

33. Kuurila. D. Clay pit on the estate of Kuurila, about 1 km. east of the railroad station. Altitude 85 m. Substratum unstratified drift. Laminated sediments 0.5 m.; 2 series:

1. 13 cm.; 49 varves (243—291), from 0.7 to 0.1 cm., like those of series 1 loc. 31 Lammasmäki and 32 Iittala.

2. 35 cm.; 94 varves (292—385), from 1—0.2 cm., like those of series 2 in Iittala. So far as any difference exists, it consists of the still greater relative thickness of the finer layers.

Connection with Iittala (distance 6 km.) is reliable, whether based upon the characters or upon the diagrams. The bottom varve is 243.

34. 3 km. northwest of Kuurila. At the same level as 33. Substratum unstratified drift. Thickness of the clay bed 1 m. 2 series:

The lower series comprises 56 varves (235—291) and corresponds with series 1 of the former, both with respect to the general character of the material and to the individual varves.

The upper series, with about 100 varves, corresponds with series 2 of the former locality.

Connection is evident from comparison of the individual features, or from the diagrams. The bottom varve is 235.

35. Sääksmäki Voipaala. Clay pit on the estate of Voipaala. Altitude 95 m. appr. Substratum coarse sand. 2 m. laminated sediments. 5 series, each of which is like the corresponding series in Iittala.

1.	65 cm.;	73 varves	(219—291),	from	5 to 0.2 cm.
2.	50 »	99 »	(292—390),	»	0.8 to 0.3 cm.
3.	60 »	73 »	(391—463),	»	1 to 0.5 cm.
4.	12 »	44 »	(464—507),	»	0.3 to 0.2 cm.
5.	More than 50 varves counted (508—), from 2 to 0.5 cm.				

Connection. Every series and every varve may be correlated with those of the Iittala section. The bottom varve is 219.

36. Pälkäne Pintele. Brickyard on the northeast shore of Lake Pintele. Altitude 82 m. About 400 varves distinct. 6 series:

1. 80 cm.; 103 varves (189—291) and a few sandy varves underneath. The varves are in all respects similar to those in series 1 in loc. 15 Hauho, 24 Lepaa, 31 Lammasmäki, 32 Iittala etc. (see fig. 6 (a) Pl. IV).

2. 16 cm.; 40 varves (292—331), from 1 to 0.5 cm., like Iittala etc. series 2.

3. 5 cm.; 27 varves (332—358), from 0.3 to 0.2 cm., like the upper part of series 1 (and series 3 in Hauho).

4. 22 cm.; 66 varves (359—424), from 0.8 to 0.4 cm., like those in series 2.

5. 14 cm.; 83 varves (425—504), from 0.3 to 0.1 cm., like those in the upper part of series 1.

6. 75 cm.; more than 60 varves counted (508—) from 2 to 2 cm. Like Hauho 6.

Connection. The sequence of strata is the same as in sections 15 Hauho, 31 Lammasmäki, 32 Iittala etc. It is, like Hauho, intermediate between the sections of the Vanajavesi basin with its typical H_2 sediment and those of Kukkonen and Luopioinen and Padasjoki—Sysmä, in which the finer layers composed of stiff, dark clay are ill developed or entirely absent. This section, however, belongs more closely to the western than to the eastern type. The uppermost series 6 thus belongs to horizon S, starting with varve 508, as in all the former sections (see fig. 6 Pl. IV). Subhorizon H_2 starts with varve 292. The lowest varve counted is 189, but under this there are several others which were not reached because of ground water.

37. Sääksmäki Annila. Clay pit. Altitude 85 m. Section in clay 1.5 m., upon unstratified drift. The section is much like that of 35 Sääksmäki Voipaala which is 3 km. east. The lowest varve is 238.

38. Toijala. D. About 2 km. south of the Toijala railway station, a large clay pit on the Kurvala estate. Altitude 85 m. Substratum sand and drift. The section has been made in regularly stratified sediments of a total thickness of 3.5 m. Three different varve series:

1. 225 cm.; 172 varves, (292—463), from 5.5 to 0.3 cm. The varves are composed almost exclusively of the finest stiff and dark clay, the finer layers dominating and the coarser layers being very thin or almost absent. This is especially the case in varves 390—430 which form a nearly homogeneous clay. In the upper part of this series some varves, again, are without any finer layers whatever. The average fineness is shown by the value of hygroscopicity in varves 390—430 which was found to be 14.45. A mechanical analysis of these varves is quoted below (1). Plasticity is 42, a very high figure.

2. 20 cm.; 44 varves (464—507), without any sharp boundary against the neighbouring series. This series resembles series 4 in Lammasmäki and Iittala (see fig. 7 and 8 Pl. V), including two kinds of

varves, the majority being thin (about 0.2 cm.) and consisting almost exclusively of light coarser layers, while a few varves (e. g. 469, 472, 478, 480, 484, 502 etc.) are from 0.5 to 0.3 cm. thick, owing to well developed finer layers. The lighter varves gave a hygroscopicity 6.36, a mechanical analysis is quoted below (2).

3. The uppermost series is more than 1 m. thick, but only its lower parts have distinguishable varves (508—550). They are thick, from 3 to 1 cm., like the thickest varves in the lowest series, and also like the latter in their structure, having thick finer layers. Hygroscopicity is 14.3. Mechanical analysis 3.

Mechanical Analyses.

Grain	1 %	2 %	3 %
> 0.2 mm.	0.8	3.5	8.9
0.2—0.02 mm.	4.6	5.6	10.8
0.02—0.002 mm.	18.4	28.6	16.9
< 0.002 mm.	77.8	62.2	64.0

Connection. In comparing the Toijala section with those of 32 Iittala and 31 Lammasmäki the corresponding series are found without difficulty. The S-horizon is represented by the uppermost series (3), below it follows H_3 (series 2) and then H_2 (series 1). Figg. 7 and 8 Pl. V shows to what a degree H_3 in Toijala recalls the same series in Iittala and Lammasmäki. Fat dark varves are better developed and even more numerous in Toijala. The agreement among the diagrams is very conspicuous. The bottom varve happens to be exactly the first varve of H_2, or 292.

39. Sääksmäki Metsäkansa. Section 2 m. deep upon unstratified drift. Altitude about 90 m. Over 300 varves counted; 3 series, all being like those in Toijala.

1. 150 cm.; 197 varves (267—463), from 6 to 0.3 cm.
2. 22 cm.; 44 varves (464—507), from 0.4 to 0.2 cm.
3. 75 cm.; about 50 varves visible (508—557), from 2 to 1 cm.

Connection. The series correspond with those of Toijala as mentioned. The bottom varve 267.

40. Sääksmäki Lotila. Section in unstratified drift, in its upper part 1.5 m. stratified sediments. Altitude 90 m. 2 series:

1. 25 cm; 37 varves (255—291), from 1 to 0.3 cm., identical with those in the lowest series in Annila and Voipaala etc., or H_1.

2. 75 cm.; more than 100 varves (292—), from 0.8 to 0.4 cm. Similar to series 2 in Voipaala, belongs to H_2.

Connection. From what was said above and from the connection based upon diagrams, the bottom varve of this section may be determined as 255.

41. Sääksmäki Lotila, clay pit, from loc. 40 2.5 km. toward Lempäälä. Section exactly like, but with a smaller number of H_1-varves, the bottom varve being 263.

42. Pälkäne Paino. Clay pit on the shore of Lake Mallasvesi. Clay and sand 1 m., similar to the two preceding sections. 60 H_1-varves, the bottom varve being 236.

43. Urjala. Brickyard 1 km. north of the railway station of Urjala, at an altitude of 96 m. The wall of the pit is 2 m. high, but the bottom of the sediments is almost 3 m. deeper, below ground water. The varves in the exposed portion are comparatively thin, between 3 and 2 cm., the uppermost varves being thickest and indistinct. The lowest varve series visible consists mainly of stiff and very plastic clay and apparently belongs to H_2. Upon this there is a thin laminated series (H_3) and the uppermost clay belongs to the S-horizon.

44. Urjala Kokko. Clay pits near the highroad. Unstratified drift exposed under the clay. Altitude 113 m. The clay is, from the bottom upward, very similar to that of series 1 in Toijala, but no individual varves can be distinguished.

45. Urjala Saviniemi. The clay is, down to the boundary against the drift, clearly of the H_2-type.

46. Tammela Susikas. Clay pit west of the village. Altitude 120 m. appr. Substratum unstratified drift. The section shows a disturbance of the strata, and it was only clear that the lower part consists of a light clay rich in silt bands, and the upper part of dark and stiff clay without distinct laminae. The former belongs to H_1 and the latter is the lower part of H_2.

47. Mustiala. Large clay pits about 2 km. east of the Mustiala College of Agriculture. The bed of laminated sediments is more than 3 m. thick. Substratum drift. Altitude about 82 m. 2 series:

1. More than 0.5 m. 19 varves (273—291), each between 6 and 1.5 cm. thick. The material is medium and fine sand, and silt. The very thin finer layers only contain some clay.

2. The remaining upper part of the section, 2.5 m. The varves are from 6 to 2 cm. thick, first chiefly composed of reddish, coarser layers with very thin, sharply bounded bands of finer clay. Going upward, the finer layers occupy an increasing portion of the varves until, in the uppermost part, the clay is nearly homogeneous, dark and stiff. The hygroscopicity was not determined, but in samples from another locality near Mustiala, Aarnio found in unaltered clay a

hygroscopicity of 16.64[1]) which is one of the highest figures ever found in Finnish clays. According to information from Dr. Aarnio, and from samples collected by him, this clay probably also belongs to the uppermost part of H_2.

Connection. The lower clay series in Mustiala undoubtedly belongs to subhorizon H_1, and the upper series to H_2. The bottom varve is 273.

48. Tammela Porras. Several clay sections. Altitude about 110 m. Bottom not reached. The exposed sediment is exactly like that in the upper part of the Mustiala section.

49. Forssa. Brickyard. Altitude 96 m. Bottom not found, the clay stratum exposed 3 m. thick. 32 varves counted in a section of 2 m., the average thickness of the varves thus being 6.2 cm., while the individual varves vary between 13 and 4 cm. Still thicker varves (to 20 cm.) were found under the floor of the clay pit. All the varves show the same structure; the most typical of them have three parts; lowest the coarsest material, coarse and fine sand or silt, as a thin light band forming between $^1/_4$ and $^1/_{10}$, or still less, of the whole varve. Above this portion follows another, thinner or thicker than the former, and appearing only in dry material as a violet-gray layer which is chiefly composed of clay. The thickest portion, from $^2/_3$ to $^9/_{10}$ of the whole varve, is black or dark grayish and has a strong lustre on the cut surface. The boundaries between these portions are sharp, the middle layer, however, in some cases passing gradually into the others. In the upper part of the section the lighter layers unite and finally disappear. Such a clay is exceedingly stiff, dark and perfectly homogeneous.

Connection. This clay clearly belongs to subhorizon H_2. As the bottom was not reached and the number of varves is small, its individual varves could not be connected with those of other sections.

50. Humppila Setälä. Clay pit, altitude 110 m. The material is quite similar to that of the upper portion of the preceding section, 49 Forssa.

51. Humppila Railway station. Altitude 108 m. Clay similar to that in loc. 49 Forssa is exposed in a deep drainage trench.

52. Humppila Venäjä. Brickyard. Altitude 108 m. The clay as above.

53. Somero Viluksela. Altitude about 95 m. According to information from the inhabitants, a well pipe was here sunk 25 m. deep into the clay deposits and the bottom not yet reached. The clay in this tract is exactly like that described from loc. 49 Forssa.

54. Turku (Åbo). A section through clay and stratified drift near the Turku-itäinen railway station, east of the city. Altitude

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[1]) B. Aarnio, Geologiska Kommissionen i Finland, Agrogeologiska kartor N:o 3, Mustiala, 1921, p. 29.

15 m. The section in clay was, in 1921, 2 m. thick, and varves, from 5 to 2 cm. thick, could be distinguished in its lower part only, as the clay passes upward into a homogeneous variety.

Connection. This section together with others in the tracts of Turku and Loimaa belongs to a special group differing in certain respects from all the other clay sediments described. The varves are thick, few in number, and uniform. This lack of variety in the individual varves makes it, in most cases, impossible to connect them exactly with those of the sections described above. In the later chapters of this paper these clays will be the subject of special discussion. From their geographical occurrence between the zones in which the H_1- and H_3 clay are known to form the bottom varves, it may be concluded that they belong to subhorizon H_2, comprising varves 300—470.

55. Kärsämäki. Brickyard about 4 km. north of the city of Turku. Altitude about 15 m. The upper part of the section consists of post-glacial (Litorina) clay, below which there is stiff glacial clay, belonging to the same class as the preceding.

56. Turku Iso-Heikkilä. Varve sediments exposed in a railroad section at an altitude of 10 m. The varves are from 30 to 3 cm. thick, and their thickness increases toward the clay plain. The structure is similar to that in loc. 49 Forssa.

57. Uusikaupunki (Nystad). North of the town a small clay pit belonging to a brickyard. Altitude about 5 m. Below the clay, drift and rock. The clay series is 0.5 m. thick and contains more than 30 varves whose thickness varies between 2 and 0.3 cm. They have a grayish finer layer which passes gradually into the lighter coarser layer.

Connection. This section could not be connected with the reference line, the sections of which are far away, but from the position of the locality this clay is most probably one of the varve sediments formed later than subhorizon H_2.

58. Loimaa Kauhanoja. Section near the highroad to Joenperä, in the wall of a trench which is 1.5 m. deep (1921). Altitude about 85 m. Varves are visible almost to the surface, being from 5 to 3 cm. thick. The boundaries of the varves are marked by thin coarser layers, while the finer layers which consist of dark, stiff and very fine clay form the largest part of the varves. The bottom was not exposed, and the varves are few in number; therefore no connection could be made. Probably the clay belongs to subhorizon H_2.

59. Loimaa. Brickyard near the town. Altitude 85 m., substratum unstratified drift. The section exposes a 2 m. thick bed of clay strata containing only nine varves within 1 m. Their thickness varies between 15 and 7 cm. No increase of thickness downward. Their structure (See fig. 10 Pl. VI) usually shows a division into three parts, as in the section 49 Forssa: First reddish silt and clay, and upon it dark gray clay showing a strong greasy lustre on cut surfaces. In the uppermost part, the material is otherwise like that of the middle part, but the colour is quite dark. The boundaries between the different parts of a varve are gradual, while the boundaries between the uppermost layer and the lowest layer of the next varve above are quite sharp. The darkest layers are of almost uniform thickness, in different varves forming between 7/10 and 9/10 of the whole varves. The lowest reddish layers are but thin bands. When the latter, in the upper part of the section, are entirely absent, the varves can be distinguished only by means of the hues of colour in the two other layers, which differ very little from each other. As they sometimes are perfectly alike, the clay may be apparently homogeneous, dark. Fig. 10, Pl. VI represents two such varves, but the lowest reddish and the middle dark gray layer can not be distinguished at all in the reproduction.

Hygroscopicity in the distinctly laminated part of the section was found to be 10.6. A mechanical analysis from the same part gave the following result:

Grain	%
> 0.2 mm.	0.4
0.2—0.02 mm.	2.7
0.02—0.002 mm.	25.9
< 0.002 mm.	72.0

A chemical analysis of this clay was made by Miss E. Ståhlberg with the following result:

SiO_2	57.00
Al_2O_3	17.50
Fe_2O_3	8.95
MgO	3.03
CaO	1.45
Na_2O	1.72
K_2O	4.66
SO_3	trace
Cl	trace
CO_2	0.00
Loss on ignition	6.02
	100.33

No exact connection of the varves could be made, as their number is so small and their thickness abnormally great. The clay is apparently synchronal with subhorizon H_2 in Forssa, Toijala etc. It may be concluded from other neighbouring sections connected with the reference line (as N:o 6, 8, 9, 47, 38, 67, 68, 71) that the lowest varves of this section belong to H_2 a little beneath varve 370.

60. Loimaa. Boring through the laminated clay about 1 km. southwest of the town. Altitude about 85 m. A dry, hard surface zone 1.5 m. deep, thereafter soft, wet clay in the ground water zone. Samples from different levels show a clay similar to that in the preceding locality, but with still thicker varves and occasional sand or silt layers separating the varves. The bottom was not reached with the bore, which was 12 m. long.

61. Loimaa Hirvikoski. Natural section, about 8 m. deep in the bluff of the Loimijoki river. Altitude 81 m. Bottom not exposed. The characters of the clay as before. In the lower part, the varves attain a thickness of 30 cm.

62. Mellilä Isoperä. A pit made for this investigation, 2 m. deep, near the Mellilä esker. Altitude about 94 m. Bottom not reached. The clay is late glacial, but no varves could be distinguished, only reddish bands of clay or silt in the dark, stiff and very fine-grained clay. It is apparently similar to that of the preceding localities, especially of 59 Loimaa.

63. Loimaa Pappinen. Pit near the Workmen's House. Altitude 90 m. The clay is as above.

64. Loimaa Krekilä. In making a tube well for the Anttila farm, at an altitude of 80 m., 30 metres of clay had to be bored through before sand and gravel (and clear water) were reached. The clay is like that of the preceding places and belongs to the late glacial sediments. Litorina clay is out of the question here, the shore-lines of the Litorina sea reaching only the 60 m. level.[1])

65. Loimaa Haaroinen. Brickyard. Altitude 75 m. Bottom not visible. Clay like above.

66. Loimaa Kuninkainen Kolkkala. A section more than 2 m. deep, made on the slope of the river. Altitude about 77 m. A 2 m. thick portion of the clay deposit contains 52 varves, from 5 to 2.5 cm. thick. They are composed of thin, light, sometimes reddish coarser layers which consist of fine sand, silt and clay, and thick finer layers which are black, and consist of the finest stiff clay. The boundary of the lower, coarser component is not sharp in either direction, and the varves cannot therefore be distinguished with certainty.

Connection. This section may be easily connected with the following.

67. Loimaa Kuninkainen Kuitu. D. About 0.5 km. west of the former locality. Altitude about 80 m. The depth of the pit, made

[1]) W. Ramsay, Litorinagränsen i sydliga Finland, Geol. Fören. Förhandl. Bd. 42, p. 257. 1920.

specially for this investigation, was 3 m. In it were counted 60 varves whose thickness varies between 10 and 2.5 cm. Their structure is quite similar to that of the preceding section.

Connection. This section may be connected with subhorizon H_2 of the sections in Central Häme, like the preceding. Connection by means of the physical characters of the clay is not practicable, as the structure of the varves here, as in the nearest of the Häme sections, 38 Toijala, is so monotonous that no other characteristic features than the variation in thickness can be traced. Connection by means of the variation diagrams, on the other hand, is quite reliable, the number of varves (60) being high enough. The same features in the diagram as here may still be recognized in the diagram of the section of loc. 78 Viiala. The bottom varve is 370.

68. Loimaa Rahnunkoski. Section made in the river slope in the summer of 1921 during a clearing of the rapids. Altitude 87 m. appr. The bottom could not be reached, being below the water level, but it was not more than 1 m. below the lowest varve counted, above which 130 cm. of the strata contained 55 varves. The characters of this clay are like those of the preceding section.

Connection. This section may be connected by means of diagrams with 67 Loimaa as well as with 38 Toijala. The lowest varve counted is 478. Considering that this was far from being the bottom varve, the formation of the clay in this place seems to have begun almost contemporaneously with that of the preceding locality.

69. Punkalaidun Kouvola. Section made for this investigation, 1.5 m. deep, substratum unstratified drift. Altitude about 83 m. The character of the clay similar to that of the former, but varves could not be well distinguished.

70. Alastaro Virttaa. Clay pit west of an esker (Virttaankangas). Altitude about 80 m. The characters the same as in the preceding localities.

71. Vampula Sallila. D. The bluff of the Loimijoki river south of the electric power station of Sallila. Altitude 61 m. The lowest varves are sandy and very thick; the substratum could not be reached for water, but the rock is not far. In all 94 varves in a section of 3 m. counted, their thickness varying between 15 and 0.7 cm. and the lowest being still thicker. In their structure the varves are of two kinds. In some of them the grain passes gradually from the light coarser layer to the dark gray finer layer, while in others there is, in addition to this normal finer layer, still another which is black and has a greasy lustre, thus apparently consisting of extremely fine clay. Varves of the former kind, resembling the clay of horizon H in Leppäkoski, are rarer and occur chiefly in the lower part of the section, while the great majority of varves in the upper part are similar to the three-parted varves of 59 Loimaa and 49 Forssa.

Connection. The observations made in the region all around this locality, especially NWN. and NE. of it, prove that the varves of this section still belong to subhorizon H_2, with varves 290—470, although some of the varves have a structure somewhat different from those of the rest. They may be connected with the reference net by means of the diagrams. According to the connection adopted the lowest varve is 405.

72. Säkylä Korpi. Steep erosion bluff at the Pyhäjoki river. Altitude about 58 m. Substratum rock. In the upper part of the section, which is 3 m. deep, the varves are somewhat disturbed. Two series of varves may be distinguished:

1. About 1.5 metres; the clay is almost black, plastic and, in a cut surface, greasy looking: in other words it has all the characters of very fine clay. The varves are between 40 and 30 cm. thick. They are poorly separated from each other by layers richer in silt.

2. The upper series comprises the rest of the section. The first varves have the same thickness as the former, but upwards they become thinner, between 5 and 1 cm. Their material, like that of the lower series, is mainly silt, the clayey finer layers being very thin.

Connection. The lower varve series has clearly the characters of subhorizon H_2, and the upper series probably belongs to horizon S. As the varves of the lower series can not be counted exactly, connection of individual varves is not practicable.

A little farther up in the valley of Pyhäjoki, Litorina clay is exposed in several clay pits, but none of them is deep enough to expose the laminated clay or other substratum under the Litorina clay.

73. Säkylä. Clay pit near the highroad in the village of Iso-Säkylä, altitude about 47 m. Substratum is not exposed, but the lowest clay is sandy. The character of the clay is similar to that of the upper part of the former locality, and it clearly belongs to the strata formed after the deposition of subhorizon H_3.

74. Punkalaidun. Section near the highroad. Altitude 75 m. The number of varves from the earth's surface down to the bottom, which consists of boulders, is between ten and twenty. The clay is like that in sections 58—68 Loimaa etc. It apparently belongs to subhorizon H_2.

75. Vesilahti Halkivaha. Clay pits near the highroad. Substratum glacial gravel. The characters and age of the clay as above.

76. Tyrvää Sammaljoki Kurki. Clay pit, altitude 90 m. Thickness 180 cm. with 65 varves, the lower between 5 and 3 cm. and upper in average 1.5 cm. Their structure is exactly like that in Loimaa. From this fact and from the situation between neighbouring localities which may be connected with certainty, this clay belongs to subhorizon H_2. The diagram also agrees well with those of loc. 71 Vampula, 38 Toijala etc. and indicates the bottom varve to be 439.

The same kind of clay, described above from localities 49—54, 58—70, and 74—76, has also been found in numerous other sections in the parishes of Punkalaidun, Alastaro, Loimaa, Metsämaa, Mellilä, Ypäjä, Jokioinen, Somero, Koski, Marttila, Pöytyä, and Oripää. Best known to me is my home district, the valley of the Loimijoki river. There I never met with any other kind of clay than that dark, fine and stiff variety described. These tracts are wellknown for their extensive and exceptionally thick clay deposits, exposed in deep

Fig. 5. Clay fields in Loimaa region, Southwestern Finland.
Photo M. Sauramo.

ravines of rivers and creeks as well as in many sections and borings through the clay (See fig. 5).

77. Kylmäkoski Pajukoski. D. A 3 m. deep section in the bluff of the rapid. 2.5 m., of the clay, from the rocky bottom upwards, is clearly laminated. Three varve series, all being like those in loc. 38 Toijala:

1. 195 cm. with 127 varves (337—463), from 3.5 to 0.6 cm. thick.
2. 12 cm.; 44 varves (464—507), from 0.6 to 0.2 cm.
3. 1.5 m.; 20 varves counted (508—527), from 2 to 0.6 cm.

Connection. This section is, in its greater features as in the details, much like the others in neighbouring localities. The similarity to loc. 38 Toijala is especially striking. The lower series belongs to H_2, the second to H_3 and the third series to S. The bottom varve is 337.

78. Viiala. D. Railway station, 8 km. northwest of loc. 38 Toijala. Brickyard, altitude about 85 m. Bottom unstratified drift. This section is much like that of Toijala. 3 series:

1. 140 cm.; 163 varves (301—463), from 2.5 to 0.3 cm. The structure is the same as in 38 Toijala series 1.

2. 20 cm.; 44 varves (464—507), from 0.5 to 0.2 cm. The series is like that in Toijala (fig. 7 Pl. V). The number of dark, thickish, fine-grained varves, however, is smaller, and instead of them there occur varves of a thinner gray and coarser type.

3. 60 cm.; 30 varves (508—537), from 2 to 0.6 cm. They are in thickness as in structure like those of series 3 in 38 Toijala.

Connection. This section shows so much resemblance to Toijala (and, also, to Iittala and Lammasmäki) that the corresponding varve series may be identified at a glance (See fig. 7, Pl. V). Even the individual varves, in most cases, may be easily identified, though less so in series 1, whose varves have thick and homogeneous finer layers without any details. The corresponding varves of series 2, on the other hand, frequently show common features, but also some differences, as pointed out above. The bottom varve is 301.

79. Mattila. D. Railway station. Section 1.5 m. deep. Altitude 85 m. Within 90 cm., 86 varves whose thickness varies between 6 and 0.2 cm. Their structure is generally as in Viiala series 1, or they consist chiefly of the finest dark clay of a violet tint, and only thin bands richer in silt separate the varves from each others. About 20 of the lowest varves are somewhat different, being composed of four parts, lowest a light band rich in silt as usual, above it 0.2 or 0.1 cm. extremely fine clay, like the finer layers in the upper part. The third part is a little lighter than the second but darker (and thicker) than the first, apparently containing much clay besides silt. The fourth and uppermost layer in the varve is, in its characters, like the second, but thinner.

Connection. The Mattila section may be connected, on account of its characters as well as from the diagrams, with the neighbouring sections 78 Viiala and 80 Lempäälä. The whole section belongs to horizon H_2 and the bottom varve is 317.

80. Lempäälä. Old brickyard 0.5 km. east of the railway station. Altitude 82 m. 200 varves within a stratum of 2.5 m. This section shows much similarity to those of loc. 78 Viiala, 32 Iittala, and 31 Lammasmäki. Three different series:

1. 120 cm.; about 150 varves (—463), from 5 to 0.6 cm.; these are, with a few exceptions, in their material and structure similar to those of series 1 in Viiala and Toijala. The lowest varves are perfectly similar to the four-parted varves of section 79 Mattila. Hygroscopicity 13.6.

2. 25 cm.; 44 varves (464—507), from 1 to 0.3 cm., corresponding with series 2 of Viiala and Toijala and series 4 of Iittala and Lammasmäki. Black, fat varves are less numerous than in the two first-named sections. Hygroscopicity 6.9.

3. 1 m., only 16 varves (508—523) counted, the very thick series above being indistinctly laminated. The varves are between 2 and 1 cm. thick, rich in silt and gray in colour, the clayey, finer portions being comparatively thin. Hygroscopicity in varves 510—520 was found to be 6.5.

Connection. Series 1, 2, and 3 in Lempäälä correspond with the Viiala series, the uppermost series (3) thus belonging to horizon S, series 2 to H_3, and series 1 to H_2. The corresponding varves may be easily identified. The diagrams also lead to the same result. The lowest varve was not determined with certainty owing to the character of the material. It is between 310 and 330.

81. Vesilahti Valkkinen. Big clay pits reaching down to the glacial drift. Altitude 85 m. Over 2 m. thick section showing 3 different varve series:

1. 90 cm.; 130 varves, (334—463), from 2 to 0.5 cm.; like series 1 in loc. 78 Viiala.

2. 15 cm.; 44 varves (364—507), from 1 to 0.3 cm.; like series 2 in loc. 78 Viiala.

3. 100 cm.; 120 varves (508—627) counted, from 2 to 0.3 cm. thick. The structure resembles the uppermost series of the Viiala section, but the finer layers are thinner and the coarser layers thicker.

Connection with Viiala and Lempäälä etc. is definite. The bottom varve is 334.

82. Vesilahti Toivola. Pit made for this investigation. Altitude about 85 m. The clay deposits resting upon unstratified drift are 110 cm. thick and contain 135 varves in three series, which correspond perfectly with those of section 78 Viiala.

1. 55 cm.; 50 varves (396—445), from 2 to 0.5 cm. thick.

2. 20 cm.; 62 varves (446—507), from 0.7 to 0.3 cm. thick.

3. 35 cm.; distinctly stratified, 23 varves (508—530), from 2 to 1 cm. thick.

Connection with the sections of Viiala and Lempäälä is definite: series 3 is S, 2 + 1 belong to $H_3 + H_2$. The bottom varve is 396.

83. Vesilahti Vakkala. Pit made for this investigation. Altitude about 90 m. Substratum unstratified drift. 160 cm., 200 varves. 3 series:

1. 65 cm.; 54 varves (392—445), thickness between 11 and 0.3 cm. Like above in series 1, but the 6 lowest varves have very sandy coarse layers and are therefore thick.

2. 35 cm.; 62 varves (446—507), from 1 to 0.2 cm. thick. 18 lowest varves show resemblance to the lower series; otherwise this series is like series 2 in the preceding sections.

3. 60 cm.; 83 varves (508—590), between 2 and 0.5 cm. thick. Like 3 in the preceding section.

Connection. Subhorizons H_2, H_3, and horizon S coincide with the three series, as above. The bottom varve is 392.

84. Lempäälä Jokipohja. Section in a creek, altitude 80 m. 2 m. clay upon unstratified drift. 220 varves, 3 series:

1. 95 cm.; 136 varves (320—455), from 2 to 0.4 cm., like the series 1 in loc. 78 Viiala.

2. 20 cm.; 52 varves (456—507), from 1 to 0.2 cm., like Viiala and Lempäälä 2.

3. 80 cm.; 40 varves (508—547), from 3 to 1.5 cm., exactly like Lempäälä 3 (S) and 81 Vesilahti.

Connection with neighbouring sections, according to the big features as well as the details, shows that series 3 = S, series 2 + 1 belong to $H_3 + H_2$. The bottom varve is 320.

85. South Pirkkala Ania. Clay pit north of the village, upon unstratified drift. 0.5 m. clay. 3 series:

1. 20 cm.; 69 varves (385—453), from 0.8 to 0.2 cm. Like series 1 in loc. 80 Lempäälä and 84 Jokipohja, but thinner than usual.

2. 15 cm.; 54 varves (454—507), from 0.3 to 0.2 cm. Like series 2 in loc. 80 Lempäälä.

3. 15 cm.; 15 varves (508—522), from 0.5 to 2 cm. thick.

Connection with all neighbouring sections definite. 3 = S, 2 + 1 belong to $H_3 + H_2$. The bottom varve 385.

86. South Pirkkala. 100 varves counted; substratum unstratified drift. 3 series as above.

Connection. Owing to the well developed varve series the connection is definite. The bottom varve 418.

87. South Pirkkala Tanila. D. Two large clay pits, 1 km. from each other. Substratum unstratified drift. More than 200 varves counted. 2 series:

1. 30 cm.; 69 varves (439—507), from 1 to 0.3 cm., whose structure is like that of series 2 in loc. 80 Lempäälä. In the lowest part some varves are like those in series 1 Lempäälä.

2. 80 cm.; 35 varves (508—542), from 3.5 to 1 cm., the lower of which are very thick, but decreasing gradually upwards. Structure like that of series 3 in loc. 81 Vesilahti.

Connection. This section may be connected definitely with all the neighbouring sections, by means of the sequence and structure. The upper series is horizon S. The bottom varve is 439.

88. Kulju. Section 0.75 km. north of the Kulju railway station. Altitude 95 m. 80 cm. clay deposited upon unstratified drift. 3 series, all being like those in loc. 80 Lempäälä.

1. 40 cm.; 91 varves (350—440), from 1 to 0.2 cm. thick.

2. 22 cm.; 67 varves (441—507), from 0.3 to 0.2 cm. thick, like Lempäälä 2.

3. 24 cm.; 20 varves (508—527), from 2 to 0.5 cm., like Lempäälä 3 (S).

Connection. The structure and all details of this clay section may be definitely connected with the sections of Lempäälä etc. Series 1 belongs to H_2. The upper 44 varves of series 2 correspond with H_3 in many preceding localities, and the lowest belong to the upper part of H_2, although they have here characters similar to the H_3-type. Series 3 = S. The bottom varve is 350.

89. Sääksjärvi. Railroad section north of Sääksjärvi station. Altitude about 110 m. 0.5 m. stratified clay upon glacial gravel. 180 varves. Section like the preceding, but the varves of the lower series are thinner, in consequence of the smaller development of the finer layers. The lowest varve 368.

A similar thin clay deposit was observed in the foot of the neighbouring hill Vuorestenvuori.

90. Lempäälä Moisio. About 1 km. from the Moisio estate toward the city of Tampere, near the highroad. Altitude 80 m. Bed of clay upon unstratified drift, 125 cm. thick, and containing more than 220 varves. 3 series:

1. 75 cm.; 125 varves (339—463), from 1.5 to 0.5 cm.; like series 1 in loc. 80 Lempäälä, 88 Kulju etc.

2. 18 cm.; 44 varves (464—507), from 0.6 to 0.2 cm. Like 80 Lempäälä 2.

3. 20 cm.; 30 varves counted (508—537), from 2 to 0.5 cm. Like 80 Lempäälä, series 3.

Connection. The section is on the whole and in all its details similar to those of 80 Lempäälä etc. The bottom varve is 339.

91. Lempäälä. Small pits in thin clay beds near the highroad from Moisio to Kangasala, about 6 km. from the Moisio crossing. About 100 varves countable, all about 0.1 cm. thick, gray and consisting only of silty clay, or the same facies as H_3 in the vicinity, and H_2 in loc. 17 and 18 Luopioinen etc. They could not be connected, as the section does not include the S-horizon which would be the only dependable starting point in this case. Neighbouring sections all around prove that the varves observed belong to horizon H.

92. Lempäälä Kelho estate. Several clay pits; the one nearest the house exposes a 1 m. thick series of 120 varves, all uniform and like those of subhorizon H_2 in loc. 80 Lempäälä, the lowest varves being exceptionally sandy and thick.

Connection. The characters and the variation in thickness indicate that the varves, except the two lowest, belong to H_2, the bottom varve being 290.

93. Kangasala Liuksiala. Brickyard about 1 km. northwest of the Liuksiala estate. Altitude 88 m. More than 350 varves counted within a 2.5 m. thick bed. They may be grouped under 6 series, like in loc. 15 Hauho, to which this section shows much resemblance in all respects.

1. 50 cm.; 20 varves (277—296), from 10 to 0.3 cm. thick. The lowest varves are thick and sandy, the upper being composed mainly of silt. The finer layers are light and very inconspicuous. Hygroscopicity, in the upper part, was found to be 1.86.

2. 15 cm.; 39 varves (297—335), from 0.8 to 0.4 cm. The finer layers are dark, and thicker than in the lower varves. The coarser layers thin and light.

3. 6 cm.; 30 varves (336—365), from 0.3 to 0.1 cm. They are light, and their finer layers are ill developed.

4. 34 cm.; 60 varves (366—425), from 1.3 to 0.3 cm. They show resemblance to series 2, but the finer layers are still thicker, reddish. The similarity to series 1 of Lempäälä etc. is therefore very striking. The clay is much more plastic than that of the other series. Hygroscopicity 10.39.

5. 22 cm.; 82 varves (425—507), from 0.3 to 0.2 cm., like those of series 3. Hygroscopicity 5.32.

6. 85 cm.; more than 80 varves (508—), from 1.4 to 0.4 cm. The varves are light, rich in silt, the finer layers but a little darker and generally very indistinct. Hygroscopicity 2.86.

Connection. The Liuksiala section may be connected definitely with the neighbouring sections. The uppermost series is horizon S, the lower series may be identified with the series designated by the same numbers in the section of 15 Hauho. Individual synchronal varves in both sections show many identical features. As the lowest varves were not accessible in the Liuksiala section, the bottom varves were studied in a section near by which was connected with it. The bottom varve here is 257.

94. Kangasala Tursala. D. Near Karttiala farm, about 4 km. north of the big Kangasala esker. Altitude about 120 m. More than 300 varves in a section of 130 cm. 2 varve series:

1. 55 cm.; 225 varves (283—507), from 2 to 0.3 cm. Their structure and the character of the material is the same as in series 5 and 3 of the former section. Hygroscopicity in varves 300—320 was found to be 5.18, in 420—450 also 5.18, and in 490—500 5.50.

2. About 75 cm.; 93 varves (507—600); from 1.8 to 1 cm., decreasing slowly toward the top. The character of the clay is the same as in series 6 in Liuksiala. Hygroscopicity in varves 513—520, 4.67, in varves 520—530, 3.15.

Connection. In comparing this section with the former, which is only 6 km. from it, attention is first drawn to the great differences. The H_2-type, present in series 2 and 4 in Liuksiala, is here entirely absent. The upper parts in both sections, however, are similar, being composed of thick varves rich in silt. This is horizon S underlain by series H. The present section therefore bears much resemblance to localities 22 and 23 Sysmä and 17 and 18 Luopioinen. The diagram also shows similarity to other sections, although the lowest series is very uniform. The bottom varve is 283.

95. Kangasala Lihasula. Clay pit 1.5 km. southwest of the Lihasula estate. Altitude 100 m. Bottom boulders. Section 1 m. thick, 260 varves forming two series:

1. 50 cm.; 210 varves (298—507) of an average thickness of 0.2 cm., the individual varves varying between 0.5 and 0.1 cm. Quite similar to those in the lower part of the former section.

2. 40 cm.; 40 varves (508—547) from 2.5 to 1 cm. The structure and characters similar to series 2 in the former section.

Connection. This section is wholly similar to 95 Tursala, 10 km. from this locality. Even the individual varves may be easily identified. The bottom varve is 298.

96. Kuhmalahti. Openings made south of the church. Altitude about 100 m. The sediment consists of sand and silt and has no distinct lamination. It apparently corresponds, however, with laminated sediments in other localities, e. g. in Luopioinen, where finely laminated clay may pass over into a perfectly uniform material.

97. Oripohja. A rather big clay pit near the railway station. The section is 2 m. deep, but the bottom has not been reached because of abundant ground water. Nearly 200 varves counted. The structure of this section is the same as that of the preceding sections; the lower varves thin, 0.2—0.1 cm., and the upper thick, 7—0.2 cm.

Connection. The varves may easily be connected with those of many preceding sections, the upper part belonging to horizon S and the lower to H.

More than a hundred H-varves were counted, but their number may be still larger.

98. Tampere. Kämäri brickyard east of the city. Altitude about 108 m. About 3.5 m. distinct undisturbed varves exposed, resting upon boulders and sand. More than 400 varves counted. 4 series:

1. About 100 cm.; with 56 varves (325—380). The lowest are between 25 and 5 cm. thick, and sandy, but the thickness decreases upwards and the varves have silty coarser layers and thin, black or reddish clayey finer layers. The coarseness in this part of the series appears from the mechanical analysis (1) and from the hygroscopicity, which was found to be 3.37. This lowest series has no sharp upper boundary.

2. 35 cm.; 83 varves (381—463) from 1 to 0.3 cm. The light coarser layers are well marked against the dark, greasy-looking finer layers which form about half of the varves. The degree of coarseness appears from the mechanical analysis (2) and from the hygroscopicity, 8.36.

3. 25 cm.; 44 varves (464—507). Their average thickness is a little less than in the former and the structure is different. Most varves have thin finer layers which are but little darker (finer) than the coarser layers, i. e. they are like the varves of series 2 in loc. 38 Toijala, of series 5 in loc. 93 Liuksiala and of series 1 in loc. 94 Tursala. In the lower part, and occasionally in the upper part, there are varves almost like the varves of series 2. Mechanical analysis (3). Hygroscopicity 5.02.

4. 100 cm.; 193 varves (508—700), the lower between 3 and 2 cm. thick, the upper gradually thinner, at the top only 0.2 cm. Their structure is like that of series 3 of Lempäälä and series 6 of Liuksiala, i e. they have ill-developed and indistinct finer layers, upon thick, silty coarser layers. The mechanical analysis (4) illustrates the coarseness, and so does the hygroscopicity, 4.3.

Mechanical analyses.

Grain	1 %	2 %	3 %	4 %
> 0.2 mm.	3.6	1.5	2.6	3.7
0.2—0.02 mm.	34.2	5.9	2.9	5.8
0.02—0.002 mm	50.1	30.0	37.3	33.6
< 0.002 mm.	11.2	63.7	57.9	57.7

Connection with neighbouring and even many distant sections is very definite, whether it be based on the structures of larger or smaller units of sedimentation or merely upon the variation in varve thickness. The uppermost series represents the S-horizon. The varves of series 3 are characteristic of H_3, while series 2 and 1 belong to subhorizon H_2. Some of these latter varves are like those in locality 80 Lempäälä, 38 Toijala, 32 Iittala etc. while others have the same facies as corresponding varves in 94 Tursala or 17 and 18 Luopioinen. Each of these different facies types appears to be synchronal with varves of the same facies, wherever both types are represented in the same section, as in 93 Liuksiala, 36 Pälkäne Pintele, and 15 Hauho. The bottom varve is 325.

99. Messukylä Turtola. Clay pit, altitude 85 m. 3 m., over 325 varves. 4 series:

1. 1.50 cm.; 69 varves (312—380), from 25 to 0.5 cm., like 1 in loc. 98 Tampere.

2. 35 cm.; 83 varves (381—463) from 1 to 0.3 cm., like 2 in loc. 98, but the finer layers considerably thicker. See fig. 9 (a) Pl. VI.

3. 25 cm.; 44 varves (464—507) from 0.4 to to 0.3 cm Structure like 3 in loc. 98.

4. 90 cm.; 90 varves (508—597) from 2 to 0.5 cm. Like 4 in loc. 98 (S).

Connection. This section is wholly similar to that of 98 Tampere, and the connection is apparent. The lowest varve counted is 312, but below there is stratified sand which may form 5 varves as a maximum.

100. Tampere. D. Section through the Tampere esker at Sorinmäki near the railroad depot. Lowest, in the plain of the depot, about 85 m. above sea level, 3 m. stratified sediment above which there is a 3 m. or more thick bed of gravels and boulders, well washed out and assorted, as in eskers; this is a shore deposit worked out by the late glacial sea. The stratified sediments, being deposited upon the north slope of the »primary» esker, dip toward the north. The lowest varves exposed consist entirely of sand and are from 25 to 3 cm. thick. The 13:th varve from the bottom, or varve 344 in the chronology, contains much coarse gravel. The varves above that exceptional varve may be grouped into four series, as in the preceding section. Their structure and sequence is the same as above.

Connection. The characteristic features of this section in the sequence of varves and in details connect it with loc. 99 (see fig. 9 Pl. VI) loc. 38 Toijala, 78 Viiala, 84 Jokipohja and all neighbouring sections. The lowest varve counted is 332, but a few more varves might exist in the underlying stratified drift which passes over into the esker drift.

101. Ylöjärvi Lielahti. Altitude about 100 m. A bed of about 1 m. stratified sediment upon unstratified drift. 190 varves, from 10 to 2 cm. thick and almost similar in structure, with thin finer layers and thick light coarser layers. Thus the material is silty clay. The uppermost varves are thicker than those underlying.

Connection. The upper thicker varves in the series may be recognized as belonging to horizon S, and the next underlying varves form a typical H_3-series. 100 lowest varves belong to the upper part of H_2, although they show another facies than the section south of Tampere. In this respect, the present section is exactly like those of 94 Kangasala Tursala and 95 Lihasula. The bottom varve is 329.

102. Ylöjärvi Epilä. Clay pit west of Lake Tohlopinjärvi. Altitude 114 m. Nearly 200 varves counted. Substratum stratified sand and drift. Four different varve series, as in Tampere. Their sequence and characters also are similar. Series 2, however, is less developed, the number of varves of this kind being less and their finer layers thinner. Thus this section approaches the preceding section.

Connection with many former sections, based upon the sequence and structure, proves the lowest varve counted to be 340. About 5 more exist below.

103. North Pirkkala Nokia. Brickyard with 3 m. of stratified sediment exposed. 281 varves counted. 4 series, all alike those of the corresponding series of Tampere:

1. 80 cm.; 27 varves (390—416), from 20 to 1 cm.
2. 35 cm.; 47 varves (417—463), from 1.6 to 0.3 cm.
3. 26 cm.; 44 varves (464—507), from 0.5 to 0.3 cm.
4. 120 cm.; 163 varves (508—670), from 2.5 to 1 cm.

Connection, based upon the varve series and the structure of individual varves, with loc. 100 Tampere and other neighbouring sections. Series 4 represents horizon S, series 3 belongs to H_3, and series 2 and 1 to H_2. The lowest varve counted is 390, but a few varves, not more than 10, may exist in the underlying sand.

104. North Pirkkala Kassila. Pit made for the investigation. Altitude about 60 m. Substratum drift, thickness of the sediments 130 cm.; 114 varves counted. Three series, each of them like the corresponding series of loc. 103 Nokia and the two upper series also like 2 and 3 in loc. 83 Vesilahti Vakkala.

1. 65 cm.; 38 varves (417—454), from 17 to 1 cm.
2. 30 cm.; 53 varves (455—507), from 1 to 0.4 cm.
3. 35 cm.; 23 varves counted (508—530), from 2 to 1 cm.

Connection with the neighbouring section is definite. Series 3 belongs to horizon S, the upper part of series 2 is H_3 and the rest belongs to H_2. The bottom varve is 417.

105. Ylöjärvi Vahanta. D. Brickyard on the shore of Lake Näsijärvi, 6 km. north of the Ylöjärvi church. Altitude 96 m. Section in clay 3 m. thick upon rock. 370 varves visible. 2 series:

1. 75 cm.; 133 varves (375—507), between 1 and 0.3 cm.; in their structure like those of series 1 in loc. 94 Tursala and 95 Lihasula, and 3 in loc. 98 and 100 Tampere.

2. 225 cm.; 258 varves (508—765). No sharp boundary against the lower series; the lowest varves are from 2.5 to 1.5 cm. thick, but they soon attain a thickness of 5 cm., and then grow thinner again. Their structure is like that of series 4 in Tampere, but the material of the thick varves is still richer in silt. The uppermost varves include some varves of exceptional characters with thick, sharply bounded and dark-reddish finer layers.

Connection. This section is, in its structure, exactly like those of 94 Tursala and 95 Lihasula, and also very similar to the Tampere sections (98—100). The uppermost series represents horizon S in a mighty development, and series 1 includes the whole H_3 and part of H_2. The bottom varve is 375.

106. Ylöjärvi Veittijärvi. More than 1 m. stratified sediments exposed in the wall of a gravel pit. 150 varves counted. This section, on the whole, is like the preceding, but the lower part of the S-clay only is present.

Connection, on the basis of sequence and structure, determines the bottom varve of this section as 380.

107. Ylöjärvi Sorvajärvi. Clay pit on the northeast side of L. Sorvajärvi. Altitude 110 m. A 2 m. thick bed of clay upon gravel. Over 200 varves were counted, but under them is a 5 cm. thick disturbed zone, in which the varves consisting of fine sand and silt are contorted and indistinct. The undisturbed part may be divided into 2 series:

1. 50 cm.; about 113 varves (395—507), between 0.7 and 0.2 cm. thick. The characters of the material and the structure of the varves are in all respects like those of series 1 of loc. 105 Vahanta.

2. 100 cm.; over 60 varves, (508—), from 3.5 to 0.3 cm. thick; like the uppermost series in loc. 105 Vahanta, but the material is still coarser.

Connection. The uppermost series represents horizon S, and the lower H_3 and H_2. The lowest undisturbed varve is 395; the varves beneath this could not be counted.

108. Pirkkala Pinsiö. D. Pit in clay upon gravel. Altitude 120 m. 130 cm. laminated sediment, 175 varves in all. Two series:

1. 75 cm.; 106 varves (402—507), from 35 to 0.5 cm.; like series 1 of loc. 105 Vahanta and series 1 and 3 in loc. 98—100 Tampere.

2. 55 cm.; 69 varves (508—576). Similar to series 2 in Tampere. In the lower varves the finer layers are considerably thicker.

Connection with all the neighbours is definite. The lower part of series 1 belongs to H_2 and the upper part to H_3, series 2 is typical S. The bottom varve is 402.

109. Hämeenkyrö Sirkkala. D. Clay pit in the village. Altitude 70 m. Substratum hard glacial drift. 196 varves, two series:

1. 40 cm.; 51 varves (457—507), between 1.4 and 0.5 cm. thick. Structure like the lower part of series 1 in the former, and series 2 in loc. 104 Kassila, but somewhat thicker owing to the coarser layers which consist of silt and sand.

2. 190 cm.; 145 varves (508—652). Structure as in all the neighbouring sections east of this locality. The lowest varves are thick and ill defined because of the poorly developed finer layers. In the upper part, the varves are thinner and more distinct, containing sharply bounded clayey finer layers which sometimes are exceptionally thick and have in that case a violet hue.

Connection. This section connects itself with all the neighbouring sections on the basis of structure as well as of the diagrams, as appears from the plate of diagrams. Series 1 is part of subhorizon H_3, series 2 belongs to horizon S, and the bottom varve is 457.

110. Hämeenkyrö Kierikkala. Pit made for this investigation. Bottom not reached. Section 200 cm. thick, contains 140 varves, exactly like those in the upper series of the preceding locality.

Connection with the neighbours shows the lowest varve exposed to be 522. The number of the underlying varves is unknown.

111. Hämeenkyrö Laitila Saavutus. Well near the house of the novelist F. Sillanpää. Altitude 65 m. 220 cm. stratified sediment. 76 varves (446—521). The lower 65 thinner, between 3 and 1 cm, in all 110 cm. The upper 15 thick, from 15 to 4 cm., in all 110 cm. All the varves have a uniform structure: a thick, light, coarser layer consisting of sand and silt, and a very meagre finer layer.

Connection. The upper, thick varves may be recognized as belonging to horizon S and the lower thin varves to subhorizon H_3. The lowest varve counted is 446.

112 Mouhijärvi Häijää. Clay and sand pit in the village of Häijää. Altitude 65 m. 125 varves counted (483—607). Substratum stratified drift (esker). The structure of the varves in the whole section is nearly uniform: thick, light coarser layers containing much sand when well developed, and thin finer layers which, in certain varves, as in the 116:th, 579:th, 592:th, and 601:st, are thick and reddish, just as in loc. 109 Sirkkala. The thickness of the varves is variable. The first 20 are between 30 and 1.5 cm. thick, the next 32 from 3.5 to 0.4 cm., the following 15 from 6 to 2 cm., the last 58 varves have at first an average thickness of 2.5 cm., which decreases gradually to 1 cm. and less.

Connection. The uppermost part of this section may be recognized without difficulty as horizon S, which characteristically begins with very thick varves and is underlain by thin varves of subhorizon H_3. All the above-named 32 thin varves and the underlying varves, though exceptionally thick because of their richness in sand, belong to this subhorizon. The diagram of the Häijää section resembles greatly those of the corresponding parts of loc. 100 Tampere and 105 Ylöjärvi: they all show a high summit in the curves between varves 510 and 525. The bottom varve is 483.

113. Mouhijärvi Selkie. Bluff on the river side. Altitude 65 m. Bottom not reached. A 2 m. thick bed of the sediment contains 200 varves, but above them there is still a more than 1 m. thick bed of clay with indistinct varves. The 200 varves counted form a series similar to that of the preceding section. In its lowest part the varves are from 3 to 2 cm. thick and have thick, silty coarser layers. In the upper part the varves are from 1 to 0.3 cm. thick and have well developed reddish and plastic finer layers.

Connection. The varves belong to horizon S, as appears from the structural characters and from the diagrams. The lowest (counted) varve is 543.

114. Mouhijärvi Hyynilä. D. Clay pit. Altitude about 92 m. A 225 cm. thick bed resting upon unstratified drift contains 105 (514—618) from 7 to 0.5 cm. thick varves. Their structure is similar to that of loc. 109 Sirkkala. The varves above 580 have thick and reddish finer layers.

Connection. This section is easy to connect with loc. 100 Tampere, 105 Vahanta etc. on the basis of the characters of its different parts, and of the diagrams. The bottom varve is 514.

115. Suodenniemi. Near the inn, on the shore of a lake, clay sections which do not reach the bottom. Altitude 80 m. The exposed portion, about 100 varves, is much like the upper part of the preceding sections, and in fact proves to be synchronal with them.

116. Vammala. Clay pits. Altitude about 60 m. Substratum coarse gravels. Nearly 100 varves counted (504—). They are all very uniform. The thickness of the two lowest is 3 cm., of the next 8 between 1 and 0.6 cm.; the following 20 varves are between 1.5 and 5 cm. and the uppermost gradually less, to 0.5 cm. The structure is similar to the upper part of loc. 109 Sirkkala.

Connection. The section of Vammala may be connected, with identical result from the graphs and from the characters, with all the neighbouring sections. The lowest thin varves belong to H_3 and the others to S. The bottom varve is 504.

117. Kokemäki Ristee railway station. Section through an esker. Bed of stratified sediment, 1.5 m. thick, includes 40 varves (516—555), overlain by a several metres thick bed of coarse assorted gravel (shore-deposit). The clay is similar to that of loc. 114 Hyynilä, series 2.

Connection. The diagram agrees remarkably well with those of the sections of 109 Sirkkala and 114 Hyynilä. The bottom varve is 516.

118. Hämeenkyrö Kyröskoski. D. Abrasion bluff, 10 m. high, below the Kyröskoski waterfall. The lowest parts of the sections show laminated clay resting upon esker sand, or, in places, upon rock. Altitude 80 m. More than 300 varves counted, but as they are, in the upper part of the section, rather indistinct, only the more distinctly laminated lower part containing 109 varves in a 2 m. thick series has been recorded on the plate of diagrams (554—662). Structure of the varves is similar to that in loc. 109 Sirkkala.

Connection. This section may be connected very definitely with the preceding sections, as those of loc. 109 Sirkkala, 100 Tampere and 105 Ylöjärvi Vahanta, by means of the diagrams. The lowest varve counted is 554 but apparently a few further varves exist in the underlying sand.

119. Hämeenkyrö Vesajärvi. A bed about 0.5 m. thick of varve clay, underlain by 0.5 m. unstratified sand mixed with small rock pieces, resembling glacial drift, and further beneath again stratified sandy sediment. Altitude 90 m.

The upper sediment contains 30 varves showing the characters of the S-clay. From the characters of the layers and from the variation diagram the bottom varve proves to be 574.

120. Hämeenkyrö Osara. D. Clay pits on the cultivated fields of the Osara estate. The clay is like that of 109 Sirkkala and 118 Kyröskoski. The bottom has not been reached. About 1.5 km. farther north, in the village of Untila, a clay pit was examined and several excavations were carried out. These Untila sections, situated upon a plain horizontal ground, are all exactly alike: The lowest varves have been disturbed, but are overlain by an undisturbed varve series. Near Huiku the section shows the following features:

Undisturbed upper part, 120 cm. thick, with 98 varves which may be connected with the preceding sections, the structure being like that of the latter and the diagrams agreeing very well. The lowest varve is 592. The disturbed lower part contains alternating layers of glacial drift and varves which are in places contorted and folded, though in other places better preserved, but in inclined positions. 5 varves were observed between two gravel beds, in others there are more of them. They apparently belong to horizon S and possibly to H, but they can not be connected exactly.

121. Luhalahti. D. Northeast of Lake Kyrösjärvi. Altitude 97 m. 130 cm. clay upon unstratified drift with 118 varves whose thickness varies between 5 and 0.4 cm. and whose structure is similar to that of the undisturbed upper portion of loc. 120.

Connection with the preceding localities by means of diagrams is very reliable; the close agreement may be seen from the graphs. The bottom varve is 592.

122. Ikaalinen. Sections in clay near the town. The upper parts belong to the ~~Litorina~~ post-glacial clay, but the lower part is laminated as in the preceding section. No connection was practicable, the number of varves being small and no bottom exposed.

123. Ikaalinen Karttu. Clay pit on the ground of the Joensuu farm. Altitude about 95 m. ½ m. laminated sediment upon unstratified drift. 35 varves. Characters as in loc. 120 Osara.

Connection. According to the diagrams, the bottom varve is 627.

124. Ikaalinen. Near the highroad from Jämijärvi, about 8 km. from the parish boundary. Altitude 97 m. 80 cm. laminated sediment upon a substratum of gravel and sand; 35 varves. Similar to loc. 127 Osara.

Connection. The bottom varve, according to the diagrams, is 605.

125.. Lavia Niemi. Clay pit in the northern part of the parish of Lavia, near the highroad. Altitude about 80 m. Substratum rock. 125 cm. clay with 110 varves whose characters are like those of sections 109 Sirkkala, the upper parts of the section having varves with reddish finer layers.

Connection. This section may be connected with the others by means of the structure and the diagrams. The underlaying rock surface being somewhat inclined, it is possible that the clay deposit upon plane surface would have a few varves earlier than 602, which is the lowest in the section investigated.

126. Kankaanpää Vihteljärvi. Near Puuska farm; upon unstratified drift. 110 cm., nearly 90 varves whose thickness varies between 4 and 0.2 cm. They have well developed reddish and plastic finer layers.

Connection by means of structure and diagrams determines the bottom varve as 634.

127. Kankaanpää. A small clay pit south of L. Ruokojärvi. About ten varves distinguishable. They are like those of the preceding section, but no connection was practicable.

128. Jämijärvi. D. Clay pit on the ground of Peijari farm, about 1 km. north of the church. Altitude about 110 m. Substratum unstratified drift. 175 cm.; 117 varves, from 5.5 to 0.5 cm. thick. The structure is the same as in the section 126 Vihteljärvi.

Connection, by means of the characters and diagrams. Bottom varve 614.

129. Ikaalinen Riitiala. D. Opening near the highroad in the northernmost part of the parish of Ikaalinen. Altitude 88 m. The section is 1.5 m. deep and includes 83 varves upon coarse sand. Their characters are the same as above.

Connection was based upon the characters and diagrams. The lowest varve counted is 645, but a few very thick and sandy varves exist beneath.

130. Parkano. A small pit near the inn. Altitude about 120 m.; 70 cm.; over 50 varves counted. Their characters are similar to those of the upper parts of loc. 98 Tampere and 105 Ylöjärvi.

Connection could not be made because of the small number of varves.

131. Siikainen Pyntäsjoki. 70 cm. laminated sediment upon unstratified drift; 45 varves counted. Their structure is similar to that of loc. 126 Vihteljärvi.

Connection from the diagrams proves the bottom varve to be 691. In view of the small number of varves, and the situation of this locality far away from the others, this connection is not absolutely safe.

132. Nakkila. Sections through the sediments in the high bluffs of the Kokemäenjoki river. Lowest, near the water edge, five or ten metres of sand which upwards gradually becomes laminated. Above that 5 or 6 metres distinctly laminated sediment. 80 varves counted. The uppermost part, about 10 cm. thick, is nearly homogeneous, non-laminated, and upon this bed follows another of homogeneous gray clay, apparently Litorina clay, which upwards becomes sandy and finally passes over into sand, forming a bed a thickness of several metres.

Connection. The laminated sediment is similar to that of horizon S in loc. 109 Sirkkala. The diagram agrees fairly well with others in such a way that the lowest varve counted is 575. This connection is not absolutely definite, however, because of the small number of varves and the great distance from the other localities.

133. Ruovesi Pekkala. 1.5 m. laminated sediment. Bottom not reached. The varves are thick, from 10 to 2 cm., and consist of sand and silt and contain but little clay in their finer layers.

Connection. The uniformity and small number of the varves (26 in all) prohibit a definite connection with distant neighbours. The varves observed very probably belong to horizon S.

134. Jämsä Yijäälä, D. A pit, 2.5 m. deep, made near the highroad. Altitude 80 m. Substratum coarse gravel Nearly 300 varves counted. Four different kinds discriminated:

1. The lowest part, exposed 60 cm. appr., with 27 varves (324—350), from 4 to 1.5 cm. thick. The material silt and silty clay. A few varves below in the sand.

2. 40 cm.; 104 varves (351—454), from 1 to 9.1 cm. thick, consisting of silty clay.

3. 10 cm.; 53 varves (455—507), between 0.5 and 0.1 cm. thick, consisting of silt.

4. 105 cm.; 93 varves (508—600) from 3 to 0.2 cm. The structure is like that of the uppermost part in sections 98 Tampere, 93 Lihasula etc.

Connection. The series of the Jämsä section may be recognized as corresponding with those of 100 Tampere, 93 and 94 Kangasala, etc. The uppermost series (4) with its thick varves clearly represents horizon S, the upper part of series 3 forms H_3, and the rest and series 2 and 1 all belong to subhorizon H_2. A connection merely based upon the diagrams leads to the same result. Varve 324 has been taken as the lowest, but a few very thick sandy varves exist beneath.

135. Jyväskylä. Brickyard northeast of the town. Substratum level rock. 50 cm.; 47 varves. The thickness of the lowest 40 is rather uniformly about 1 cm. but then quickly decreases to 0.1 cm. and finally no varves can be distinguished. The structure is the same as in the upper part of the former section.

Connection. The characters of the clay indicate that the varves belong to series S. The diagram shows many varves in which the variation in thickness well agrees with that of 134 Jämsä. According to this connection the bottom varve is 559.

136. Mukkula. (Cf. Südfinnland No. 51, pp. 20—21, fig. 3). Three large horizons:

1. 2.5 m.; about 240 varves, from 15 to 0.5 cm. thick, the material being either coarse and fine sand or silt.

2. 1.5 m.; 183 varves counted, their thickness varying from 3.2 to 0.6 cm. Dark and stiff clay (visible in fig. 3 Südfinnland).

3. 1.5 m., with about 300 varves, from 2 to 0.2 cm. thick, composed of light fine sand and silt.

Connection. Series 1 represents horizon iSs, series 2 horizon IISs, and series 3 horizon H, as described in Südfinnland.

137. Herrala. Southwest of the town Lahti. Altitude 85 m. Substratum sand and rock. Varve sediments 5.5 m. thick investigated, containing five large varve series:

1. 2 m.; 230 varves, from 2 to 0.4 cm. thick, average 0.9 cm. The varve lines in moist substance are indistinct, and the material in the lower portion is fine sand and silt, but in the upper portion there is much clay also.

2. 250 cm.; about 250 varves counted. The exact number could not be found, the boundaries of the varves being indistinct, as in series 1. Their thickness, also, varies considerably even within a horizontal distance of a few metres. The material on the whole, and especially in the upper part, is coarser than in series 1.

3. About 75 cm.; nearly homogeneous clay.

4. 30 cm.; the varves hardly distinguishable, from 1 to 0.5 cm. thick, composed of silt.

5. Dark, clayey material with thicker varves than the former series but distinguishable in the lower part only.

Connection. This section has been connected directly with 136 Mukkula and and 138 Jokela. Series 1 corresponds with the second horizon in Jokela, or ISs. Series 2 is synchronal with the third horizon in Jokela and the first in Mukkula, or iSs, and series 3 with the fourth horizon in Jokela and the second in Mukkula, or IISs. Series 4 and 5 apparently represent horizon H, the former series corresponding with the lower part of H_1.

Series 1 has been connected with the corresponding horizon in loc. 138 Jokela means of the individual varves and their smaller features. The bottom varve is — 673. The locality of Herrala thus represents the beginning of the first Salpausselkä stage, and the ice border arrived here at about the same time as at Hyvinkää in the West and Uusikylä in the East.

138. Kolsa birckyard nearly 1 km. north of the railway station of Jokela. (See below).

139. Jokela, brickyard 1 km. south of the same railway station. This and the preceding section are, in their size and usefulness for the investigation, comparable with the Leppäkoski section, and have been described in full above (pp. 14—15), in connection with the methods.

140. Nurmijärvi Numlahti. About 20 km. southwest of Jokela. Altitude 42 m. A more than 10 m. deep section formed by erosion during the drainage of a lake. The varve sediments rest upon rock.

Connection. This section is in all ways like those of Jokela. The same four large horizons may be recognized, but the lowest horizon, aSs, is here much thicker and consists of coarser material than in Jokela. The other portions are similar in all their details.

Through the investigation of the last described five sections of exceptional size (loc. 136—140) I have been able to complete and check the chronology of the Salpausselkä stages, described in my earlier paper (Südfinnland). No change in the big features has been necessary. The number of individual varves in horizon ISs, or the varves synchronal with the First Salpausselkä, has proved to be a little (3) larger than I assumed before. This result is in agreement with my presumption expressed in the earlier paper, concerning the possible changes after a closer investigation based upon a larger number of localities. Near the boundary of horizons iSs and IISs a similar small increase might possibly result from still closer studies.

140—150. The parish of Vihti (Wichtis), between the two Salpausselkä. They are all alike in so far as the varves could not be distinguished from each other in the lower parts of the sections. They are not, therefore, available for very exact chronology. Among the big features it may be mentioned that the uppermost varve series in the sections next to the second Salpausselkä may be recognized as identical with that in Högfors, or H_1. The diagram of the variation in thickness of these varves agrees exceedingly well with this series, and the lowest varve corresponds with varve 0. Below it the sediment is, in every section, indistinctly laminated. In most sections the underlying beds have a thickness of 4 or 2 m., and the bottom has been reached in a few cases only. In their structure these varve series show resemblance to the IISs- and iSs-horizons in the section of 136 Mukkula, 157 Herrala, 138 and 139 Jokela and 140 Numlahti, but the material tends to assume reddish tints. The sections of 2 Högfors and 140 Numlahti indicate in fact that these beds are equivalent to the horizons mentioned.

151. Imatra. Near the well-known rapids of Imatra in Karelia, 5 km. south of the First Salpausselkä. A big section was made here during the construction of an electric power station. In places the thickness of the laminated sediments that were cut through exceeded 8 m. The substratum is drift and rock. 600 varves were counted in the lower part of the section. Four large series may be distinguished:

1. 1.5 m.; with 304 varves, some of the lowest from 5 to 1 cm., the others between 0.5 and 0.2 cm. thick. The material is sand and silt and silty clay.

2. 2.5 m.; about 300 varves, from 2.5 to 1 cm. thick, and consist of fine silty clay. This series passes gradually into

3. 0.5 m.; nearly homogeneous, dark and stiff clay.

4. Several metres of silty clay with indistinct varves.

Connection. The lowest series may be recognized as corresponding with aSs and ISs of the Jokela section. The lower part of series 2 is iSs, its upper part and series 3 is equivalent to horizon H. When thus placed in relation, there is a good agreement among the diagrams of this section and the Jokela and Herrala sections. The bottom varve is — 684.

152. Helylä. In Karelia, about 7 km. north of the town of Sortavala, 20 km. southeast of the First Salpausselkä and more than 300 km. east of Leppäkoski. Dr. E. Mäkinen, in 1912, measured here 1,060 varves within 5 metres of sediment. Later I have visited this place myself.

Three large horizons may be distinguished in the diagram of Mäkinen:

1. The lowest horizon contains 840 varves which are, except the lowest, thick and sandy, between 1 and 0.5 cm. thick.

2. 190 varves, thicker than the former, due to the well developed finer layers.

3. The uppermost 30 varves are between 10 and 5 cm. thick and consist of fine sand and silt.

Connection, based on the characters of the varve series described, on the situation of this locality in relation to the Salpausselkäs, and on the diagrams, shows the uppermost series to correspond with the lowest part of horizon H, the middle series with IISs and the lowest series with earlier horizons. The lowest varve is about — 1,030 (as in Nordbo Mäntsälä, Südfinnland, Plate IV).

Chapter IV.

Stratigraphy of the Varve Sediments in Southern Finland.

General Features of the Stratigraphy.

Accuracy of correlation. — With regard to accuracy of connection the sections described above may be grouped into three classes. The first class includes those sections in undisturbed beds and with a great number of distinctly bounded varves. About 75 such sections have been studied. Their connection, not only with their nearest neighbours but also with more distant sections, is easy and definite. The sections of the second class differ from those of the first in their smaller number of varves; reliable connection, therefore, is usually possible with the nearest neighbouring sections only. The third class finally comprises most of the sections of the Loimaa—Turku region containing indistinct varves. The main purpose of their description was to present examples of the peculiar type of clays of that region.

A zone about 30 kilometres broad extending from loc. 138 Jokela over loc. 1. Leppäkoski to loc. 129 Ikaalinen, includes most of the sections of the first class forming the skeleton of chronology and stratigraphy. The variation in facies in a direction at right angles to the elongation of this zone, also, takes place mainly within the same zone, and the extreme developments in the southwest and northeast could be well compared by starting from the transitional types near its principal axis. The plate of diagrams (Pl. X) has been compiled largely with the aim of illustrating the different types, and not to show the best connections.

As may appear from the preceding descriptions, most of the sections situated within this zone afford connections not only with their nearest neighbours, but also with several distant sections. Thus, the observations form a dense net-work, and the stratigraphy is based upon several parallel series. This mutual checking is really more needed for the stratigraphy than for the chronology, the latter having a sufficiently safe foundation in a few sections which afford reliable connections with each other.

In the 730 varves of + sign studied, the possible error is very small, not more than 3 units as a maximum. This possibility does not depend upon any unreliability in the connections, but two varves may sometimes be mistaken for one, or one for two, in spite of the fact that most of those 730 varves have been studied in several tens of sections. The chronology of the Salpausselkä epochs studied earlier by me, may, however, still embrace a somewhat greater error, the figures possibly being some ten units too low, as good sections are rare. The somewhat greater uncertainty in the — varves is the reason why I have retained the starting point of the chronology at the first varve subsequent to the Second Salpausselkä epoch, although this implies the use of + and — signs which, of course, is an inconvenience for the chronology.

Peculiarities of the stratigraphy of varve sediments. — The stratigraphy of the glacial sediments differs from that of most other sedimentary formations in its greater exactness and minuteness, owing to the well defined character and small thickness of their smallest natural unit, the *varve.* Larger units are composed of the smaller: several varves form *varve series*, and several series, *horizons.* Each group has some *petrographical characters* as its distinctive features, and these characters are subject to investigation. The changes in those characters may be followed, first, in a *vertical direction*, from one unit to the next and, second, in a *horizontal direction*, through the area of distribution of each unit. An investigation of varves over sufficiently wide areas shows that the characters of a certain unit of sedimentation may vary from place to place, or it shows varying *facies.* The facies, again, offers a basis for a study of those physicogeographical conditions that prevailed during the deposition of the sediments.

The areal distribution of each varve, varve series, and horizon may be determined directly from the connection of the varves in the sections investigated, described in chapter III. The most important boundary line of the distribution of a varve is that line from which it has spread out at the bottom of the sedimentary series, in Southern Finland toward the southeast. This line is called the *proximal line of the varve*[1]). It may be determined directly for any varve and with any accuracy desired. This fact may be specially emphasized here, and we do not yet apply the theoretical conclusion

[1]) The terms proximal and distal are those used by G. De Geer in the discussion of eskers.

that the proximal line of a varve marks the position of the land-ice border in a definite year, self-evident as this conclusion may seem. The proximal lines of varves belonging to a varve series or horizon

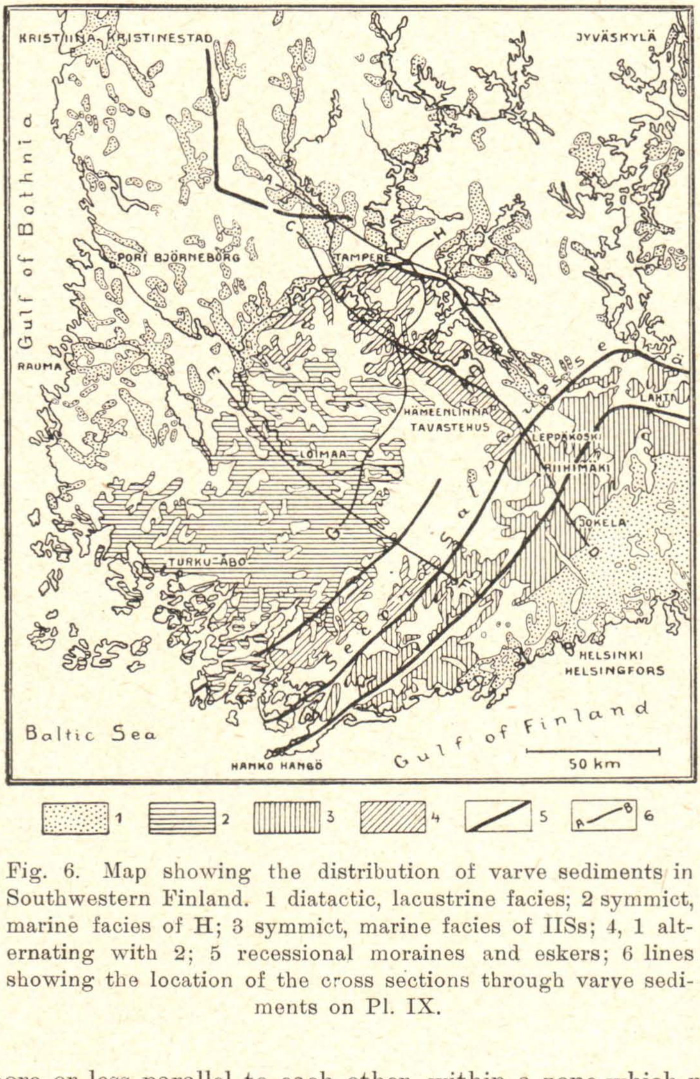

Fig. 6. Map showing the distribution of varve sediments in Southwestern Finland. 1 diatactic, lacustrine facies; 2 symmict, marine facies of H; 3 symmict, marine facies of IISs; 4, 1 alternating with 2; 5 recessional moraines and eskers; 6 lines showing the location of the cross sections through varve sediments on Pl. IX.

run, more or less parallel to each other, within a zone which may be called the *proximal zone* of that complex of varves.

The map (fig. 6) illustrates the distribution of the varve sediments and their different divisions within the special area. Owing to the small scale of the map their extension can, of course, be shown in the big features only. Their discontinuous occurrence, however, appears clearly. Those areas without any varve sediments at all are the higher parts of the country. But even in low regions, outcrops of rocks, hills of drift and eskers penetrate the sediment mantle. In spite of their discontinuity, the sediments maintain the same characters within wide areas even in isolated occurrences.

The diagrams (Pl. IX) give a synoptical view of the combination of the observations. They show four imaginary cross sections through the varve sediment within the whole area investigated. Three of them, A—B, C—D, and E—F, are parallel in a northwesterly direction, as indicated on the map (fig. 6) by the same letters. The fourth cross section, G—H, is at right angles to the others, or in a northeasterly direction. The cross sections are schematic in that they have been drawn continuous, although the beds of sediments are discontinuous. The varying height of the sections indicates the relative thickness of the sedimentary beds. As may be understood, the actual thicknesses can be represented between somewhat wide limits only, as it is not possible, from the sections investigated, to determine the thickness of the strata in the whole neighbouring areas, the localities having been chosen with other aims in view. But very good approximate information may be gathered, by considering the extension of the clay fields, the characters of the topography, the thickness of clay beds in bluffs on rivers and brooks, and in wells and borings etc.

The following three circumstances, especially, should appear from the cross sections: (1) *the age of the varve sediments*, expressed as horizons and subhorizons (IISs, H_1, H_2, H_3, and S); (2) *the average coarseness* (by dots and lines); (3) *the mutual arrangement of portions of different grain* (by white and gray).

For specific scrutiny, each horizon and its smaller divisions may be discussed separately, taking first those later than the chronological 0-line, and afterwards the earlier groups.

Description of the Stratigraphical Divisions.

Horizon H. — The proximal zone of horizon H is situated immediately northwest of the 0-line and is bounded northwestward by the proximal line of its uppermost varve which is No. 507. It has been divided into three subhorizons: H_1, H_2, and H_3.

1. Subhorizon H_1 includes varves 1—291, and the proximal line of varve 291 marks the northwestern boundary of its extension. Its distal parts extend in most places to the Second Salpausselkä and farther. Its varves have even been met with, in a well distinguishable development, even outside the First Salpausselkä, in loc. 137 Herrala.

The thickness of the individual varves shows regular variation reaching its maximum at the proximal lines. Here the varves are, in the vicinity of eskers, often 100 cm. thick and more, while it is much less in places far away from eskers. As one proceeds toward the distal parts the varves grow thinner, first very rapidly, within 2 or 3 km. to 1 cm. in average. Thereafter the varves maintain a more uniform thickness, being still after 30 or 60 km. a few millimetres. There are also horizontal variations of thickness in a direction parallel to the proximal lines, the varves being thinnest in the northeast half of the area, between lakes Päijänne and Vanajavesi, and gradually thicker toward the southwest.

The variation in thickness of the individual varves in the vertical sections appears best from the plate of diagrams.

The thickness of the whole subhorizon varies in the same way as that of the varves, in a horizontal direction. Those 291 varves form the thickest bed on the southeast border of the proximal zone, immediately northwest of the O-line. In the distal direction the whole group, like the individual varves, grows gradually thinner and finally tapers out as a wedge. At loc. 1 Leppäkoski, the thickness is 150 cm. The total thickness is less in the northeast than in the southwest.

The coarseness, in the individual varves as well as in the whole subhorizon, shows horizontal variation between the proximal and distal parts and between the northeastern and southwestern parts and, also, vertical variation in the separate varves and varve series.

The proximal parts of the varves consist of the coarsest materials: gravels, coarse, medium and fine sand. Toward the distal parts the material becomes gradually finer, being chiefly silt, silty clay and in a few cases stiff clay. This gradual decrease in grain and the decrease in thickness take place simultaneously. Variation in the grain between the northeast and southwest is also considerable. While the material between lakes Vanajavesi and Päijänne belongs to the groups of sand, silt, and silty clay, the hygroscopicity at Leppäkoski being only 3 as a maximum, the sediments in Högfors, Pusula and Perniö are, for the most part, silty clay and even stiff clays. Hygroscopicity at Högfors is between 3 and 11 (see the diagram, fig. 7).

Among the variations in a vertical direction, attention may first be directed to the individual varves, as the variation in grain within the varve is the most characteristic feature of the late glacial sediments. Over the whole extension of a varve, its lowest portion is made up of the coarsest material and its top of the finest. The transition from the coarser to the finer material is either gradual or sudden, the varve in the latter case being composed of different, sharply bounded small layers or bands. The boundaries of these bands may sometimes be discerned by the naked eye (see fig. 3 and 4 Pl. III). A still better idea of the structure of the varves and the mutual arrangement of different grains may be got from microscopic preparations[1]). The reproduction from a photograph (fig. 11 Pl. VII) shows a varve from loc. 1 Leppäkoski. The average material is silty clay. With the magnification used, the larger grains only may be discerned, while the finer clay particles appear as a grey homogeneous mass. The arrangement of grain pointed out above appears clearly, however. Further, it may be seen that the coarser mass of the lower portion also contains fine grains, but in small amounts. Upward the number of the smaller grains increases and that of the larger grains decreases.

I propose to call a varve in which the different grains are thus assorted a *diatactic* varve.

The next upper varve begins again with coarse materials, and the boundary between the varves is, of course, the more marked the greater the difference is between the coarser and the finer portions of the varves. The difference in colour, due to the different coarseness of grain, makes the boundary line still more pronounced. A comparison between the varve structure at Högfors and Leppäkoski (fig. 3 and 4 Pl. III) is instructive in this respect. If, hower, the varves are composed mainly of materials having the same colour, either light or dark, the determination of the boundaries of the varves may involve considerable difficulty, as mentioned occasionally in the description of the sections.

The whole subhorizon H_1 is, in the northeast of its extension, composed of diatactic varves. The sediment of Leppäkoski is most representative in its kind. In the southwest portion the structure is somewhat different. The arrangement of different materials in this type, however, may be better described in connection with subhorizon H_2, as it is there best developed.

The variation in grain in the whole subhorizon is most marked in the southwest part, especially in Högfors and Pusula. In Högfors, the material passes rapidly from coarse (hygroscopicity 3.9) to much finer. In varves 105—155 the whole material is stiff clay (hygroscopicity 11.5) so that the boundaries between the varves are hard to determine. In spite of the fineness of material, the varves are as thick

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[1]) The preparations have been made by the method of R. Sayles, by impregnating the sediment with Canada balsam dissolved in chloroform, and treating the endurated mass like rock. R. W. Sayles: Microscopic sections of till and stratified clay, Bull. Geol. Soc. Amer., Vol 32, 1920, pp. 59—62.

as and even thicker than the lower and coarser varves. In these fine varves the structure shows most deviation from the diatactic arrangement. In Leppäkoski and other sections near L. Vanajavesi, the dark carbon-rich varve series is equivalent to those varves.

The upper part of this subhorizon in the southwest, again, more resembles the lower part in coarseness.

2. Subhorizon H_2 includes the following 172 varves, or 192—463. In distal direction it extends, in places, as in the valley of L. Vanajavesi (Leppäkoski) and in the neighbourhood of the town Lahti almost as far as H_1, forming its hanging layer. In loc. 2 Högfors and 4 Pusula and in several places nearest the Salpausselkä, its lowest parts only have been found. The separation of this varve series as a special subhorizon was found desirable because of its special facies development, which is greatly different from that of H_1. This facies is most typical in the southwest of the area, to the parishes of Kangasala, Pälkäne and Hauho of Central Häme in the east. In other parts the characters are the same as those of H_1.

The thickness of individual varves varies from the proximal to the distal part in the same way as in the preceding subhorizon. The difference between the northeast and southwest portions also is similar to that in H_1, but the increase in thickness southwestward is considerably greater. The varves of H_2 are, in Central Häme and especially in the southwest, in the region of Tammela—Loimaa—Turku, several times as thick as those of H_1, provided the localities are not very close to the proximal lines of the latter. This appears immediately from the diagrams. The thickening does not take place uniformly in all the varves, but in rhythmical swellings. In Central Häme there are two such swellings. The first and smaller occurs in varves 300—340, and the second, larger swelling, in varves 390—440. Between these swellings there is a depression in thickness which increases northeastward, at the same time as the maximal thicknesses of the swollen varves decrease. Northeast of the large esker which runs through Hauho, Pälkäne and Kangasala, a slight trace of these swellings only may be noted (see diagrams Pl. X and fig. 6 Pl. IV). In the valleys of L. Päijänne, and in the southern part of the Vanajavesi valley (Leppäkoski), the H_2 varves are as thin as the H_1 varves. On the opposite side, in the region Tammela—Loimaa—Turku, the varves of H_2 seem to reach a uniform unusual thickness along the whole series. In places, the thickness of single varves attains 30 cm., and in deeper valleys probably still more, at a distance of about one km. from the proximal line.

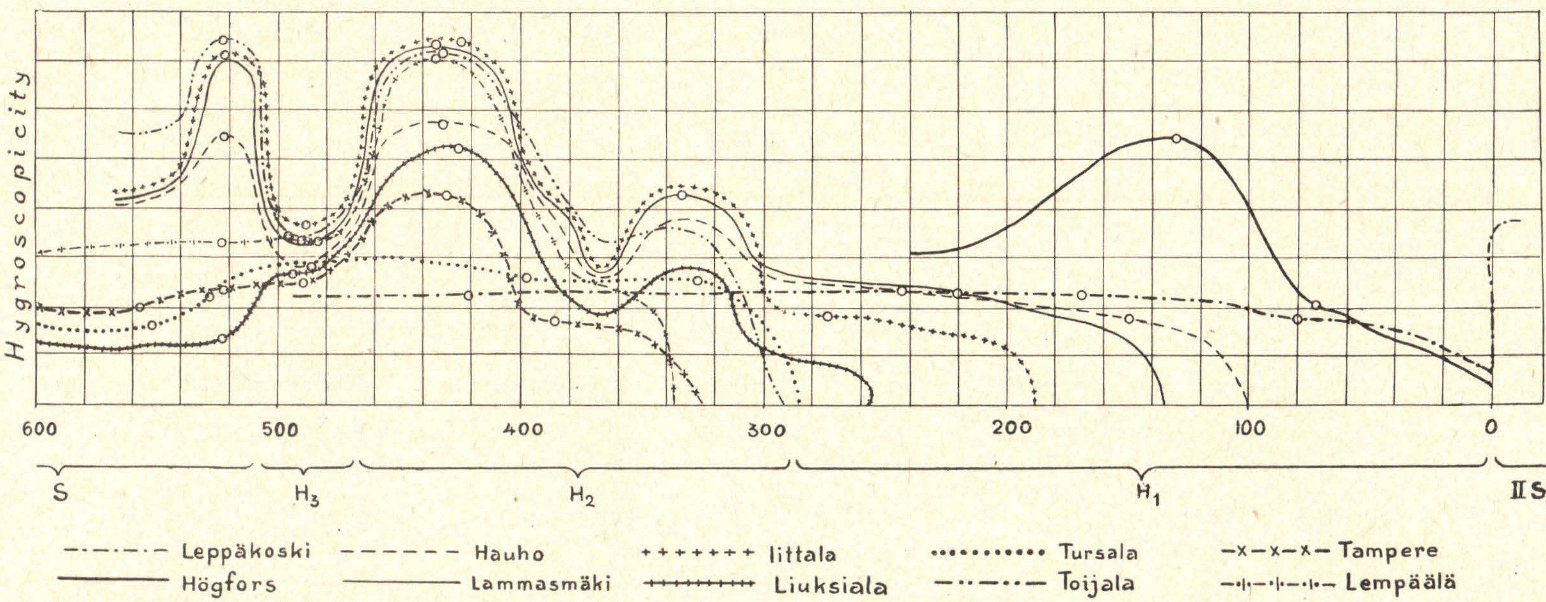
The total thickness of subhorizon H_2 varies in the same way as that of the individual varves, being in loc. 22 Sysmä, the valley of

Päijänne, 35 cm., in 1 Leppäkoski 23 cm., in 24 Kangasala Tursala 50 cm., in 31 Lammasmäki 75 cm., in 38 Toijala 2 m. and in 65 Loimaa more than 30 m. (See fig. 5 p. 53). There the clays, also, are most abundant.

The coarseness of the material varies from the proximal to the distal part, on the whole, in the same way as in the H_1 varves. This is exactly true with respect to the northeast area and the southern part of the valley of Vanajavesi. In the other parts, or in the district where the abnormally thick varves occur, quite different rules hold good. There the thickness of the varves and the coarseness of their materials are in no direct relation to each other at all. The coarseness does not decrease as the thickness decreases. The H_2 varves in the southwest of the area are, in spite of their great thickness, exceedingly fine and belong to the stiffest clays in Finland. The large amount of true clay in proportion to the coarser particles is indicated by the mechanical analyses (see loc. 32 Iittala, 38 Toijala, 59 Loimaa, 80 Lempäälä and 98 Tampere). The high percentage of colloidal materials appears still better from the determinations of hygroscopicity, which constantly show figures above 8, and in most cases as high as 14 or 15, or the highest values generally obtained in Finnish clays.

The variation in hygroscopicity in the different varve series and horizons of the sections investigated has been expressed by a diagram (fig. 7). Each curve is based upon determinations of hygroscopicity (marked by rings), and the intervals between the points determined have been drawn on the basis of other characters expressing the hygroscopisity, as mentioned in connection with the methods of working. Leaving out of consideration the first parts of the curves, referring to the bottoms of the sections, the curves of hygroscopicity in the H_2 clay are parallel to the variations in thickness of the varves (the diagrams). Thus the relation is entirely opposite to that in the sections of H_1, as in the latter the curve of hygroscopicity is at 0 when the varves, at the bottom of the sections, are thickest, and as it rises in the upper part of the sections, the thickness decreases. In the boundary district against the northeast half (locc. 15 Hauho, 93 Kangasala Liuksiala, 98 Tampere) the hygroscopicity gradually decreases. In the valley of Päijänne and in the region of Leppäkoski the grain is just the same as in the upper part of H_1. The last mentioned observation leads to the very strange result, that the distal part of this subhorizon is composed of much coarser average material than the more proximal part in Central Häme. It may be remarked, however, that there are in Leppäkoski two thin reddish bands of exceedingly fine material in the middle part of this varve series. They represent

Fig. 7. Diagram showing the variations of hygroscopicity of the varve sediments in the sections named below.



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the last tapering wedges of those maximums which appear in all the sections of Central Häme.

The great abundance of fine materials and the great thickness of the varves is connected with a third exceptional feature, namely, the lack of assortment of material of different grain. The structure of the varves, especially in its most typical development, as in locc. 33 Iittala, 38 Toijala, 59 Loimaa (see fig. 10 Pl. VI), and many other places where the whole varve is homogeneously dark, differs radically from the diatactic structure. No difference between the finer and coarser portion is noticeable to the naked eye. The varves are separated from each other by very thin lighter bands containing coarser grains (see fig. 8 Pl. V). Now, one might suppose that the high figure of hygroscopicity would indicate that the varve consists entirely of fine materials and that the homogeneity of the varves would be a consequence of this fact. But this is not the case. The mechanical analyses show that coarser materials also are present. In the very thick varves (loc. 59 Loimaa) the coarse materials are even more abundant than e. g. in the lower part of H_1 in 1 Leppäkoski. *The homogeneity of the varves can not therefore result from the uniformity of the particles, but apparently from the fact that the grains of different size are mixed together and not assorted, as in diatactic varves.* The relative abundance of fine materials then characterizes the mixture. This conclusion is confirmed by examination of thin sections under the microscope. Fig. 12 Pl. VII shows a varve from loc. 79 Mattila. It appears undubitably that the varve has been made up chiefly of the very finest materials, in the picture appearing as a grey uniform matrix. In this are embedded some bigger grains, more numerous in the lower part than in the upper. I propose to designate this kind of structure in which the different grains are mixed together as *symmict.*

The symmixis is of a variable degree. The band of coarse material between the varves may be thicker or thinner and constitute a larger or smaller part of the whole. The arrangement of grain in that part is the same as in a diatactic varve. As a whole the varve is diatactic in its lower part and symmict in its upper part. One may find varves of all possible degrees of combination. There are varves in which the symmict part forms only a thin dark band in the uppermost margin of an else diatactic varve. Or, the varve may be megascopically perfectly symmict, so that, in a moist condition, it can not be distinguished from its neighbours, but in drying the finer upper part shrinks away from the coarser lower part, and the boundary of the varves becomes visible, though indistinct. It is quite possible that the distal end of such a varve series may be homogeneous even in its inner structure. In that case no lamination could be traced by any means, not even by microscopical examination.

The proportion of the symmict and diatactic parts may be briefly expressed by fractions. ½-symmict varves are common e. g. in the sections of locc. 15 Hauho, 31 Lammasmäki, 32 Iittala, 36 Pintele, 93 Liuksiala and 100 Tampere (see figg. 8 Pl. V, 6 (a) Pl. IV, 9 Pl. VI). Examples of ¼—1/10-symmict varves are found in the sections mentioned. Almost entirely symmict are for instance some varves in locc. 38 Toijala, and 77 Kylmäkoski.

A special kind of symmixis has been developed in those varves which are composed of more than two sharply bounded layers, as in the sections of 49 Forssa, 59 Loimaa (Fig. 10 Pl. VI) and 80 Lempäälä. As a whole they are diatactic, but these separate parts in themselves are symmict, the uppermost part usually in the highest degree, and the lowest part least.

As mentioned above, the symmixis and the exceptional varve thickness occur simultaneously. This is especially apparent in the boundary district between the southwest and northeast halves, where the H_2 clay includes entirely diatactic as well as partly symmict varve series. The varves are the thinner, the smaller portion of them is symmict. The clay series with thick and partly symmict varves in locc. 15 Hauho, 36 and 16 Pälkäne and 93 Liuksiala are synchronal with the maximums of thickness and symmixis farther west (see figg. 6 Pl. IV, 7 and 8 Pl. V). The meagre diatactic varves between those fat varves correspond with the maximums of depression of both characters in the west.

Now we recognize the meaning of the exceptionally thick H_1 varves in loc. 2 Högfors etc. They also are partly symmict. In varves 105—155 of Högfors the symmixis has developed almost to perfection. In earlier and later varves it is more imperfect.

3. Subhorizon H_3 comprises only 44 varves, or 464—507. It extends, in the distal direction, less far towards the southeast and south than the subjacent H_2. It has been met with in locc. 22 and 23 Sysmä, 17 Luopioinen, 31 Lammasmäki and 1 Leppäkoski, but has not been proved definitely to be present in the Loimaa region, though it is probable that it exists as a part of the thick beds of sediments in this tract.

The thickness of the varves is between 0.5 and 0.1 cm. or very small; greater thickness occurs near the proximal lines only. In the northeast section it is almost the same as that of H_2, but in the southwest it is much smaller. The thickness of the whole series is in loc. 109

Sirkkala 35 cm., 105 Vahanta 35 cm., 38 Toijala 20 cm., 31 Lammasmäki 13 cm., 17 Luopioinen 9 cm., 22 and 23 Sysmä 8 cm.

The grain in the proximal part is like that in the preceding subhorizons. In the more distal part in the northeast, the tract of Tampere, and in the whole of Central Häme as far as Leppäkoski (the material as a rule is silty clay. Hygroscopicity varies from 5.5 to 7. The structure, at the same time, is always diatactic. This subhorizon is not, however, quite uniform in this respect, for in the southwest section there appear varves similar to the H_2 varves in this tract: thicker, fine, symmict. They become more and more numerous as one proceeds southeastward (see figg. 7 and 8 Pl. V). In locc. 76 Sammaljoki and 71 Vampula they all show these characters. This subhorizon is here, like H_2, quite different from what it is in the central part of the area and in the northeast. These features are well illustrated by the curves of hygroscopicity in these two subhorizons (fig. 7).

Horizon S. — Horizon S comprises the youngest of the clay varves within the area investigated, from 508 to about 700. In the distal direction, this horizon spreads at least as for as to locc. 22 Sysmä and 21 Padasjoki, and 1 Leppäkoski. In the southwest, it has been met with in loc. 72 Säkylä, but very likely it exists still farther southeast.

This horizon may be identified in all the sections from its thick varves, which are the more striking in their contrast to the meagre H_3 varves. The first varves, as a rule, are thicker than the later. In the northeast, in loc. 134 Jämsä, 97 Orivesi and 105 Ylöjärvi, the thickness of the varves in the lower part varies from 3 to 7 cm., thus being 20—30 times as thick as that of the subjacent H_3 varves. In loc. 111 Hämeenkyrö Laitila the thickness is as much as 15 cm., but elsewhere in the southwest the difference from the next lower series is not so great. Farthest in the distal parts, the thickness remains considerable in Central Häme, but drops to a few millimetres in the south end of the valley of Päijänne and in loc. 1 Leppäkoski.

The total thickness in the tracts of Tampere—Hämeenkyrö is from 150 to 200 cm.

The great thickness of the varves in the lower part of this horizon is mostly connected with a great coarseness of the material. In Central Häme, however, the varves are mainly composed of fine clay. The material of S is also finer than usual in the sections of 109 Hämeenkyrö and 116 Vammala and other localities northwest of these, having thick and reddish finer layers. This great variability of the grain causes the curves of hygroscopicity to divide into two bunches at the passing from H_3 to S. In the sections of the region of Tampere they fall (the coarse grained facies), in the sections of Central Häme they rise (the fine grained facies).

The structure in the coarse grained varves is, again, diatactic, and in the fine grained varves, symmict.

As appears from the features now described, the structure of horizon S is, unlike that of horizon H, almost identical in the northeast and the southwest seetions of the district. The same is true as tho the regional distribution of clay: the southwest section, does not contain any more S clay than the northeast section. The coast belt of Satakunta, where varve clays of horizon S and Litorina clays only exist, is therefore much poorer in clays than the Loimaa-Turku region and Central Häme.

Horizon II Ss. — In passing from horizon H to older varves backward in time, the next horizon is II Ss. It comprises nearly 200 varves whose proximal lines lie within the belt of the Second Salpausselkä. Thus the varves do not overlap in the ordinary manner, but their proximal lines almost coincide. In distal direction this horizon extends to the First Salpausselkä and outside of it. South of the town Lahti in loc. 137 Herrala, in 138, 139 Jokela, and in 140 Nurmijärvi Numlahti, 10 km. south of the First Salpausselkä, it is still well developed.

This horizon is characterized by varves of exceptional thickness: in loc. 1 Leppäkoski from 14 to 1.5 cm., in 136 Mukkula from 13 to 0.5 cm., in 138, 139 Jokela and 140 Numlahti (in the lower part) from 4 to 2 cm. The total thickness is therefore great: in Leppäkoski 6 m., in Mukkula 1.5 m., in Jokela, in deeper depressions in which almost the whole horizon is present, about 2 m. East of the town Lahti, in the higher regions between the Salpausselkäs, the thickness is less than 0.5 m.

In the lower varves of Leppäkoski the material is very coarse, the chief part being coarse and fine sand. In the upper parts, stiff violet clay is dominant in the finer layers of the varves, but the coarser layers still contain sand and silt. Hygroscopicity in the uppermost varves is 7.4. In Launonen (Südfinnland, loc. 64) the material is of the same kind. In all the other places mentioned above, and also in Anianpelto (Südfinnland, loc. 61) the varves, abnormally thick for the distal region, are composed mainly of the finest clay. Hygroscopicity in Jokela is 12, in Lahti and Numlahti probably about the same, as the other physical characters are identical.

The structure in Leppäkoski, in the lower varves, is diatactic, and in the upper parts, partly symmict. South of the Salpausselkä, in Lahti, Jokela and Numlahti, the lower varves are almost entirely symmict. In the upper part, the varve structure almost disappears. The same is the case in the parish of Vihti, locc. 141—150. In Herrala and east of the town of Lahti the material of this horizon is perfectly homogeneous. Even in loc. 136 Mukkula the lowest varves are indistinct.

Horizon iSs. — This horizon comprises about 250 varves, or — 200 — — 431 (in Südfinnland, Pl. II varves — 185 — — 431). The proximal zone of this horizon occupies the belt between the proximal lines of the varves mentioned, or the belt between the Salpausselkäs. Of the varves, about 150 have the proximal lines close to each other near the First Salpausselkä. In their distal direction, the horizon iSs extends at least as far as the overlying IISs.

The thickness of the whole horizon is in loc. 136 Mukkula 450 cm., in 137 Herrala 250 cm., in 138 Jokela and 140 Numlahti 120 cm. The individual varves in the more distal parts have almost uniform thickness. In Jokela and Numlahti the lowest 140 are thicker than the next.

The material is everywhere coarser than in IISs. The proximal parts between the Salpausselkäs are rich in sand and silt. In the more distal parts the clayey finer layers are more prominent. In Jokela especially, the two lowest series consist of stiff clay, hygroscopicity 8.8. The uppermost series, again, belongs to silt, hygroscopicity 3. Variation in the same direction may be noticed in Numlahti and Herrala.

The structure in the Salpausselkä zone is generally diatactic. In the distal parts only, some of the varves are symmict, e. g. in Jokela and Numlahti.

Horizon ISs. — About 230 varves (in Südfinnland Pl. II. varves — 432 — — 660). Their proximal zone, almost reduced to a line, is at the First Salpausselkä.

The total thickness of the proximal part in Herrala and Numlahti is 200 cm., in Jokela 125 cm. The thickness of individual varves is small as compared with those of the preceding horizons. In Herrala, the average thickness is 0.9 cm., in Jokela 0.5 cm.

The material in the more distal part is clay, though not comparable in fineness to the IISs material. This appears from the hygroscopicity which, in Jokela, in the most fine grained upper part of this horizon, does not exceed 4.8. In Herrala and Numlahti, it is apparently still less.

The structure is diatactic.

The older varve series, designated as aSs, have not been studied very closely except in Jokela. They are in structure similar to ISs, but lamination is generally more distinct, the material being coarser. The structure is diatactic.

Review. — The classification presented in the preceding chapters opens a view of the dominant features in the distribution of different facies of laminated sediments in southwestern Finland. First, a marked general difference may be noted on each side of the 0-line, the Second Salpausselkä. In the sediments deposited after that epoch, chiefly in H but also in S, the difference between the northeast and southwest facies is marked, while those earlier than the 0-varve have more uniform characters throughout the area. The change in facies, here mainly takes place vertically from one horizon to the other, and horizontally toward the southeast, the distal direction. Among the horizons starting from the belt of Salpausselkäs, ISs and IISs are alike in that their proximal zones are very narrow or almost reduced to lines, marked by the First and Second Salpausselkä. In their structure, however, they are in many respects contrary to each others. The material of the varves of ISs is silt and silty clay, the thickness is small and structure diatactic, while the material of IISs is finest clay, and the varves thicker than usual, — both features connected with symmict structure.

iSs mediates the transition from horizon I ss to IISs, not in position only, but also in structure. Where all three horizons occur upon each other, the thickness of the varves in iSs is smaller than in IISs but larger in ISs. In grain, the ISs-clay likewise represents a transitional stage. The structure in a large part of horizon iSs in the southwest is partly symmict, farther east entirely diatactic.

Excepting the change in structure just mentioned, each horizon maintains its characteristic features almost throughout the area, as mentioned above. They are thickest near the bend of the Salpausselkä belt on each side of the line drawn from Jokela to Leppäkoski. The thickness of the sedimentary bed attains here, according to the observations, as much as 10 m. but it comprises varves of horizon H also. Toward the northeast and east the thickness decreases, at least upon the higher Salpausselkä belt. South of it, on the other hand, sediments are abundant as far east as in the tract of the Kymi river. Southwest of the Leppäkoski—Jokela line the area covered by varve sediments, and apparently also their total thickness, decreases, although the thickness e. g. in the parish of Vihti may be several metres even upon the higher hills. The surface of the rock foundation in it self is very uneven here.

In passing from the area last described to the inner side of the Second Salpausselkä, one is surprised by the great change that may be noticed in the laminated sediments. It is most striking in the northeast, e. g. in the tract between lakes Vesijärvi and Päijänne. Outside the recessional moraine large amounts of sediments, among which are true clays, continue to the foot of the Second Salpausselkä. Inside it the sediments are very sparse and what are found represent the coarser kinds only. In the southwest, in the tract of Högfors and Pusula, the difference is much smaller, sometimes scarcely noticeable, horizon H being here thick and fine-grained and IISs not showing its most characteristic feature. But still farther southwest, in the parishes of Karjalohja (Karislojo) and Pohja (Pojo), the Second Salpausselkä forms a sharp boundary between two different kinds of laminated sediments similar to that in the northeast.

As emphasized several times in the preceding pages, there is a marked difference between the varve sediments of the northeast and southwest halves of our area. The halves are not separated by any sharp boundaries, which is quite natural, the variable features being so many.[1])

[1]) The difference in the coarseness of the clay sediments of the central and the coast region has long been known (J. J. Sederholm, Om istidens bildningar i det inre af Finland, Fennia 1, N:o 7, 1889).

Chapter V.

Deposition of Sediments in Water.

Need of Investigation.

The stratigraphy of the varve sediments in southern Finland, as described in the preceding chapter, raises several problems: What is the reason of the great difference in the sediments in the southwestern and northeastern halves? Why does the facies of the sediments present repeated variations, even in one place? Are there any material conditions of formation which control the development of structure, either diatactic or symmict? And finally, has the varying pace of the recession of the ice-border had any influence upon the origin of the laminated sediments?

It is clear that the variation in the varve sediments must be caused by a variation of the conditions prevailing during the deposition of the sediments. The factors controlling sedimentation have not been the same everywhere, nor have they remained unchanged anywhere. But our knowledge concerning these variations is so far incomplete, and the sediments, which surely should give the clue to the conditions, are only very vaguely known. The investigations done so far are not directly applicable and to do not give any satisfactory answers.

The problem of sedimentation may be attacked from two different sides: (1) by following the course of fine drift on the front of existing glaciers and (2) by experiments and mathematical calculations. The late glacial sediments may then be investigated in the light of the results obtained in either of these two ways.

Deposition near existing Glaciers.

The former method no doubt is the better for clearing up the factors controling the deposition of the sediments in question. Investigations in this direction, at least so far as checking of the chronological method and explanation of the varve sediments is concerned, are so far rather scanty. Some of the most important features, however, are clear. It is known that the clay matter has been derived from the drift of the glacier from which it has been carried, mainly by streams of glacial water, to ice-ponded lakes or to the sea[1]). The amount of suspended matter depends upon the amount of water, and its concentration in the suspended matter, which is very variable in different glaciers. Besides this, there are smaller or larger seasonal variations with maximums in the summer and minimums in the winter. Reid[2]) estimated that 15,000,000 m^3 of sediment was the yearly product of the Muir glacier, from all its glacial streams. The corresponding figure in the case of Unteraar glacier in Switzerland is, according to Heim[3]), only 6,000 m^3.

Water into which glacial streams have flowed contains suspended matter almost as uniformly distributed as a homogeneous solution. According to Reid[4]) the sea water near the Muir glacier contains in suspension an average of 12 grm. a litre. The amount increases steadily toward the sea bottom and the edge of the glacier. Helland[5]) quotes from several glaciers of Greenland and Norway smaller figures varying between 2 and 0.5 grm. per litre.

The observations made near the Muir glacier show that even the finest suspended matter settles quickly from salt water, as the water at a distance of a few kilometers from the glacier contains only a very small amount of suspension and farther away is quite clear. This is due to the flocculation (coagulation) of the clay particles by the salt water.

The vast quantity of sediment in the front of the Muir Glacier is therefore deposited within a comparatively small area, and forms thick beds. From calculations as well as by direct observation, Reid finds that Glacier Bay shallows by nearly three metres in a year through sedimentation.

In fresh water the clay particles remain suspended much longer than in salt water, and are therefore carried farther from the glaciers. In the Lake of Geneva, for instance, they get as far as the outflow of the Rhone river[6]). It is only in the winter, especially when the wave motion of the water ceases as the ice forms, that the finer material

1) Cf. e. g. E. v. Drygalski, Grönland-Expedition der Gesellsch. für Erdkunde zu Berlin, 1897, p. 441.

2) H. F. Reid, Glacier bay and its glaciers, U. S. Geol. Survey, Sixteenth. Ann. Rept., pt. 1, 1894—95, p. 458.

3) A. Heim, Handbuch der Gletscherkunde, 1885, p. 363.

4) H. F. Reid, op. cit. p. 457.

5) A. Heim, op. cit. p. 363.

6) A. Heim, op. cit. p. 362.

settles. The sediment thus formed is light and fine grained, and has regularly alternating coarser layers of sand and finer layers of clay. It would probably not be impossible to prove from nature that these layers represent respectively the summer and winter deposits.

Experiments on Sedimentation and Mathematical Calculations.

Deposition in fresh water. — The deposition of clays in glacier lakes and in the sea may be very well imitated on a small scale in the laboratory. It is thus possible to follow the process at close quarters. Such experiments have been carried out in several places and for different purposes, and many important questions have thus been cleared up. The results obtained during the later years are especially due to the quick development of colloid chemistry, a science in whose domain the clays may be included. The deposition of clay takes place in very different ways from fresh and salt water, and the laws controlling its deposition are those of the coagulation of dispersed suspensions in general.

In fresh water free from electrolyts, deposition results from the settling of each particle separately, the rate of sinking depending upon the size (and form) and density of the particle, provided there is no disturbance by convection currents, variations in temperature, and other factors that influence the velocity of sinking. The density of all the mineral constituents of glacial sediments being very nearly the same, it may be assumed without any considerable likelihood of error, that all the particles of the same size sink at the same rate. The rates are as follows, according to the experimental results of Atterberg[1]):

Diameter of the grain less than	Sinks a distance of 10 cm. in
0.06	50″
0.02	7′30″
0.006	1 h
0.002	8 h

The increase of rate of sinking with the increase of the grain, expressed quantitatively by the above figures, is the basis of mechanical analysis by Atterberg's method (see p. 17).

[1]) A. Atterberg, Die mechanische Bodenanalyse und die Klassification der Mineralböden Schwedens. Intern. Mitt. f. Bodenkunde Band II, 1912, p. 319.

The rate of deposition on the bottom of a containing vessel has been investigated by Odén[1]) mathematically and experimentally, with a special apparatus. The results obtained in the two ways agree surprisingly well with each other and also with earlier results. The following of his results may be quoted: If the suspension is perfectly uniform and of equal grain, the rate of deposition on the bottom is directly proportional to the amount of solid matter suspended, and inversely proportional to the thickness of the layer of water, but independent of time. In other words, the more matter is suspended and the thinner the layer of water, the quicker the deposition of sediment, which is the same in each unit of time.

It is different in non-uniform systems, i. e. when particles of varying size are suspended at the same time, as in all natural clay suspensions. The amount of suspended matter and the thickness of water has the same effect as before, but the rate of deposition also varies with time, as each group of grains settles at its own definite pace. Grains of each size, of course, begin to reach the bottom at once, but the bulk of each group of grains settles separately, the coarsest first and then the finer in order of size. The rate of deposition is therefore greatest at the start and is gradually retarded, the rate of retardation being first quick, but slower afterwards when only the finest groups of grain are settling. Odén has expressed the rate of deposition by a curve, derived from experiments and from mathematical deductions. The rate of deposition, also, increases with temperature.

Deposition in salt water. — In salt water, deposition takes place in a different way. The settling of finer materials is much quicker than in fresh water. This appears from the fact that salt water becomes clear in a few hours, while fresh water remains turbid during several months, from suspended clay particles. The same phenomenon has been observed in nature also, as stated above (p. 90). In colloid chemistry, the precipitation from salt water is understood as being caused by changes in the electrical charges of the particles, due to the electrolyts[2]). Instead of keeping away from each other, the primary particles now group together into larger aggregates which sink at the same pace as primary particles of the same size do in fresh water. Deposition therefore takes place as if there were no finer materials present and is soon complete. This *coagulation* of colloidal materials

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[1]) S. Odén, Automatisch registrierbare Methode zur mechanischen Bodenanalysen, Bull. Geol. Instit. Upsala, Vol. XVI, 1919, pp. 15—64.

[2]) R. Zsigmondy, Kolloidchemie, Leipzig, 1918, pp. 69—73.

is a phenomenon not yet perfectly understood. The following general conclusions have been arrived at chiefly by experiment[1]):

»The percentage of electrolyts must reach a definite limit before coagulation will begin. This limit is higher for small particles than for larger ones.

The velocity of the flocculation of the particles increases greatly with the number of particles per unit of volume, as well as with the quantity of electrolyts in excess of the limit.»

A non-uniform suspension coagulates more quickly than a uniform one, as pointed out by G. Wiegner[2]) (on the basis of the results obtained by his coinvestigator René Gallay). The bigger grains attract smaller ones as they move down, and thus act as »germs» of coagulation (Koagulationskeime).

»Certain substances present in very small amounts, the so-called protective colloids, may prevent coagulation, or raise the limits very considerably. The humus substances are especially important on the coagulation of clays.»

»The limits are quite variable for different salts. Finally, it is important for the coagulation of clays that not only is the flocculation *reversible,* but that it is possible, by means of gentle agitation or movements within the liquid, and without removing the coagulating agent, to disperse the flocculation and separate the coagulated parts again completely into the primary particles.»

Factors of the latter kind, such as whirls, convection currents, and horizontal movements of water, must also be taken into consideration when the water is free from electrolyts, or fresh. The influence of the two first-mentioned kinds of movement is exceedingly difficult to investigate, and seems to be restricted to local cases.

Deposition in running water. — The horizontal movements of water, on the other hand, seem to be much more common and of cardinal importance for the varve sediments. To ascertain theoretically the character of this factor, I consulted Dr J. W. Lindeberg, Professor of mathematics. He kindly undertook the calculation of the deposition of non-uniform clay suspension from water moving horizontally, the particles sinking without coagulation each at its own rate, as in the cases discussed above. The main purpose was to find out what would be the shape and structure of the bed of sediment at the bottom. I quote the explanation given by Professor Lindeberg:

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[1]) S. Odén, Allgemeine Einleitung zur Chemie und physikalischen Chemie der Tone. Bull. Geol. Instit. Upsala. Vol. XV, 1916, pp. 175—194.

[2]) Georg Wiegner, Agrikultur- und Kolloidchemie, Kolloid-Zeitschrift, XXXI, 1922, p. 273.

»Suppose water running as a horizontal stream of breadth l and depth k with and equal velocity v. The question is, how the amount of matter which is at a certain moment concentrated in a section L at right angles to the stream, will be deposited at the bottom. Suppose the stream cut in a longitudinal section; take the intersection of this section with the bottom as the axis x, and its intersection with the plane L as the axis y (fig. 8). Suppose the matter in plane L to be composed of particles which have different rates of sinking, η, in such a way that each rate is represented uniformly in all parts of the section L. $V(\eta)\,d\eta$ may be the total volume occupied by the particles whose rates of sinking are between the limits η and $\eta + d\eta$, when deposited on the bottom. Only particles whose velocities are between the limits m and M $(m < M)$ are taken into account.

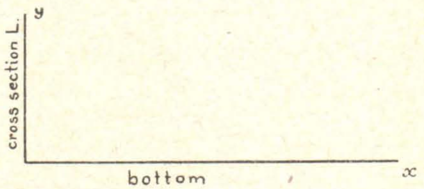

Fig. 8.

The particle of the class or the velocity η situated originally at the top of the water, reaches the bottom at a distance $\frac{kv}{x}v$, and the swiftest particle which reaches the bottom at the distance x has the velocity $\frac{kv}{x}$. Of the class of velocities $(\eta, \eta + d\eta)$ remains within the distance $(x, x + dx)$ an amount of the volume[1])

$$\frac{V(\eta)\,d\eta}{k} \cdot \frac{dx}{v}\eta,$$

which there gives the height of sediment

$$\frac{V(\eta)\eta}{lkv}\,d\eta.$$

The total thickness of sediment within this distance, $P(x)$, will therefore be

$$P(x) = \int_{m}^{\frac{kv}{x}} \frac{V(\eta)\,\eta}{lkv}\,d\eta.$$

This equation, however, does not apply to those values of x which are larger than $\frac{kv}{m}$, as no sediments would form here, nor to those values smaller than $\frac{kv}{M}$, as in that case the thickness would remain unchanged, or the same as at the distance $x = \frac{kv}{M}$.

[1]) The sediment is here supposed to fill the space entirely, without any pores.

If we suppose that

$$V(\eta) = A\, l\, \eta^{\alpha},$$

where A is constant, we obtain

$$P(x) = \frac{A}{(\alpha+2)\, kv} \left(\frac{(kv)^{\alpha+2}}{x^{\alpha+2}} - m^{\alpha+2} \right).$$

Two cases in which the results seem to approach the actual conditions may be treated somewhat more closely.

a) Suppose $\alpha = -1$, i. e.

$$V(\eta) = \frac{A\, l}{\eta},$$

in which case

$$P(x) = \frac{A}{x} - \frac{A\, m}{kv}.$$

Suppose further (cm. and sec. as units), $m = 10^{-5}$, $M = 1$, $v = 10^{-1}$, $k = 10^4$ (or 100 metres) and $A = 5.10^5$. Then

$$P(x) = \frac{5 \cdot 10^5}{x} - 5 \cdot 10^{-3},$$

or, if the distance x be expressed in kilometres and the thickness of the sediment layer in centimetres:

$$P(x) = \frac{5}{x} - 0.005$$

The bed of sediment, in this case, would extend 1,000 km. from the starting point and its thickness would begin to decrease at 10 metres. The thinning out appears from the following diagram (fig. 9)

The thickness of the bed of sediment depends upon the supposed velocity v in such a way that an increase of the velocity causes the

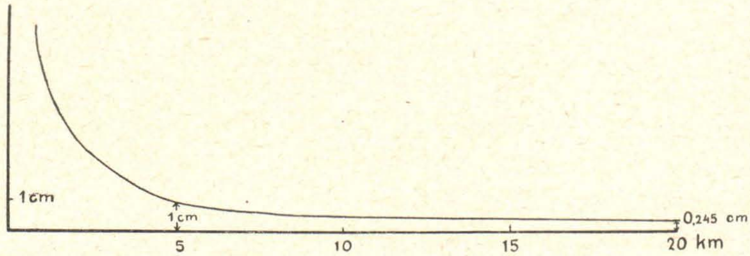

Fig. 9. Section through a theoretical varve. Starting point on the left hand side.

first part of uniform thickness to become thinner, while the layer farther away from that point in which it begins to thin out becomes thicker, although in a very small degree.

b) Suppose $a = -3/2$ or

$$V(\eta) = \frac{A\,l}{\eta\sqrt{\eta}}$$

In that case

$$P(x) = \frac{2\,A}{\sqrt{R\,v}} \cdot \frac{1}{\sqrt{x}} - \frac{2\,A\sqrt{m}}{R\,v}$$

Suppose further $m = 10^{-5}$, $M = 1$, $v = 1$, $k = 10^4$ and $A = 10^{\frac{9}{2}}$. If the distance x be expressed in kilometres, then

$$P(x) = \frac{2}{\sqrt{x}} - 0.02$$

The bed of sediment extends, in this case, 10,000 km. from the starting point and the thinning begins 100 metres from the starting point having, in the initial part, a thickness of about 6 cm.

With the increase of the velocity of the water, the thickness of the bed decreases to a distance of 2,500 km. from the starting point, but thereafter it increases.

The value of A depends, in all cases, upon the total quantity of matter. Its value has been so chosen, in both special cases, that the bed, at a distance of five kilometres from the starting point has a thickness of 1 cm. appr.

The velocities of water are, expressed in metres per 1 hour, in case a) 3.6, and, in case b), 36».

In these calculations, the suspended matter is supposed to be evenly distributed all through the layer of water which starts to move with a constant velocity in a horizontal direction. The motion of each particle then consists of two components, the horizontal which is the same for all, and the vertical which depends on the size of the particle. The resultant is an oblique falling motion. In this case, just as in falling from motionless water, the class of coarsest grain reaches the bottom first, but the grains that have started from a definite vertical cross section do not settle upon one cross line but spread themselves out in the direction of propagation. The uppermost row of grains, which has the longest falling time, moves farthest; the other grains remain between this place and the starting point. The next smaller class of grain reaches, on the whole, the bottom somewhat later and spreads out like the former but extends farther from the starting point. The same is true concerning all the following classes of grain. The smaller their velocity of falling, the farther they move in the horizontal direction.

The amount of sediment deposited is largest near the starting point and the longitudinal section of the upper surface of the accumulated bed is therefore a curve of the type shown in fig. 9. The general form of the curve is expressed by the equation quoted above. When its variable members are given definite values, the course of the curve becomes definite. With the increase of the horizontal velocity the curve becomes steeper in its first part, or the layer becomes thicker at the source of sediment, or »debouchure». The increase of finer materials, again, causes a thickening of the distal part and the extension of the layers in this direction.

As the sediments are actually porous and do not fill up the whole volume, the bed will be, along its whole length, thicker than shown by the calculation. On account of variations in porosity, this thickening also varies, but the deviation from the theoretical curve due to this cause does not alter the general character of the curve more than the other variable factors.

The calculation also gives account of the arrangement of grains of different sizes in the deposit. The coarseness accordingly decreases in the horizontal direction and, also, in the vertical direction from the bottom upward, although there are, among the coarse grains of the lower part, some finer particles which originally happened to be nearer the bottom, and therefore had been deposited together with coarser grains carried from a greater distance. *The arrangement of grains is therefore similar to what has been earlier called diatactic.*

Considering the effect of coagulation together with horizontal currents, the conclusion is that the finest primary particles coagulate, and sink as larger secondary particles, nearer the starting point than when no coagulation takes place. Deposition is therefore much quicker, and great quantities of primarily fine particles are deposited in the initial part. The same deduction has been presented by Sayles[1]), and Reid's[2]) observations at the Muir Glacier are in good accord with these conclusions.

A conclusion pointing to the same direction was early drawn by Högbom from experiments on the settling of clay in fresh and salt water[3]).

The section of the bed deposited in salt water is therefore different from that of a bed deposited from water containing no electrolyts.

[1]) R. W. Sayles, Seasonal deposition in aequeoglacial sediments. Memoirs Museum of Comp. Zoöl. Vol. XLVII, N:o 1, 1919, p. 33.

[2]) H. F. Reid, Glacier bay and its glaciers, U. S. Geol. Survey Sixteenth Ann. Rept., pt. 1, 1894—95, p. 456.

[3]) A. G. Högbom, Studier öfver de glaciala aflagringarna i Upland, Geol. Fören. Förhandl. Bd. 14, 1892, p. 288.

It depends greatly upon the intensity of coagulation, but in any case the bed becomes *shorter* (or *narrower*, if it starts from a line) and *thicker* than without coagulation.

The arrangement of grains of different size is also different, as the fine particles sink, as secondary aggregates, at the same time as the larger primary grains, and are deposited together with them. When a layer thus formed is investigated with regard to the primary grain, as happens in the mechanical analysis and determinations of hygroscopicity, much *greater quantities* of fine matter are found among the coarser grains than in a bed deposited, under similar conditions, from fresh water. *In other words, the different classes of grain are mixed together*, and the degree of mixing is the greater, the quicker and stronger the coagulation has been. This kind of arrangement of the material, occurring at different stages of development in some of the varve clays studied, has been called by me *symmict*.

Periodical deposition. — Diatactic structure cannot be formed unless the suspension be discharged into the water at one time, or discontinuously. During the period of pause following the addition of matter, even those particles that have the smallest rates of sinking have time to sink *alone*. This would not happen, if the material were carried by a uniform continuous stream, but the sediment would, in that case, become symmict even without coagulation. But if a new portion of clay suspension be added after the settling of the finer materials during the pause, a new diatactic bed will form upon the first one, and the coarser lower part will contrast against the fine upper part of the former bed. Thus one diatactic bed after another is formed periodically; the beds are, of course, similar in shape and have similar coarseness in their corresponding parts, provided the controlling factors, the horizontal velocity of water, the depth of water and the amount of suspended matter remain constant. The deposit from each period, then, is a *varve*. A series of depositions is a *varve series*.

If coagulation takes place, the periodical deposits are not distinctly separated from each other, as all their parts are rich in fine materials. Only if coagulation is comparatively slight may fairly large amounts of coarse matter reach the bottom early in the process of deposition, and in that case may the periodical deposits, or the varves, be clearly distinguishable.

An important factor in the formation of a series of varves is the position of the line at which the matter is discharged into the water in each period of deposition. In the case of glacial varve sediments, the following cases may occur:

1. The line along which the suspension is discharged does not move; the varves will then lie exactly one upon another. 2. It moves backward, i. e. in a direction opposite to the horizontal stream of water, during each period; the varves will overlap each other. 3. Similar movement forward, or in the same direction as the water. 4. Combinations of these simple cases.

A cross section through a series of deposition, or varves, shows a definite character in each of these four cases.

In case 2 the section cuts, from the bottom upward, successively more distal parts of the varves. If the varves are all alike (diatactic) and their proximal lines are at the same distance from each other, a diagram showing the gradual upward decrease of varve thickness assumes the same general character as a section through a *single varve* from the proximal to the distal direction. (cf. fig. 9). At the same time, of course, the coarseness of material also changes upward, in the same way as it does in a single varve in a horizontal direction.

In case 1 every varve in a section has the same thickness and coarseness. The other cases may be easily derived from these two cases.

Chapter VI.

Record of the Varve Sediments in Southern Finland.

Origin and Periodicity.

Spreading of the varves from the proximal lines. — The varve sediments are, in their mode of occurrence, structure of the varves, and characters of the material, similar in all details to beds deposited in water from non-uniform clay suspension. The thick and coarse grained proximal parts have the characters of the bed deposited nearest the place where the material has been discharged in each period of sedimentation, while the gradually thinner distal parts correspond with the parts of the bed respectively more distant from the starting point.

In Southern Finland, the proximal lines of the varves run in a northeasterly direction, and the varves grow thinner toward the southeast, in the direction of the motion of suspension. The thinning out, in the proximal part of the varves, is very rapid. The normal average thickness of the varves is attained within a few kilometres, and their decrease of thickness thereafter is slight. As an example may be mentioned the diatactic varve no. 485 in the centre of the area. In loc. 112 Mouhijärvi, 0.5 or 1.5 km. from its proximal line, it is 30 cm. thick and consists of sand; in 109 Sirkkala, 4 km. from the line, it is 1 cm. thick and consists of silt; in 83 Vesilahti, 22 km., 0.7 cm., of silty clay; in 38 Toijala, 50 km., 0.4 cm., of silty clay whose hygroscopicity is 6.36; in 32 Iittala, 67 km., 0.2 cm., of clay, hygroscopicity 7.3. This varve still exists in loc. 1 Leppäkoski, 120 km. from the proximal line. The cross section of this varve, as well as of many other diatactic varves, is very nearly identical with what a varve should be according to the above experiments and calculations. Some deviation is a matter of course, for the variation in depth of water and velocity of the currents, local whirls etc. are all factors that must have played a certain rôle.

Such close agreement in thickness and coarseness of material of the proximal parts of varves with the theoretical beds is, however, only found in rather small portions along the proximal lines of varves. Most of the sections show more distal characters, i. e. thinner varves and finer material, all through. The observations prove, that coarse grained thicker proximal parts exist near longitudinal eskers only, e. g. in sections 14 Tuulos, 15 Hauho, 36 Pintele, 99 Messukylä, 98 and 100 Tampere, 102 Epilä, 103 Nokia and 112 Mouhijärvi, all situated near a big esker. Examples from the vicinity of other eskers are: locc. 20 Maakeski, 17 Aitoo, 12 Vanaja, 31 Lammasmäki, 35 Voipaala, 83 Vesilahti Vakkala, 49 Forssa, 71 Vampula, 72 Säkylä, and 132

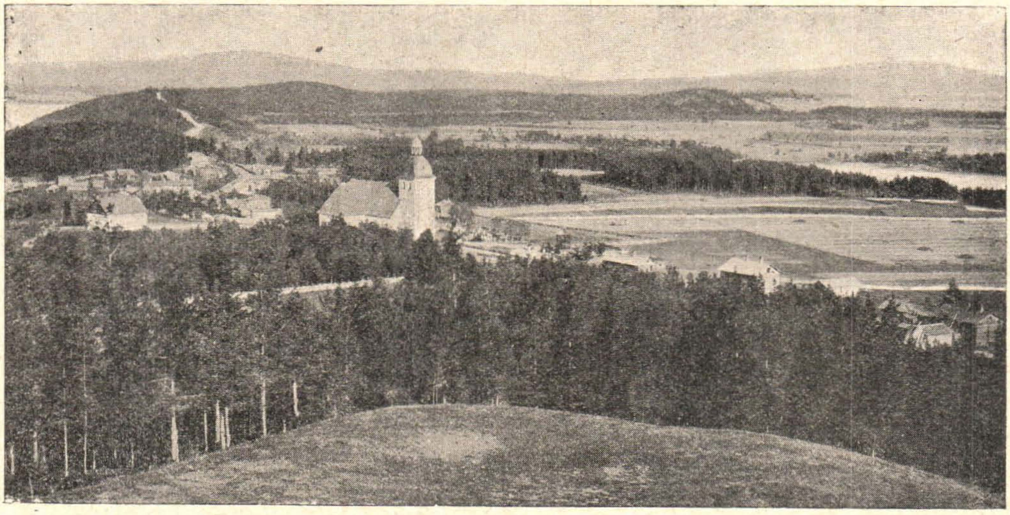

Fig. 10. View of the Kangasala esker in Häme (Tavastland).

Nakkila. Sections representative of distal characters near the proximal lines are e. g. 94 Kangasala Tursala, 95 Lihasula, 105 Ylöjärvi Vahanta, 109 Sirkkala, 85, 86 and 87 in South Pirkkala, 33 Kuurila, 78 Viiala, 66 and 67 Loimaa. The sections of 38 Toijala and 77 Kylmäkoski, though near small longitudnial eskers, are of the same kind. The sections 93 Liuksiala and 22 Sysmä, on the other hand, show coarse and thick proximal parts of varves although no large longitudinal eskers exist in their vicinity.

All these observations may be accounted for by assuming that the discharge of material has not happened uniformly along the whole proximal lines, but in isolated places, several kilometres from each other, chiefly near eskers. The thickening of the proximal parts, and the increase of grain in these parts toward the eskers, undubitably proves that the materials of the eskers and the clay varves have a common origin. The eskers include the coarsest classes of grain, — the boulders and gravels — that remained at the starting points, or the places of discharge. All the finest materials are found in the varve sediments. As a whole, the deposit has the character of a delta, formed at the mouth of a stream of water.

Where the varves overlap each other, the places of discharge of material are generally situated along definite lines at right angles to the proximal lines. Zones of thicker beds of sediment are thus formed around the eskers. This is exactly the actual mode of occurrence of eskers and varve sediments. In Central Häme this connection between the eskers and the clays is most apparent, and gives the landscape quite a peculiar character (cf. fig. 10), while such a relation is less striking in the clayey country in the southwest[1]).

Special attention may be directed to the fact that those varves which have their proximal lines on recessional moraines, as the Salpausselkäs, resemble all the others in so far as they have proximal parts of distal character in all tracts where longitudinal eskers are not immediately adjacent. Examples of this are e. g. the sections of Anianpelto (Südfinnland 61) and Heinjoki Kinnari (Südfinnland 68), both situated at the foot and on the distal side of the great recessional moraines but far from longitudinal eskers. In such places, therefore, the recessional moraines have not been formed in the manner of delta deposits. But the case is different near the eskers. The thick IISs-varves in Leppäkoski clearly indicate that more material than usual has been deposited in the vicinity. The mighty Hausjärvi—Hämeenlinna esker here runs across the belt of recessional moraines, and south of it, in the neighbourhood of the church of Janakkala, a number of smaller eskers occur. Thus delta deposits in the form of eskers occur here instead of true recessional moraines, represented in the main parts of the Salpausselkäs by the evidence of the varve sediments.[2])

Thus, coarse-grained, thick, swollen proximal parts indicating that sediment has been there brought in the water may be found only locally. The special effect makes itself sensible within approximately semicircular areas the radius of which varies from two to

[1]) G. De Geer has demonstrated the connection between the varve sediments and the eskers by his very detailed investigations in the vicinity of Stockholm: On late Quaternary time and climate, Geol. Fören. Förhandl. Bd. 30, 1908, p. 460.

[2]) Cf. De Geer's investigation on the recessional moraines near Dals Ed in Sweden: Dal's Ed, some stationary ice-borders of the last glaciation, Geol. Fören. Förhandl. Bd. 31, 1909, pp. 511—556.

ten kilometres. Farther away the total effect of the vicinity of the proximal lines is only noticeable in the development of the varves.

A further characteristic of the varve sediments in Southern Finland is that the sediments brought to the proximal lines have spread out southward only, and never to the opposite side of these lines. The lines, in themselves, have moved at a variable rate in the opposite direction, or northward, and at the same time the whole zone of sedimentation has moved in the same direction. The proximal lines under such circumstances must indicate the positions of the sea shore during each period of deposition.

Glacial origin of the varve sediments. — Of what a character was this coast? A positive movement of the boundary line between land and sea of the usual kind can not be supposed in this case, as several facts indicate that the sea was not deepening during the formation of the varve sediments, but instead shallowing. The only possible explanation, therefore, is that the moving shore line was the receding edge of the vanishing land-ice in the late glacial time. Another positive and conclusive evidence for this assumption is the immediate connection between the varve sediments and the eskers and recessional deposits,[1]) etc. All these are formations whose glacial origin is beyond any doubt.

Annual periodicity. — We have finally to discuss the question of the length of the period of deposition, or the time of formation of one varve. The great regularity, and the very limited variation in thickness, especially of the diatactic varves, indicates that each of them has been formed within a unit of time of very regular periodicity, independent of factors of short duration and local influence. The unit of time must include two epochs, a shorter epoch during which the material has been discharged into the sea, and a longer during which the finer materials have had enough time to settle. It may be added that such a period of two epochs has not effected varve structure during the late glacial period only, but even in recent times. Quite similar varve structure, apparently owing to a similar periodicity of sedimentation, occurs in the deposits of older geological periods, as in the Permo-carboniferous,[1]) and in many pre-Cambrian formations. A very constant order of thickness of the varves in all

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[1]) G. De Geer, A Geochronology of the last 12,000 years: Compte rendu XI:e Cong. geol. internat., pp. 241—253.

[2]) R. Sayles, Banded glacial slates of Permo-carboniferous age, showing possible seasonal variations in deposition. Proc. National Acad. Sci. Vol. 2, 1916, p. 167—170.

R. W. Sayles, Seasonal deposition in aqueoglacial sediments, Memoirs Museum of Comp. Zool. Vol. XLVII, N:o 1, 1919, pp. 42—63.

these laminated sediments of so widely different ages makes it most probable that the period has been of the same length.

The earth globe has two regular recurrent periods that may be considered as possible causes of varve structure: day and year. Of these, the daily period is so short that grains smaller than 0.002 mm. in diameter have no time to sink more than 30 cm. (cf. p. 91). Nor does there occur any daily pause of sedimentation, necessary for this structure. The year is the only period whose length and seasonal variation of conditions, according to all that is known from experiments and theory, agree with the requirements of varve structure.

The varves actually formed in nature cannot, of course, be exactly similar to the theoretical varve. The suspension has not been carried into the sea momentarily, but continuously during the summer, the length, as well as the temperature of which is variable. Nor are all winters alike. This annual variation of conditions, in fact, causes the variations in thickness and other features of varves, and afford the possibility of identifying them in different localities. It is possible, moreover, that in fresh water all the finest material does not settle during the winter, but some remains to be deposited in the summer portion of the next varve. The theoretical varve may serve as a basis in explaining these and other still larger variations in the characters of the sediments.

The Variations in the Mode of Sedimentation.

Establishment of variations. — In proceeding to read the record of the varve sediments as closely as possible, it is appropriate to analyze each section from its bottom upward. The characters of subsequent varves and varve series then allow some conclusions as to the conditions of deposition. A section as a whole may be compared with the theoretical varve series constructed for any place on the basis of the results given above, namely, by assuming that all the diatactic varves have the same form, and that the peculiar structure of the series depends only upon the distance of the locality from the points of discharge of material, mainly mouths of the glacial streams, (see p. 103). The amount of sediment, depth of water and velocity of the horizontal current were supposed to be constant, and no coagulation was assumed. Variation in one or more of these factors must become evident from disagreement between the actual and the theoretical series. An increase in amount and concentration would make the varve thicker, introduction of salt water would cause coagulation and symmict structure, a change in the depth of water would cause change in the horizontal velocity of water and structure of varves. Attention is directed to such discrepancies, and their probable causes established. Each section is a problem for itself. A favorable circumstance in solving the problems is the possibility of comparing synchronal varve series in different places, as local disturbances may thus be eliminated, and the importance of more widely effective factors estimated.

In examining the sections from this point of view, the variations in the successive individual varves are left out of consideration, or the diagrams are *rounded.* It is not necessary for this purpose to apply any special mathematical method of levelling of curves, but the rounding may be made by eye, taking the approximate average thicknesses of some (5 or 10) successive varves.

In view of their great number, the sections may be treated in four groups, each comprising sections from a limited area of similar character and containing synchronal varve series. The grouping is based upon the stratigraphy.

Lacustrine facies of horizon H. — In the first group may be included all the sections of the northeast half of the area comprising varves of horizon H, as locc. 1 Leppäkoski, 12 Vanaja, 14 Tuulos, 20 Padasjoki Maakeski, 22 and 23 Sysmä etc.

The diagram of section 1 Leppäkoski is very regular (considering that the lowest varves, belonging to II Ss, have not been measured). The other sections of this group also approach the ideal type, excepting loc. 12 Vanaja where local disturbances appear from an irregular variation in thickness. The diatactic structure in all the varves (except two fine clayey varves in Leppäkoski) *proves that no coagulation has taken place.* The change in grain from the bottom upward, also, is wholly analogous to the variation in thickness: near the bottom coarse materials, farther up, in more distal parts of varves, gradually finer. After about 100 or 150 varves from the bottom the grain (like the thickness) remains nearly constant (silty clay). This appears best from the curve of hygroscopicity (fig. 7). The repeatedly mentioned dull clay-bands alone make an exception.

The sections in question therefore represent sediments deposited in fresh water, or a *lacustrine facies.*

Shallowing of water. — There is, however, a remarkable exception from the regular variation in grain in the sections of loc. 1 Leppäkoski and 14 Tuulos: After an initial regular decrease the amount of coarse materials begins to increase upward, in Leppäkoski at about varve 200, in Tuulos still earlier. This feature was first noticed from the results of mechanical analyses (Leppäkoski), but is noticeable even to the naked eye, and with distinctness which increases upward in the series. Silt and fine sand is present in, or, more correctly, between the varves. Fig. 5 Pl. IV represents a sample from the horizon S in Leppäkoski showing lenses of sand between the varves. As the average grain does not decrease (as appears from the hygroscopicity, Leppäkoski) finer materials must be present in large amounts.

How shall this exceptional combination of finest and coarsest materials be understood? It may hardly be accounted for by an increase in the velocity of sea-currents, as this would explain the presence of coarse materials but not that of a normal quantity of fine sediment in addition. These two opposite classes of grain consequently cannot be derived from one and the same source, the ice border. The fine material only has that origin, while the coarsest must have come from somewhere nearer. With the lapse of years the amount of material of nearer origin increased.

The most natural explanation of this phenomenon is to assume that the water in which the sediment was being deposited became gradually shallower. At the end of the Salpausselkä epoch the sea in Leppäkoski was probably about 160 m above that level in the lithosphere which is now at sea level.[1]) The highest esker hills and rocks, the nearest of which is half a kilometre east of Leppäkoski, are between 135 and 145 m. high. In the first part of the H-epoch, therefore, these hills were still below water and deposition was normal. But during the next decades and centuries the depth of water decreased; the highest places became reefs and small islands. The waves started their work on their sides. The abraded materials which, of course, included various grains, were deposited on the floor of the surrounding sea together with the sediment brought from the remote ice sheet. Hence these strangely coarse admixed materials.

The amount of the additional materials in the clay varves increases upward, indicating a continued shallowing of the sea and increased effect of abrasion.

How much the sea has shallowed in a century can not be stated with certainty, as the exact position of sea level immediately after the retreat of the ice sheet from this tract is not known, any more than the localities from which the first foreign materials were derived. The eroding work of the waves, moreover, begins on reefs before the emergence of land. So much is clear, anyway, that the water surface did not touch the highest points in Leppäkoski before year 200. In loc.

[1]) According to private information from Prof. I. Leiviskä, the plateaus of Salpausselkä in Lammi, 30 km. northeast of Leppäkoski, are 163 m. above sea level.

14 Tuulos, coarse materials appear somewhat earlier, or about year 125, and in the upper parts of H their amount is larger than in Leppäkoski and thick layers of sand occur between the ordinary varves. This section is situated in the vicinity of a big esker, and at a higher level than Leppäkoski, so that the water was shallower from the start.

The same phenomenon is also observed in section 21 Padasjoki, though less marked. In section 22 Sysmä it is not visible to the naked eye. These sections are situated in flat terraines. All the other sections are so small that they furnish no evidence in this respect.

The arrangement of the foreign materials between the ordinary materials as bands, like the »summer layers», indicates that their deposition has taken place during part of the year only and not continuously. This means that the waves may have been active in summer time only; during the winters the sea was perhaps covered with ice.

The peculiar features of horizon H in the southwestern area. — In the second group may be included all the sections within the northeast and southwest halves, inside the lines drawn through locc. 134 Jämsä, 105 Ylöjärvi Vahanta and 116 Vammala, those of Högfors and Pusula remaining outside. Among the numerous sections in this area, those in Central Häme are best suitable as a basis of discussion, as the varve series here combine features characteristic of both sides, the northeast and southwest.

The diagrams of the sections 24 Lepaa, 15 Hauho, 31 Lammasmäki, 32 Iittala and 6 Somerniemi (when rounded), represent, from the bottom to H_2 the same normal type as the sections of the first group. The same is the case in loc. 33 Kuurila, but its thin lower varves indicate that this locality is farther from the places of discharge of material, or the delta cones. The sections 36 Pintele, 35 Voipaala, 93 Liuksiala, and others not taken to the table of diagrams and containing H_1-varves, are normal from the lowest parts to H_2.

But the character of all the sections in question changes in passing from H_1 to H_2. The thickness of the varves increases, and the curves rise, though less in the northeast than in the southwest section. This rise has two maximums, and in the depression between them the varves in locc. 24 Lepaa, 15 Hauho, 31 Lammasmäki, and 32 Iittala have nearly the same thickness as in the upper part of H_1. This thickness may be regarded as normal, being what may be expected in diatactic varves, considering the distance of each varve from the proximal line.

In passing from upper H_2 to H_3 the swelling disappears, and the thickness drops to the normal in all sections. Exceptional thickness occurs in a few dark symmict varves only.

The last and in many sections greatest swelling is met with in the lower part of horizon S. This horizon, however, may be appropriately discussed in connection with the sections farthest northwest.

The swellings in H_2 also occur in the sections starting with H_2, situated northwest of the proximal zone of H_1, as locc. 38 Toijala, 78 Viiala, 77 Kylmäkoski, 81 Valkkinen, 82 Vesilahti Toivola, 80 Lempäälä, 84 Jokipohja, 90, 91 Moisio, 88 Kulju, 99 Messukylä, and 98, 100 Tampere. The lowest varves only are normal, either of a proximal or distal character.

In examining the other features in all the sections under discussion it may be noted that normal thickness and diatactic structure are parallel: Varves of exceptional thickness are symmict. The degree of symmixis increases toward the southwest and also the southeast. The coarseness of the material and the thickness, also, are in a definite proportion to each other. In sections of normal thickness and diatactic structure the hygroscopicity is about 7 as a maximum. (Note the meeting of all the curves of hygroscopicity in subhorizon H_3!) In varves of exceptional thickness and symmict structure, again, hygroscopicity attains unusual high values. The material in varves of exceptional thickness is exceptionally fine.

In passing from the central area just discussed to the extreme northeast, sections of much simpler structure are encountered. In the sections 134 Jämsä, 18 Luopioinen, 94 Kangasala Tursala and 95 Lihasula, 105 Ylöjärvi Vahanta, 108 Ylöjärvi Pintele, 109 Hämeenkyrö Sirkkala etc. the varves from the bottom to horizon S are normal in their form, diatactic structure, and coarseness of material (mostly silt and silty clay). Horizon H shows in them no anomaly. But towards the southwest, section 17 Luopioinen Aitoo shows some exceptional thick and fine varves in H_2. Still farther west in loc. 16 Pälkäne Kukkonen, the same swellings are greater. The last-mentioned sections may be compared with those of loc. 36 Pintele, 31 Lammasmäki, and 32 Iittala, and, finally, with loc. 38 Toijala and 78 Viiala (figg. 6 Pl. IV, 7 and 8 Pl. V). In the continuous natural varve series, the anomalies appear and increase gradually, as a rule. In a few cases only is the change more rapid, as between loc. 94 Tursala and 93 Liuksiala.

The anomaly reaches its maximum in the southwest half. Representative of the type is section 67 Loimaa, although no deformation of the varves is there apparent at the first glance, as the few varves are all alike. Even thick sections contain but few varves, because these are so exceedingly thick. This is a common feature, connected with symmixis and great fineness. The small number of the varves indicates that their extension from the proximal lines in the distal direction is small, or that the varve sheets are narrow, generally between 25 and 50 km. This feature, also, is an anomaly, the normal varves in the northeast being characteristically broad, from 100 to 150 km.

Discussion of the possible causes of these features. Marine facies. — In the search for possible causes of this different formation of the varve sediments, their chemical composition draws first attention. Several analyses, however, prove that there is no difference in this respect within the whole area (cf. the analyses of varve sediments p. 20). No varve sediments within the area contain any calcium carbonate. The mineralogical composition is strikingly uniform in all parts, just as the subjacent rocks are. The phyllites of the Tampere region, for instance, are distributed equally within the two halves where the clays are so extremely different.

As the difference can not be accounted for by different composition of the material, the physico-geographical conditions of sedimentation must be considered, and the first suggestion might be to look for differences in the depth of water. There certainly was a difference in this respect, the depth being smaller in the east. Near L. Päijänne it is not more than 40 or 50 metres. (The highest marine shore-mark on the Second Salpausselkä, in Asikkala, is a little over 160 m.,[1]) the average elevation now being about 125 m.).

In the southwest, in the region of Loimaa and Tammela, the sea must have covered places now nearly 160 m. above sea level, for the varve sediments in the highest region in the parishes of Urjala and Tammela may be found at elevations of 130 or 140 meters.

The variation in the depth of water, the other factors remaining constant, would affect the character of sedimentation in the following way: In shallow water near the edge of the ice sheet, a definite quantity of water emptied by glacial streams causes a more rapid horizontal current than in deep water. The greater velocity and more considerable wave action prevent the finer classes of grain from settling; the greater part of those materials is carried to deeper waters. This circumstance is very important in the present case. Southern Finland inside the Salpausselkäs, or the northeast half of the area investigated, was, during the decadence of the land-ice, covered by a shallow sea with many islands. The Salpausselkä belt formed a nearly continuous barrier in the south, and the waters from the melting ice in Central Finland very probably moved chiefly southwestward. This water carried most of the fine clay, and only the coarser materials were deposited in front of the mouths of the glacial streams. The small

[1]) I. Leiviskä, Der Salpausselkä, Fennia 41, N:o 3. pp. 277, 371.

amounts of varve sediments in the northeast are, in fact, mainly built up of such coarser products.

This consideration, however, does not explain the thickness and small distal extension of the varves in the southwest. Still less does it explain the alternation of numerous series of thick and thin varves in the central area. If, in a certain section, the thick and fine varves had formed in deep, and the thin and coarse varves in shallow water, it would be necessary to assume repeated local changes in the distribution of land and water in both directions within a few years. Such changes are utterly unprobable, and in no way registered in the geological record by any other evidence. The different development of the clay in the northeast and southwest halves cannot therefore be accounted for by differences in the movements of sea-water.

A satisfactory explanation may be found by assuming a difference in the character of the water from which the sediments were deposited. The sediments of the northeast half have in every respect a structure that can only originate where there is no coagulation, in fresh water. In the southwestern half, again, the clay has all the characters of the coagulation facies: the varves have narrow extension, great thickness, fine grain, and symmict structure. *As there can have been no other salt solution than sea water, the sediments of the southwest half may be called the marine facies.*

Varying intensity of the marine facies. — It is very interesting to study somewhat closely the mutual relations of salt and fresh water during the deposition of H_2 and H_3, as they appear from the intensity of coagulation, indicated by several characters: the degree of symmixis, amount of fine clay, and abnormal thickness of the varves. It was shown above, from the percentages of materials of different grain, that the great varve thickness is chiefly due to the accumulation of fine materials. The result of the analyses may also be used to the same purpose in another way: The weight percentages of the different classes of coarseness are regarded as identical with volume percentages,[1]) and the proportion of each class of coarseness in the varves is now established by measuring the average thickness of the varves from which the samples were taken. The following results were obtained from section 32 Iittala:

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[1]) The difference between the percentages of weight and volume is negligible, if the latter refer to dry matter. The thickness of the varves, for the present purpose, has therefore been measured in dried material.

Grain	H_1	H_2	H_3	S
>0.2	0.04 mm.	0.2 mm.	0.13 mm.	1.16 mm.
0.2—0.02	0.26 »	0.5 »	0.14 »	1.97 »
0.02—0.002	2.7 »	1.2 »	0.41 »	2.88 »
<0.002	1.5 »	4.2 »	1.13 »	10.4 »
Total thickness ...	4.5 »	6.1 »	1.81 »	16.00 »

The thickness of the varves in H_1 is chiefly due to the next finest class of grain, but in H_2 to the finest class, whose proportional amount is here 4 times as great as in H_1 and 2/3 of the whole thickness. But the absolute amounts of all the other classes, also, are larger than in H_1 and H_3. This is as may be expected in the coagulation facies, as the bigger grains also coagulate. But at a distance from the ice border the amount of the latter decreases in proportion to the finer materials. As the H_2-varves, in the northeastern lacustrine facies, do not show any tendency to swell, their swelling in the marine facies is due to coagulation and not to the increase of matter suspended in water. Coagulation of the fine materials raises the average fineness, or hygroscopicity. The highest values are therefore found in the marine sediments. Farther from the edge of the land ice it is, as a rule, over 8, a figure never reached in the lacustrine clays of the area investigated. Great average fineness (and dark tint) is therefore — within certain limits — a diagnostic of the marine clay.

It may be concluded from what has been said that salt water comes to the area investigated in year 292. Its effect is very strong in loc. 6 Somerniemi and 8 Somero, but slighter in the basin of Lake Vanajavesi. During the subsequent decades its effect increases greatly and spreads to a wider area, being noticeable as far as Hauho. In several single years, however, the lacustrine facies intrudes. This alternation may be due to several different causes. It may be remembered that coagulation is reversible and may be nullified by agitation of waves, or local disturbances from icebergs. An occasional increase of sediment, a long quiet period, or a smaller amount of water from the land ice during the winter may have acted in the opposite direction, although no general change in salinity occurred. Coagulation actually — here as in other similar cases — took place in winter time only, the lower parts of the varves being diatactic, as a rule. Therefore the intermittent occurrence of the marine facies does not necessarily mean local and annual movements of salt water, but it is apparent that salinity was very low. More correctly the water may be called brackish.

The increase and extension of the effect of salt water in the central zone, however, soon ends, and even a decrease may be noticed. About year 370 brackish water just reached the line 31 Iittala — 35 Voipaala — 80 Lempäälä. But about year 400 a new and still greater increase begins, reaching its maximum about year 430, when salt water, in the deeper parts, extended as far east as to 17 Luopioinen Aitoo. There-

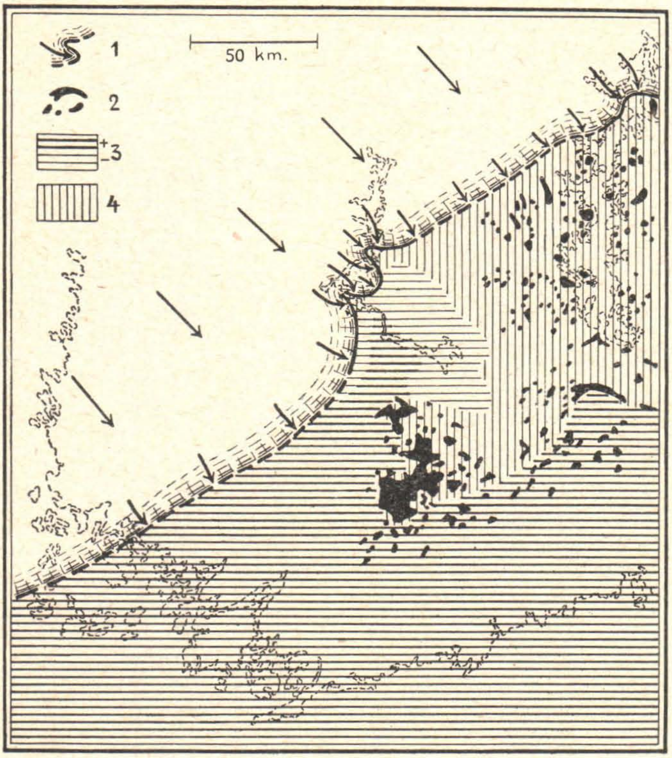

Fig. 11. Map of Southwestern Finland in year + 350 (after the end of the Second Salpausselkä epoch). 1 land ice; arrows indicate its movement; 2 shallows and dry land; 3 salt and brackish water; 4 fresh water.

after a new decrease takes place, and in year 463, at the beginning of the H_3 epoch, no coagulation is noticed except occasional varves in 38 Toijala and 78 Viiala. Thus brackish water, in the central area, existed at that time only in the tracts farthest from the ice front and the northeast half. The dark and thick marine H_3 varves in the last-mentioned sections, only partly synchronal in the different localities, prove the effect of salt water to have been very slight.

The map (fig. 11) shows the extension of salt water in year 350. In the west, it was generally bounded directly by the land ice, as far as in loc. 80 Lempäälä in the north. Northeastward it extended to the large row of eskers in the parishes of Pälkäne and Kangasala, but not over them farther east, except in the deepest places, as in Tampere. In the basin of L. Vanajavesi brackish water during some years intruded through the tract of Hämeenlinna to Leppäkoski, as indicated by the two dark bands in H. Apparently it did not come to that district from the south.

Farthest southwest salinity of the water was, during the whole H-period, sufficient to cause coagulation. Salt water was bordered directly by the land ice. The narrow distal extension of the varves proves that the sediment was deposited comparatively near the ice border, and as near as 40 or 50 km. from it the water was clear and nothing at all was deposited. Coagulation took place during the whole year and not only in winter time. The occurrence of several layers in the annual varves (loc. 59 Loimaa, 49 Forssa) proves, however, that salinity, at least near the ice border, varied during the year, being smallest in summer and largest in winter. Between the seasonal layers, especially in passing from summer to winter, there are distinct transitional zones. Such transition occurs, also, between the annual varves apparently representing deposition during the spring (79 Mattila and 80 Lempäälä).

The lustrous dark and symmict materials that compose the largest parts of the varves of salt water facies have, for a great part, formed in summer time, and such layers cannot properly be called winter layers. I have therefore avoided the terms »winter layer» and »summer layer» altogether.

Attention may still be directed to a very interesting phenomenon: Where much sediment and esker material has been discharged into the sea, the deposits show fresh water facies at some distance from the proximal line which indicates the location of the ice border, as seen e. g. in the sections 71 Vampula, 83 Vesilahti Vakkala, 99 Messukylä, and 98 and 100 Tampere (see fig. 9 Pl. VI), while elsewhere salt water facies occur close to the line, as e. g. in the sections of 67 Loimaa, 74 Punkalaidun, 76 Sammaljoki, 79 Mattila, and most sections in Lempäälä. This relation no doubt means that where abundant material was carried into the sea, there was a debouchure of a glacial stream that emptied much fresh water. Especially large areas of fresh water facies formed round loc. 71 Vampula and 98, 99 and Messukylä—Tampere. These two localities, in fact, are those where the largest eskers of the area occur. In the former place, moreover, there was a narrow channel bordered by higher land serving as the outlet for glacial waters, the present valley of the Loimijoki river. Near Tampere, again, the glacial stream emptied itself into a narrow and long bay in the ice border. (See the position of the ice border on the map fig. 11). Coagulation in these cases, however, was also prevented by frequent calving of icebergs, which agitated the waters.

Abundance of clays in the Loimaa region. — The intensity of marine facies thus, according to the testimony of the varve sediments, decreases toward the northeast half and, also, toward the ice border in general and the debouchures of glacial streams. Toward the southwest, and in the distal direction, it increases, though not quite evenly, as might be supposed from the deepening of the sea. The marine facies, as described above, is best developed in the parishes of Loimaa, Tammela and Somero and decreases from this tract toward Turku, (See fig. 6 p. 75). Is this fact due to less salinity here? That is hardly probable, as there is no reason why salinity should not have increased toward the deep basin of the Baltic. Another very natural and simple explanation for the unequal distribution of the clays may in fact be found:

As is visible from the map (fig. 11), the high region of the parishes of Tammela and Loppi formed, during the decadence of land ice in southwestern Finland, a hindrance over which salt water could not intrude. To the basin of Lake Vanajavesi it could reach, as undercurrents through a deeper channel in Toijala (loc. 38). The greater part of the glacial water in Central Finland was compelled to flow out as surface currents along the same channel, though it had another narrower passage at Hämeenlinna and Leppäkoski in the southeast. The fresh water flowing on the surface contained suspended fine clay matter derived from Central Finland, where such matter does not exist in the varve sediments deposited in that district. The small amount of salt in the basin of Lake Vanajavesi could not precipitate it altogether. It moved farther southwest. There, in the wide waters on the far side of that shallow sea they met salter water, which attacked the suspension and caused coagulation. The bulk of the fine material was deposited here, and little if any went farther and reached the Turku tract. Only the materials derived from the nearest ice border were deposited there. Thus the region of Loimaa—Tammela—Somero became rich in clays at the expence of Central Finland and represents an exceptional case.

A proof of elevation of the land. — In the sections of the second group mentioned above (32 Iittala, 38 Toijala etc.) the amount of the coarsest classes of grain increases in the same way as in loc. 1

Leppäkoski (see p. 105). The reason, of course, is the same, or the shallowing of water. As we know from the preceding that the water was salt, and therefore at level with the ocean, the shallowing cannot be due to a lowering of the water surface, but was caused by *an upheaval of the lithosphere.*

Presence of salts in the marine facies. — The clays of southwestern Finland show an interesting minor feature that may be demonstrated experimentally. When samples of different varve sediments are suspended in water in beakers and allowed to settle, water becomes first clear in those beakers containing marine clay, while in those containing lacustrine clay, although these have coarser average grain, it remains longer turbid. This is owing to the fact that the marine clays contain chlorides and sulphates, as may be determined by analyses. In Loimaa, for instance, wells made through this clay contain enough chlorides to give a distinct precipitate of silver chloride, while waters percolating through lacustrine sediments give a much fainter reaction. It cannot, of course, be stated that those salts were all primary, or »relict» from the sea water, as it is well known that the colloidal clays have a special power of absorbing such salts.

Comparison with clays of Eastern Sweden. — Formerly the occurrence of marine or lacustrine facies has been determined exclusively from the fossils and not from petrographic structure as in the present investigation. It might be interesting to compare the marine sediments of southwestern Finland with analogous sediments from other regions where they contain salt water fossils. Such sediments occur on the opposite side of the Baltic Sea, in central Sweden, but have not been thoroughly investigated in the same way as the Finnish clays, and no direct comparison is therefore possible. I myself had an opportunity of looking at them in one place in the vicinity of Stockholm. They are there surprisingly similar to those clays in southwestern Finland which I have described as marine: the thickness of varves is great and their number is small just as in Loimaa. The material is largely dark and fine, and the narrow coarser bands have commonly a red tint, as in southwestern Finland. The small-sized individuals of *Yoldia arctica* found in this clay point to a low salinity. As coagulation is much more advanced in many places in southwestern Finland than in the Stockholm region, it might be supposed that the salinity was higher here. This would not seem at all unlikely. In central Sweden there was a sound, through which a mighty stream of fresh water ran to the ocean, while southwestern Finland was covered by a wide sea where salt water could remain unmixed. A more concise estimation of the salinity might perhaps be achieved by comparing the sediments on both sides of the Baltic, in places where other conditions of deposition are as similar as possible. It is not possible to use the fossils as criteria, as no fossils have yet been found in Finland.[1])

It may be mentioned that varve sediments of the same marine type as in eastern Sweden and southern Finland also occur on the Aland islands. Owing to their character I have not yet been able to determine their age by exact connections.

The possibilities of an inflow of salt water to southwestern Finland will be discussed below.

Lacustrine and marine facies of horizon S. — The third group embraces the sections in the most northwesterly portion of the area. They contain mainly clays of horizon S. In this connection may also be discussed the occurrences of S-clay in the sections of the former groups.

Horizon H in this group has a normal form up to the boundary of S. The structure is diatactic and the material consists of sandy clay whose hygroscopicity is lower than 7. Thus it belongs to the lacustrine facies.

Horizon S shows a different structure in the whole area over which it extends, having varves several times as thick as those of H_3. Where the section begins with S, no direct comparison is available, but the absolute thickness is greater than in the nearest occurrences of H. About 20 of the lowest varves are thickest, and the upper gradually thinner.

As the swelling may be observed everywhere, independent of the occurrence of the coagulation facies, it cannot possibly be due to any other cause than a sudden increase of the amount of material. All classes of coarseness are here more abundant than in H_3, but, especially the coarser materials. Even hygroscopicity sinks in those sections in which coagulation did not cause a simultaneous increase of the finer materials (note the division of the curves of hygroscopicity into two bunches, fig. 7).

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[1]) The absence of varve structure in the glacial clays of western Sweden has been explained by G. De Geer in the following way: The glacial fresh water was lighter than the salt sea water and therefore kept flowing upon the surface. The finest materials only could be carried to a distance from the ice border and therefore, as no coarser materials were available, no varve structure developed (G. De Geer, Om den gotiglaciala isrecessionen inom västra Sverige; Geol. Fören. Förhandl., Bd. 35, 1913, p. 404). This explanation is not at all supported by the study of the clays in southwestern Finland. Poor development or absence of varve structure does not depend upon the absence of coarse materials, but upon the mixing together of different classes of grain which clearly means *coagulation.*

Coagulation has taken place in the most distal parts only, or in the basin of L. Vanajavesi within the lines drawn through locc. 78 Viiala, 38 Toijala, 17 Luopioinen, 15 Hauho, 31 Lammasmäki and 32 Iittala. The varve thickness is there very much greater than in those sections in which this horizon is represented by the lacustrine facies. The increase of fine as well as coarse materials compared with the H_3-varves appears from the figures given on page 111. This swelling does not necessarily mean any increase in salinity, but may be due to the general increase in the amount of sediment, an interpretation confirmed by the fact that the area of the salt water facies decreases continually from H to S. Later, about year 600, the marine character of the sediments is exceedingly faint, and limited to a few varves only in the district between the Kokemäenjoki river and Hämeenkangas, where the sea was deeper.

The causes of the increase of material in horizon S can not be discussed in this paper, as observations are available from a part of its proximal zone only.

Alternation of various facies in the Sälpausselkä belt. — As the fourth group may be described the sections in the neighbourhood of Salpausselkä, namely, locc. 138 and 139 Jokela, 140 Numlahti, 137 Herrala, 136 Mukkula, 1 Leppäkoski, 2 Högfors, 4 Pusula, and the remote section 151 Imatra.

The factors determining the structure and characters of these large sections are combined in many different ways. In the first place the stratigraphy is more complicated than in the former cases. ISs, IISs, the lower part of iSs, and varves 100—200 of horizon H in the southwestern half have been deposited in such a way that the proximal lines of all the varves are nearly coincident, being situated on the recessional moraines, or in their vicinity. The varves in the sections embracing these series have a nearly uniform thickness. The other series, again, have an overlapping structure, and the thickness of varves accordingly decreases upward in the sections (see Südfinnland Pl. IV, diagrams of locc. 49 Jokela, 65 Leppäkoski, 51 Lahti S and 52 Lahti Mukkula). Another difference in the structure of the varve sediments is due to the circumstance that some series have been deposited from salt, and others from fresh water. The lacustrine facies is represented in aSs and ISs all over the area, and in iSs in the northeast half. This appears from the diatactic structure of the varves and coarseness of the material in locc. 138 and 139 Jokela, 140 Numlahti, 137 Herrala and 136 Mukkula. Marine facies occurs in the greatest part of iSS in the southwest, in IISs all over, and in the greater part of H_1 in the southwest. These series have all the characteristics of the coagulation facies: abnormal thickness of varves, symmict structure and fineness of material. These characteristic features have been best developed in IISs. The varves show, in this horizon, a sudden swelling in the sections 138 and 139 Jokela, 140 Numlahti and 136 Mukkula (and 51 Lahti S, Südfinnland), and at the same time hygroscopicity (in Jokela) rises to 12. It therefore differs, in a striking way, from ISs and the other varve series deposited during the halt periods of the ice border in Central Uusimaa (Südfinnland, p. 41).

Intensity of coagulation and frequency of icebergs. — According to the record of the sediments, salt water was first introduced into southern Finland in year — 431, or toward the end of the first great Salpausselkä halt. Thereafter its influence is always strongest in those series formed during halt periods. This fact raises the question: do these variation in the intensity of coagulation mean corresponding variations in the salinity of sea-water? Such a correspondence is not by any means self-evident, as there are other factors also effecting variations in the intensity of coagulation, and these may have played a rôle in the phenomena under discussion.

Coagulation is favoured, as may be remembered from what has been said above, by increase of the concentration of suspended materials. The importance of this factor was illustrated by the S-horizon. Concerning the cases with which we are dealing now, it may be stated that the varve series of H_1 deposited during the third Salpausselkä epoch does not show, in the northeast half where it was deposited from fresh water, any swelling of the varves at all when compared with the under- or overlaying varves. Just the same is true with regard to the initial part of iSs. As to the IISs-horizon it is not equally clear, the clays showing marine facies all over the area. But the thickness of varves being rather small in the northeast, where salinity was smaller, points in the same direction as the two above cases, namely, that there was no general increase of matter. All the other series of sediments formed during halt periods, as ISs and those in Central Uusimaa, moreover, are rather thinner than normal. The increase of the intensity of coagulation during the later halt periods is not therefore due to any general increase of the quantity of sediments.

Coagulation may also be favoured by greater tranquillity of water, caused e. g. by ice in winter. Temperature might have been lower during the halt periods, producing winter conditions throughout the year. This supposition, however, does not agree with the fact that varve sediments have been deposited during the halt periods also, as this means melting of ice in summer time. We shall find, moreover, that the halts of the ice border, at least during the great Salpausselkä periods, probably were not caused by refrigeration of climate, but by other factors. Greater tranquillity can not therefore have been caused by changes in climate.

But certain features in the sediments point to other factors that may have contributed to the same effect. In the big Jokela sections it is a striking fact that the boulders and rock fragments in each varve series show quite a definite character. They are very frequent in the upper part of iSs, about 3 or 5 in each square meter of a vertical section, while very few boulders if any were found in ISs and IISs. The boulders probably were dropped to the beds of sediments from icebergs that had broken off from the edge of the ice sheet and were floating and melting on the water. The regular distribution of the boulders indicates that icebergs were more common during the periods of recession than during the halts of the ice-border. The same conclusion will later be arrived at from different considerations; calving of ice was in fact in many places quite impossible when the ice border lay at the big Salpausselkäs which reached the surface of the sea.

A greater or smaller frequencey of icebergs makes for a greater unrest or tranquillity of water. First, the calving of icebergs, according to observations made near existing glaciers reaching the sea, causes enormous waves and whirls. The waves sent out at the birth of a great iceberg extend for 50 kilometres or more, driving the smaller floating bergs together and thus assisting their fragmentation.[1]) Tarr describes the commotion of water caused by the calving in the following words:[2])

»The calving of a large iceberg causes a profound disturbance of the fiord waters, sending out a series of waves whose effect on the neighboring coast must necessarily be important. From twenty to twenty-five large waves were counted accompanying a single iceberg discharge of moderate size; and in addition there were numerous smaller waves. At a distance of a mile or mile and a half from the glacier, the larger waves produce a surf of such violence that it is often difficult to land a boat even on a beach, while landing on a rocky shore seriously endangers the boat.»

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[1]) E. v. Drygalski, Grönland-Expedition der Gesellsch. für Erdkunde zu Berlin, 1897, pp. 367—404.

W. H. Hobbs, Characteristics of Existing Glaciers, 1911, pp. 178—185.

[2]) R. S. Tarr and B. S. Butler, The Yakutat bay region, Alaska, U. S. Geol. Survey, Prof. Paper 64, 1909, p. 34.

Secondly, where the number is not too large the stranded icebergs apparently increase the activity of waves by breaking them up into swirling surf currents of great velocity.[1])

Thirdly, the melting of icebergs renders the sea turbulent. Melting of ice is much like weathering: the solid ice gets porous and breaks into pieces that drop into water.[2]) The main iceberg may be repeatedly displaced from equilibrium and turn over, and where icebergs are numerous, the whole sea is in the state of continuous agitation.[3])

The variations in intensity of the coagulation facies may therefore be in a causal relation to the frequency of icebergs floating on the sea during the corresponding periods.

Variations in salinity. — The above conclusion does not imply that there was no change at all in salinity. At least during the later part of the H_1-epoch salinity was clearly on the decrease, while later a new and very rapid increase took place at the start of the H_2-epoch extending eastward as far as to Central Häme. Thinning of the uppermost IISs-varves in locc. 1 Leppäkoski and 136 Mukkula, on the other hand, apparently is due to a decrease not so much of salinity as of the amount of sediment. In the more distal parts this varve series does not change, and e. g. in loc. 151 Imatra its uppermost varves only show a pronounced coagulation facies.

The assumption proposed is also confirmed by the horizontal extension of the coagulation facies. It is constantly more pronounced in the southwest than in the northeast, illustrating the relative salinity. In the southwest half, the minimum necessary for coagulation was present even during the periods of recession, but in the northeast, in the quieter conditions during the halts only. The contrast between IISs and the varve series below and above is therefore very marked in that part. If salinity during the halt had been greater than in other times, the maximum corresponding e. g. with the third Salpausselkä period should appear somewhat farther northeast. as later in a similar case in Häme. There is, however, no sign of this in Leppäkoski more than in any other section.

The tranquillity of the halt period nevertheless appears in varves 100—150 of H_1 somewhat farther northeastward, in the district between Hämeenlinna and Leppäkoski, in another way. Exactly at

[1]) R. S. Tarr and B. S. Butler op. cit. p. 33.

[2]) G. v. Boguslawski — O. Krümmel, Handbuch der Oceanographie, Band I 1884, pp. 376, 377.

[3]) E. v. Drygalski, op. cit. pp. 376—379.

this time there was deposited that dull carbon-bearing sediment whose occurrence is confined to this tract and this varve series only (p. 28).

Relation between sedimentation and recession of the ice border. — Besides the deviations from the normal type due to coagulation the sections show some other differences. The horizon iSs in the northeast consists of coarse material and thick varves compared with ISs, even if the influence of coagulation be considered. In the same way the lowest H_1-varves are thicker and coarser than the underlying IISs. This appears only in the southwest (in the parish of Vihti) where these series have been deposited from salt water. In the northeast half it is less apparent, as the difference is there mainly due to the marine facies of IISs and lacustrine facies of H. Considering the analogous varve series in Central Uusimaa (Südfinnland, p. 39) we arrive at the conclusion presented in my earlier paper, that there is a marked difference between the sediments deposited during the periods when the ice border halted and the subsequent times of rapid retreat: in the former, the varves are thinner and finer in grain, in the latter, thicker and coarser. Comparison is, of course, possible in that case only when the varves in all the series are diatactic. Closer investigation of the series from the longest halt period, ISs, proves that its material is not exceptionally fine. Its hygroscopicity nowhere reaches higher values than 4, a very low figure compared with those found in the diatactic clays of Häme. Nor is the thickness of varves too small. Exceptional features are rather found in the next series, iSs, and in the same way, in the lowest part of H compared with the underlying IISs.

The recession of the ice border is therefore depicted in the sedimentation, in such a way that the series formed during halt periods are composed of nearly uniform varves, which — if not affected by coagulation — are thinner and consist of finer materials than the series next above formed during a maximum velocity of retreat. The change in the character of the varves is not less marked than the change in velocity. This correspondence is likely to suggest the idea that these rapid changes might be due to changes in climate. This conclusion was in fact proposed in my first paper, though modified and, with regard to IISs, with some hesitation. Now, in the light of results obtained by better methods of investigation, this idea must be looked upon still more critically. The problem of the possible causes of the variations in recession may appropriately be discussed in a later chapter from a broader point of view.

Abundance of clays in the Salpausselkä belt. — The great abundance of clays within the Salpausselkä belt and in the connecting distal zone is due to the two causes discussed above: (1) to the great number of varves deposited in the same area, and (2) to the thick horizons, IISs, parts of ISs, and H_1, in which coagulation has attracted large amounts of finest clay which otherwise would have been carried farther from these tracts. The coast region of Uusimaa is much poorer in clays, apparently because (1) little of the sediment from the Salpausselkä zone reached that region, and (2) because those varve series whose proximal zones are situated there, are exclusively composed of thinner fresh water varves.

The first appearance of salt water in southern Finland. — The sections of locc. 138 and 139 Jokela and 140 Numlahti show a further abnormal feature deserving a special attention. I refer to the extraordinary varve in the uppermost part of the horizon ISs (see figg. Pl. I and II, and Südfinnland Pl. IV, varve N:o —435), alike in all those big sections, conformable with its neighbours, but about 20 times as thick as any of them, and mainly composed of sand, locally of grit and boulders that may be, as far as seen in the sections, more than 5 cm. in diameter. These materials are superposed, as usual in the varves, by finer grains. The section studied in Numlahti contained less grit than in Jokela. It may be remarked that no such varve in a corresponding position was found in locc. 137 Herrala, (51 Lahti S, Südfinnland), or 151 Imatra.

What does this singular varve mean? It is clear that it cannot have been deposited from matter suspended in water. Some other factor must have been at work. The strange coarseness of the material also excludes the assumption of abrasion by waves, in such a sense as in Leppäkoski and elsewhere, especially as there are in the neighbourhood of Jokela no high places that might have reached nearly to the surface of the sea. The neighbourhood of Numlahti is more uneven, but even in that region there could not have existed any shoals. Nor can the material possibly be interpreted as dropped from a few occasional icebergs, as it is evenly distributed over a wide area and its occurrence is restricted to a single varve.

It may be suspected that the origin of this exceptional varve stands in causal connection with the most important event of this epoch, *the first arrival of salt water in southern Finland.* All the sediments formed before this varve have been deposited from fresh water. Two or three years later salt water arrived here for the first time during the late glacial period, and it then remained here, continuously, though varying in concentration, for at least 1,000 years. Such an event has exceedingly far-reaching consequences, with regard not only to the area under investigation but to the whole late glacial Baltic Sea.

On the Late Glacial History of the Baltic Sea.

Connection between the Baltic and the Ocean. — The submerged area of southern Finland, during the late glacial period, was part of the Baltic Sea. As early as the first Salpausselkä epoch, the sound between the ice sheet and the supra-aquatic territory of Esthonia was nearly as broad as the present narrowest part of the Gulf of Finland, and much deeper. The greater phenomena occurring at the boundaries of the Baltic could therefore be manifested in southern Finland also.

As the sediments clearly bear evidence of deposition from fresh water before the last phase of the first Salpausselkä epoch, apparently no salt water existed in the Baltic basin during those earlier centuries (perhaps even millenniums). Its arrival in southern Finland at the beginning of iSs would therefore mean that direct connection between the Baltic Sea and the ocean was first opened exactly at that moment. There are three possible passages by which this may have happened: (1) In the east, the sounds that may have connected the Baltic with lakes Laatokka (Ladoga), Onega, and the White Sea. (2) In the south, the channels of Denmark. (3) In the west, the sounds of central Sweden.

1. The first possible passage would have been situated in East Karelia, a region whose Quaternary history is little known. Ramsay[1]) thinks that the connection between lakes Onega and Laatokka was narrow and of short duration. The introduction of salt water from this direction would have been most probable a few thousands of years before the first Salpausselkä epoch. As no marine facies occurs in southern Finland so early, not even in Karelia, where it might be most expected, this way must be regarded as entirely closed.

2. The level of the channels of Denmark — Öresund and the Belts — in the late glacial time is not known definitely. Munthe[2]) assumes that the land was there much elevated relatively to the ocean level, and that the Baltic Sea was ponded by that threshold. Antevs[3]) proves that the evidence set forth by Munthe is not dependable. Positive evidence, according to Antevs, only proves the elevation to have been great enough to make Öresund an isthmus, while the shallowest place in the Great Belt, Darsser Schwelle, between Falster and Germany, formed a threshold that reached near ocean level. As

[1]) W. Ramsay, Quartärgeologisches aus Onega-Karelien, Fennia 22 N:o 1, 1905, p. 10.

[2]) H. Munthe, Studies in the late-Quaternary history of Southern Sweden, Geol. Fören. Förhandl. 32, 1910, p. 1205.

[3]) E. Antevs, Senkvartära nivåförändringar i Norden, Geol. Fören. Förhandl. 43, 1921. p. 647—649.

immense masses of fresh water poured out that way into the Cattegat, no salt water apparently could intrude through the same channel into the Baltic.

3. In Central Sweden the varve sediment deposited from salt water and containing shells of *Yoldia arctica* (see above, p. 115) extends to the Stockholm region in the east. As ocean water accordingly had a passage into the basin of the Baltic, it could freely spread farther, at least in the deepest parts, and reach southern Finland. This sound opened, according to Munthe and others, as soon as the border of the ice sheet had passed Mt. Billingen, which formed the northernmost edge of the supra-aquatic territory of southern Sweden. This district has been studied in detail by Lundqvist[1]) who describes several old shore-marks at different levels on the eastern slope of Mt. Billingen. Lundqvist has combined the best of these marks as belonging to three continuous shore-lines. The highest of them, situated 150 metres above sea level, is interpreted as the shore-line of the ponded Baltic lake before the drainage, and the middle one, 17 metres lower, as a »marine» shore-line, while the lowest, 111 metres above sea level, would be a post-glacial shore-line. He has farther verified the existence of a 1.5 metres deep channel, first observed by A. G. Högbom, carved in sandstone and partly filled up with drift, 113 above sea level, testifying to the erosion work of running water — the outlet of the Baltic lake.

After the drainage, salt water, according to Munthe, made its way through the narrow sounds near Karlsborg and Motala to the Baltic basin. Later on a better passage opened, when the land ice vanished from the lower district in Närke, 60 km. northeast of Mt. Billingen.

Events connected with the discharge of the Baltic. — From this information we may combine the events connected with the appearance of salt water in central Sweden and southern Finland in the following way: *The arrival of salt water in southern Finland at the end of the first Salpausselkä period was subsequent to the opening of sea connection north of Mt. Billingen* (beginning of the Yoldia epoch). Owing to the shallowness of the sounds, which at first increased in consequence of the upheaval of land, salinity was kept low during the first seven centuries and was almost unnoticeable during the later part of the H_1-epoch. *The opening of the new sounds in Närke is depicted in the intense marine facies of H_2 in the Loimaa region.* Sub-

[1]) G. Lundqvist, Den baltiska issjöns tappning, Geol. Fören. Förhandl. 43, 1921, pp. 381—385.

sequently these sounds in turn became shallow, and salinity decreased once more, being very low about year 600 (the Ancylus Lake of Munthe?).

This combination of events is in fairly good accord with the conclusions reached concerning the variations in salinity in southwestern Finland, but it is at variance with some ideas put forward by former investigators in their efforts to explain the problem of the Baltic Sea.

The first contradiction arises with regard to the lowering of water level. It is clear that some lowering must take place, if a lake be suddenly put in direct connection with the ocean. The only question is how great this lowering was. Lundqvist and after him Antevs[1]) assume, as mentioned above, that it was 17 metres. Munthe apparently assumes a still greater lowering.

In Finland, the following considerations may have some bearing on the question of lowering. The plateaus west of Lahti in the Salpausselkä, which indicate the water level immediately after the withdrawal of the ice sheet from this zone, are about 155 m. above the present sea level.[2]) Now, in the first place, the plateaus formed in the subsequent period, as far as the Second Salpausselkä in the parish of Lammi, rise gradually *thus indicating that the relative position of the water level has remained nearly constant.* Secondly, 10 or 11 metres below these highest plateaus, there is an exceedingly distinct and precise terrace cut in the recessional moraines and eskers. This terrace may be followed for several tens of kilometres without interruption and still found on the Second Salpausselkä and inside it, rising slowly and approaching the plateau levels of that tract. It can not therefore designate the lowered level of the Baltic, in the sense of Munthe and others, but something much later. As there are, between this shore-line and the plateau level, several shore-marks, accumulation banks, one above another, *the surface of water can not possibly have fallen by 10 or 20 metres at one time.*

We may also get a good idea of the amount of lowering in another way, by comparing the signs at Mt. Billingen with those made in cases where the falling of lakes is exactly known from historical records. Lake Höytiäinen, in northern Karelia, the area of which had previously been 430 km², broke its dam in 1859, and its surface sank 9 metres within less than a month. During this catastrophe, about

[1]) E. Antevs, On the late-glacial and post-glacial history of the Baltic, Geographic Review, Vol. XII, October 1922, N:o 4.

[2]) I. Leiviskä, Der Salpausselkä. Fennia 41, N:o 3, 1920. p. 368, and oral communications.

3.8 km^3. of water rushed out and dug a vast ravine in the ground. At present this channel is, for the most part, »dead». At the mouth of this outlet in Lake Pyhäselkä, there was deposited a huge delta which covers an area of about 180 hectares above the surface.[1]) Several other much smaller lowerings of lakes have left signs that are recognized even by non-geologists. Now, assuming the area of the Baltic during the period in question to have been 400,000 km^2. and a lowering of 17 metres, the amount of water discharged through the channel at Mt. Billingen to bring the Baltic to level with the ocean would have been 6,800 km^3. It might be expected that the outpouring of such an amount of water should have left somewhat clearer signs than the lowering of Lake Höytiäinen, or the catastrophic discharges of many ice-ponded lakes in the Swedish highlands that have produced distinct terraces, channels with pot-holes, and drainage varves. As Lundqvist remarks, the signs observed near Mt. Billingen certainly are not likely to force conviction that any huge catastrophe had happened here.

The above conclusion, that no very considerable sudden lowering of water level has taken place in southern Finland, is in best accord with the stratigraphy of the varve sediments. It is clear that the lowering must have occurred briefly before the first appearance of the salt water facies at the bottom of iSs. Now, the third varve below this bottom in ISs is the exceptionally thick varve referred to above (figg. Pl. 1 and II). It may have been formed somewhat in the following way: When the new outlet opened north of Mt. Billingen, the water level sank in southern Finland also, and the waters moved westward along the ice border and pulled along ice floes from the edge of the ice sheet at Lohjanselkä which did not reach the surface of the water. Owing to the agitation effected by the movement, great amounts of grit and sand dropped off these ice floes and were deposited as a uniform bed. But east of the town of Lahti, the Salpausselkä, in most places, reached nearly to the surface and prevented the calving of ice. The fact that no disturbance in the deposition was noticed there, confirms the conclusion that the lowering of water level must have been small. If it had been lowered e. g. by nearly 20 meters, this should have washed out sand and gravels from the Salpausselkä and the land ice over the ISs-sediments.

Another discrepancy exists in the chronological results. *The combination Billingen — First Salpausselkä means that the northern-*

[1]) E. G. Palmén, Äldre och nyare sjöfällningar i Finland, Fennia 20, N:o 7, 1903, p. 87.

most series of the northern recessional moraines in central Sweden is almost synchronal with the First Salpausselkä in Finland, or more exactly a little earlier, as the series of moraines just mentioned is situated nearly 10 km. south of the north edge of Billingen. The earlier opinion was in favour of the combination of the northern moraines with the Second Salpausselkä. Moreover, the views now proposed by me raise the question: does De Geer's line, Billingen—Södertelje, really mean a synchronal position of the border of the ice sheet?[1]) For if the H_2-clay, indicating the maximum of salinity in Southern Finland, is synchronal with the Yoldia clay in the valley of Lake Mälar, and both owe their character to the opening of the Närke sound,[2]) these series of sediments can not have been deposited immediately after the withdrawal of ice from Mt. Billingen, in other words during the later stage of the First Salpausselkä epoch. There are more than 700 varves (iSs, IISs, H_1) between ISs and H_2. So many years are needed in Sweden also for the retreat of the ice border from Billingen to Närke, a distance of about 60 km. Chronological equivalence to Billingen, in eastern Sweden, then must be looked for somewhere south of Södertelje. This is in no way a new idea, as Munthe[3], and earlier De Geer[4]) have drawn the curve in question about 50 km. farther south, through Broviken. In my opinion, this combination is more probable, and in fact looks more probable from a mere inspection of the map.

This combination also makes, as it seems to me, the former connections made by G. De Geer between Finland and Sweden questionable (Südfinnland, p. 34, 35) at least as far as they are concerned with the Salpausselkä epochs. As these connections were inconsistent in other respects too, the error in the connection made by the diagram method may be great as easily as small. The chronological discrepancy, therefore, is no reason for misgiving, so much the less, as other considerations will lead us to the conclusion that the halts of the ice border in Finland and Sweden were not necessarily synchronal. On the other hand, it is quite certain that the commonly accepted idea of their synchronism has had an influence in the making of connections[5]) — and possibly been misleading.

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[1]) G. De Geer, Fjärrkonnektioner längs de finiglaciala gränsmoränerna, Geol. Fören. Förhandl. Bd. 39, 1917, p. 185.

[2]) G. De Geer, Finiglaciala Yoldiarelikter, Geol. Fören. Förhandl. Bd. 35, 1913. pp. 307—309.

[3]) H. Munthe, op. cit. map. Pl. 47.

[4]) G. De Geer, Om de finiglaciala gränsmoränerna och motsvarande klimatväxlingar, Geol. Fören. Förhandl. Bd. 39, 1917, p. 20.

[5]) G. De Geer, op. cit., p. 18, 19.

In spite of what was said above, the question may be asked whether the lowering of the level of the Baltic in Finland and Sweden was at all the same event. A doubt is so much more justified, as W. Ramsay has communicated — though in reports of a preliminary character only[2]) — that he has found signs of lowering by the opening of the Billingen sound inside the *Second Salpausselkä.* This is the third discrepancy. The shore-marks within the Salpausselkä belt and nearest northward to a definite line are, according to Ramsay, at higher levels than north of this line. The difference is 22 or 23 metres and should be due either to an upheaval of the lithosphere or to the lowering of the surface of water at the opening of the sound in Central Sweden. This hypothesis is, in my opinion, contradicted by many facts.

1. No lowering of the surface of water was possible, because the Baltic Sea had already been, during several centuries before the supposed lowering, on a level with the ocean.

2. During that time in which the catastrophe should have taken place according to Ramsay, the sea was becoming gradually shallower owing to the upheaval of the continent without any sudden decrease of depth. This is positively proved by several clay sections (see especially locc. 1 Leppäkoski and 31 Iittala, pages 105 and 114). And no section shows, in the varves from the time in question, any such anomalies, — unconformities, thick sand varves — as might be expected to result from a sudden thinning of the sheet of water. At least in the northeast half, where 22 metres is about a half of the depth of the sea at that time, such phenomena should occur. A study of the sediments leads to the conclusion that the conditions during that time were quieter than in many other periods, as appears from the preceding discussion.

3. The rate of retreat of the ice border after the Second Salpausselkä implies a water-sheet of nearly uniform thickness in front of the ice border, without any considerable sudden thinning, as will be shown below.

In my opinion, therefore, no particular change in level has happened in these times in the waters bordering the ice sheet.

It is too early to conjecture what may be the reason of the apparent discrepancy between Ramsay's and my results, before Ramsay has published his investigations.

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[2]) W. Ramsay, De s. k. marina gränserna i södra Finland, Fennia, 40, N:o 7, 1917, p. 7.

W. Ramsay, Strandlinjer i södra Finland, Geol. Fören. Förhandl. Bd. 43, 1921, p. 495.

From the record of the sediments, Ramsay's views therefore do not contain any conclusive argument against the combination proposed by me. Nevertheless, it may be possible that the discharge at Billingen and the lowering at the end of the first Salpausselkä epoch is not the same event. A small jump in the water level might have occurred in passing from H_1 to H_2, year 292, and these might belong together. The considerable decrease of salinity appearing in the later part of the former series might depict a small rise of the water surface, while the sudden reappearance of intense marine facies at the start of H_2 would mean a return to the former level. But if this be taken as synchronal with the discharge at Billingen, an earlier connection between the Baltic and the ocean must have existed elsewhere, and the only possible way is through the sounds of Denmark. The opening of the Närke sound should also have some effect. The salt water that arrived this way should have its effect some time after the deposition of horizon H. There are, however, no signs of such an event in Satakunta or Pohjanmaa. *Thus the combination First Salpausselkä — Billingen is anyway in best accord with the facts.*

As a matter of course, my interpretation of the causal relations of the events connected with the development of the Baltic during the late glacial time is only hypothetical, as long as the varve sediments and the decadence of the ice sheet in central Sweden, as well as the significance of old shoremarks in the whole of Fennoscandia, await their definite unravelling. It is true that such a great problem can not be solved on the basis of varve sediments alone. On the other hand, it can not be denied that these investigations may help very considerably to clear up this problem which, for several centuries, has attracted the attention of scientists on both sides of the Baltic.[1])

Recession of the Ice Sheet.

Recession of the ice border in the subaquatic area. — The proximal line of each varve indicates the position of the ice border during the corresponding period of deposition, or year. A proximal line is therefore practically identical with what De Geer has called an *equicess.*[2]) In the whole preceding treatise, the term proximal line has been used exclusively, the varves being considered as concrete things; now, turn-

[1]) A. G. Högbom, Nivåförändringarna i Norden, Göteborg 1921.

[2]) This statement does not imply that the position of the ice border would have been, at a certain moment, exactly that indicated by the corresponding proximal line. The amount of deviation, however, can hardly be determined and is generally not large enough to appear on the maps.

ing to the historical record, we may use the theoretical but well-founded conception of equicess.

On the map of the special area, (Pl. VIII) every hundredth, and in the region of Tampere even every fiftieth equicess has been indicated. Where they rest upon numerous observations in adjacent localities, the lines have been drawn full, but in other cases dotted. Continuous recessional deposits have been used as subsidiary indicators of the equicesses in those parts where the record of the varve sediments has not proved them to be non-synchronal.

The equicesses indicate directly the extension of the ice sheet every hundredth year. Detailed information concerning the rate of retreat of the ice border may be derived from the observations described in Chapter III.

Attention may first be directed to some smaller details in the bends of the equicesses, which are very numerous in that part of the area that has been most closely investigated. Some of them protrude outward from the ice sheet, as *ice capes*, while others intrude toward the centre of the ice sheet, as *ice bays*, the land ice having generally been bounded by the sea. Now, it is easy to find that there is a quite definite relation between those bends and the topography of the land that once underlay the ice sheet: ice bays were, as a rule, situated in depressions, and ice capes upon higher places. The particular ice cape that originated about year 100 at the southeast end of the basin of Lake Vanajavesi moved gradually, marking all the bends of that basin, through Toijala, Lempäälä, and Pirkkala, existing for almost 300 years. Another analogous feature may be found somewhat farther north: The equicess of year 300 forms a neat bend toward the centre of the land ice in the low district of Kangasala. This bay remained, moving north, during that century, in Messukylä and Tampere where it divided itself into two bays. One of them moved into the basin of Lake Näsijärvi, but its later development was not followed in this investigation. The other bay, again, turned westward, following the basin of Lake Pyhäjärvi toward Pirkkala. Here it met, about year 400, the other ice bay mentioned above, moving from Lempäälä, and the ice front was therefore straightened.

Upon the higher land between these basins (the rocky hills of Vuorestenvuori south of Tampere reaching an altitude of about 200 metres) there was a protruding ice cape. When the ice bays moving from different directions turned towards each other, the *ice isthmus* between the two bays became gradually narrower and was finally cut through, the cape remaining as a separate *ice island*. This island only vanished entirely much later, when the edge of the main ice sheet had retired far away to Ylöjärvi and Hämeenkyrö, about years 440—450. A diagram of the varve sediments between Lempäälä and Pinsiö (fig. 12) really indicates that there existed, in South Pirkkala, a gradually decreasing hindrance preventing the deposition of sediments.

Another ice cape existed for about two centuries in the higher country southwest of the basin of Lake Vanajavesi. When the ice border reached the more level valley of the Kokemäenjoki river, it was somewhat straigthened. Meanwhile a new long ice bay appeared in the deep narrow valley of Hämeenkyrö.

Similar relations are also well exemplified in the basins of Lakes Vesijärvi and Päijänne. There existed, in that basin, an ice bay

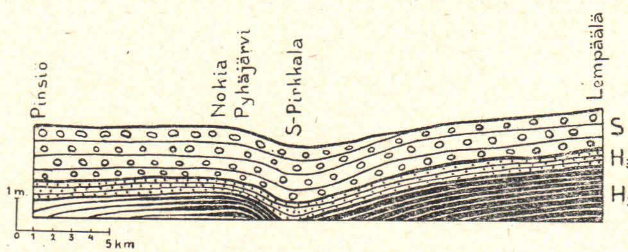

Fig. 12. Section through the varve sediments along the line Lempäälä—Ylöjärvi Pinsiö, showing how the deposition in South Pirkkala was later than south and north of it.

which moved successively northward between the Second Salpausselkä and Jyväskylä, during about 1,000 years in all.

The basin of Lake Kyrösjärvi, closed in the south, represents a case in which an ice cape was formed first and later an ice bay (not visible on the map, as close equicesses have not been drawn).

Now, it is apparent that the ice border, thus adjusting itself to the underlying land-surface, must show corresponding variations in its rate of recession. As long as the basin and the ice bay existing in it retain a straight course parallel to the motion of the land ice, the sourrounding capes and the end of the bay recede at almost the same pace. But when a bay is forming in a basin, the ice border must there recede quicker than in the surrounding areas. Where the basin has bends, or is not parallel to the movement of the land ice, the rate of retreat of the corresponding ice front must vary, accelerating in the area of deep water and retarding in that of shallow water. And in South Pirkkala a high area surrounded by deep waters was freed from the ice later than all its surroudings, even on the side of the continuous ice front. *The minor features of topography, the*

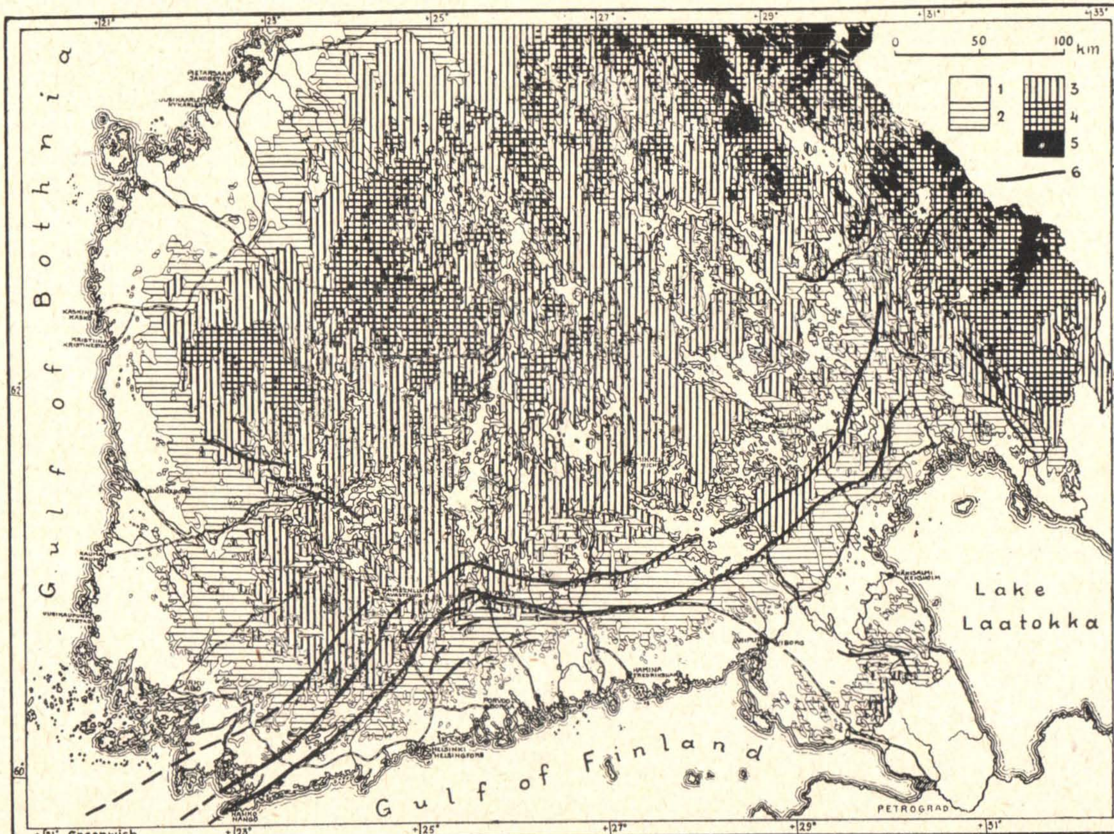

Fig. 13. Hypsometric map of Southern Finland. 1 0—50 metres; 2 50—100 metres; 3 100—150 metres; 4 150—200 metres; 5 more than 200 metres above sea level; 6 recessional moraines (the three long parallel Salpausselkäs etc.). After Atlas de Finlande 1910, Société de Géographie de Finlande.

variation of deep and shallow waters, the course of the ice border and its rate of retreat thus stand in a direct causal relation to each other.

This conclusion applies not only to the minor details, but also to the great features. To understand the meaning of this statement, one must have a clear idea of the character of the country underlying the ice sheet during the late glacial period. The territory of southern Finland was at that time lower, relatively to the level of the Baltic, and almost entirely below water level, but the upheaval still in progress had already started, when the land was covered by the thinning ice sheet. It was constantly greater in the central than in the peripheral parts of the glaciated area.[1]) The present grade of different parts of the country, as described on p. 8 and shown on the map (fig. 13) is therefore a result of a long-continued unequal upheaval. The earlier inclination may be determined from the positions of ancient synchronal shore-lines referring to continuous waters. Thus that shoreline representing the water level of the ancient lake Suursaimaa (Great Saimaa) which extended continuously from the Salpausselkä to the divide of Pohjanmaa, over a distance of 264 kilometres, is at its northwest end 38 metres higher than at its southeast end.[2]) The average upwarping within this interval was thus about 1.4: 10,000 metres. Another ancient lake, Muinais-Päijänne (Ancient Päijänne) emptied itself in an early post-glacial time in a direction opposite to that of the present outlet of L. Päijänne, or into the Gulf of Bothnia.[3]) According to Schjerfbeck[4]) even the Suursaimaa had its first outlet into the Gulf of Bothnia, before the southward outlets through the Kymi river and finally through the Vuoksi river were formed.

Still in the early postglacial time, therefore, the position of the land surface was such as to make the Salpausselkä belt the divide between the Gulf of Bothnia and the Gulf of Finland. A still earlier shore line from the late glacial time is the above-mentioned (p. 125) large terrace near the town of Lahti. It rises 12 metres within an interval of 25 kilometres, or 4.8: 10.000 metres[5]). Among the highest shore lines formed immediately after the withdrawal of the ice sheet from any locality, on the other hand, only those are synchronal which are

[1]) According to R. Lidén, the area of Ångermanland rose during the vanishing of land ice in that district from 10 to 13 metres in a century (Geokronologiska studier öfver det finiglaciala skedet i Ångermanland. Sveriges Geol. Undersökning, ser. Ca N:o 9, p. 28).

[2]) A. Hellaakoski, Suursaimaa, Fennia 43, No. 4, 1922, p. 105.

[3]) V. Tolvanen, Der Alt-Päijänne, Fennia 43, N:o 5, 1923.

[4]) M. Schjerfbeck, an unpublished investigation.

[5]) I. Leiviskä, op. cit. p. 378.

situated along the same equicess, as shown by Ramsay[1]), and they do not record the total upwarping of the land-surface. But as a matter of course the inclination at the withdrawal of the land ice from the Salpausselkä belt was still greater than that of the earliest synchronal terrace observed near Lahti.

The highest plateaus of Salpausselkä indicate the position of water level at the time of their formation. Near the ancient lake Suursaimaa they are about 108 metres, and near Lahti about 155 metres above the present sea level. The Salpausselkä belt between Karelia and Häme formed at that time a large bow-shaped shallow zone where the highest rocky hills reached the water level[2]). Southward the depth of the sea increased uniformly. The same was true in the opposite, northwesterly, direction, in the southwest half of the special area; in the northeast, again, the sea was shallow all the way to northern Häme and Satakunta, where another shallow region with islands existed. The wide and flat lake district was that time very nearly horizontal, while the southern narrow coast zone was not much less inclined than nowadays.

In examining the successive positions of the ice-border in the whole of southern Finland *it is apparent that the Salpausselkäs and the earlier equicesses running parallel to them adjust themselves according to the topography of the country, just as was found in the smaller details.* They follow faithfully the bow-form of the coast zone from Karelia to Uusimaa. In Uusimaa they turn farther north than might be accounted for by the present topography, but here the sea was, at the withdrawal of the ice sheet, deeper than farther east. When the coast zone west of Lahti turns southwest, inclining from the high land of Tammela-Loppi southeastward, the equicesses also show conformable bend to the southwest. Farther west they run across the deep basin of the Baltic. This circumstance does not mean any exception to the rule observed, as the ice border crossed other basins as well, usually bending inward, but sometimes outward.

Attention may finally be directed to the distribution of the equicesses. It will be found that they are much nearer to each other in the southeast than in the northwest. In other words, the retreat was slow in the southern coast zone, and rapid in the country inside of it. *The boundary between the areas of slower and quicker retreat coincides with the northern margin of the coast zone, but not exactly with any*

[1]) W. Ramsay, Geologiens Grunder, Helsingfors 1912, p. 237.
W. Ramsay, Strandlinjer i södra Finland, Geol. Fören. Förhandl. Bd. 43, 1921, p. 496.

[2]) I. Leiviskä, op. cit. pp. 276, 277, 380.

equicess, being in the northeast half and the whole of central Finland at the Second Salpasselkä (year 0), but in the southwest half at the Third Salpausselkä (year 200). Furthermore, the rate of retreat decreased as the ice border came to shallower waters within the coast zone. The maximum of retardation occurred on the shallows of the Salpausselkä belt (see fig. 14). In the flatter lake district the ice border receded first rapidly and uniformly, *but having reached other shallows farther north, another retardation occurred.* Within the southwest half, on the other hand, *where the depth of water increased as the ice border retired farther, the recession was all the time rapid and*

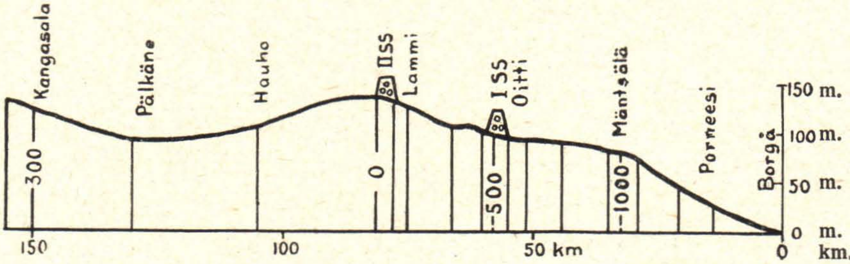

Fig. 14. Diagram showing the variation in altitude along the line Borgå (Porvoo) Kangasala, and the positions of the ice border (the vertical lines) every hundredth year.

even accelerating. Thus there appears to be a distinct causal relation between the rate of recession of the ice border and the character of the subjacent land-forms, in small details as well as in major features.

Halts in the recession. The lines at which the ice border, during its recession, was stationary for shorter or longer periods are generally situated in those areas where it was retiring slowly upon subaquatic ground inclined away from the ice sheet. This appears from the chronology as well as from the distribution of the recessional moraines, which are most frequent in the southern coast zone, especially on its higher inner margin, and also in northern Häme and Satakunta. Closer examination reveals a definite relation to the minor topograhy, as may be first illustrated by the recessional moraines between Jyväskylä and Korpilahti on the northwest side of L. Päijänne. They indicate that the halt, like retardation of retreat, occurs most usually upon the highest country, i. e. in the shallowest water. The halt was not synchronal along the whole of the line mentioned, but the stationary portion of the ice border moved successively northward as the high slope was uncovered from the ice. The recessional moraine is somewhat discontinuous and especially swells where a tributary valley joins L. Päijänne from the direction of the ice sheet (Lake Muuramenjärvi and the moraine Muuramenharju).

In northern Satakunta, the recessional deposits of Hämeenkangas between Hämeenkyrö and Kankaanpää represent a similar case still more clearly. Here also the ice border was stationary on the higher northeast side, but moved continually on the lower southwest side. The halt lasted longest at the east end of the slope near the basin of L. Kyrösjärvi which, as pointed out before, is separated by a higher ridge from the deep valley of Hämeenkyrö in the south. Even at the outlet of L. Kyrösjärvi, under the moraine itself, there is a threshold of rock which gives rise to the Kyröskoski falls, 20 metres high. There seems to have been some oscillation of the ice border in this special tract. The disturbances in locc. 120 Osara and 119 Vesajärvi may be due to this effect. Furthermore, there was found, near the church of Hämeenkyrö, a layer about one metre thick of unstratified drift interbedded with clay.[1])

West of L. Kyrösjärvi, the difference in the rate of retreat upon each side of Hämeenkangas decreases and becomes unnoticeable in Kankaanpää, where the whole area is flat. The recessional moraine also ends here, dividing into several eskers. Most continuous among them is the Pohjankangas esker bending north and again locating itself to the boundary line between higher and lower grounds. Two other much lower eskers trend toward the NW and NWW.

Among the few halts inside the Salpausselkäs may be mentioned that marked by the recessional moraine south of loc. 32 Iittala, upon the high west shore of a lake. The halt has consequently taken place when the ice border suddenly moved from the deeper water to a shallower place. Another shorter recessional moraine is situated in an analogous position northeast of loc. 77 Kylmäkoski. Still another, the wide plateau of Maakeski northwest of loc. 20, is situated in an elevated place sheltered from the south by high rocky hills.

The numerous long halts in the southern coast zone may likewise be found to stand in a definite relation to the smaller features of the land-forms. The first slow recession farthest south occurs upon the eastern line of investigation (Südfinnland, Pl. II), on the rocky land south of Hopom Lake. The same is the case on the western line in Porneesi. Another retardation which lasted nearly 200 years occurred on the rugged country between the lake basins of Artjärvi and south of them. Farther west the ice border, about the same time, halted

[1]) Notes of J. J. Sederholm at the Geological Commission. The observation was made by the county chemist, but has not been confirmed by any professional geologist, and can therefore not be regarded as absolutely reliable.

twice in Mäntsälä, the first time upon rocks near Ylikartano (Andersberg), and the second time on the southern edge of a rock cliff near Hirvihaara. A regular recessional moraine trending from this place in a southwesterly direction, runs, on the other hand, over a rather

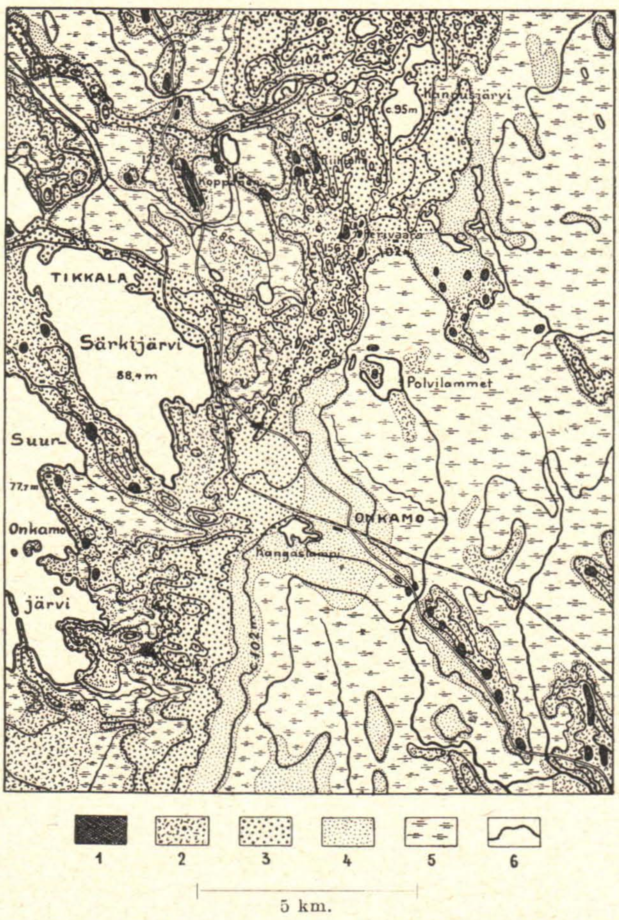

Fig. 15. Topographic map of an area on the Second Salpausselkä near Tikkala, Karelia. 1 rock; 2 moraines; 3 stratified drift; 4 sand; 5 bog; 6 isohypses, equidistance 17.04 metres.

level tract. East of Mäntsälä, the geological map shows numbers of esker plateaus resembling recessional moraines in the rocky area south of the basin of Lake Mallusjärvi in Orimattila.

North of the last mentioned series of halts most recessional deposits are again situated in that zone where the more level district of Uusimaa passes over into the very rugged and rocky country of southern Häme. Numerous recessional moraines in Ridasjärvi, south of the higher hills, are among the best examples of the control of topography with respect to the location of halts. A recessional deposit, parallel to the Lohjanselkä (First Salpausselkä), trends from this tract toward Jokela, constantly following a series of rocky hills elevated some 30 or 40 meters above the surrounding land.

The large Salpausselkäs and the neighbouring smaller recessional moraines show a similar regular relation to the subjacent land and its topographical features. A detailed description of the Salpausselkä zone cannot be given in this place, partly because it has not been studied especially from this point of view and the available geological and topographical maps do not form a sufficient basis for such a description, and partly because the description would require too much space. Instead, I shall describe a few special parts of this zone studied by myself.

One is situated in Karelia, in the northern part of the parish of Tohmajärvi, where the Second Salpausselkä, running in a northerly direction as a mighty zone of moraines and ridges of stratified drift from 3 to 10 kilometres broad, marks the first distinct halt of the ice border on this part of the ice front (fig. 15). Its distal margin slopes gently toward the level and monotonous Valkeasuo moor extending far north and south. A few low, wooded islands with their rock substratum consisting of mica-schist and phyllite rise above the swampy plain. The altitude of this area falls entirely between the isohypses of 90 and 100 metres.

Going west from this distal plateau, the centre of the recessional deposits is reached. Plateau-like level portions alternate with a labyrinth of ridges and dales, hills and depressions, of which the map does not give any true idea. The elevation of the northern plateau near L. Murtojärvi proves, according to Leiviskä, that the water level has been here about 129 metres above the present sea level. Among these deposits of stratified drift there are, also, transversal moraine ridges and irregularly arranged hills on which the rock is exposed or only covered by a thin mantle of fine drift of the character of unassorted glacial gravel. They reach altitudes of 130 or 140 metres, or above the late glacial water level. Inside the recessional deposits there are rocky hills and, between these, deep depressions the floor of which is considerably below the rocky ground outside the Salpausselkä.

Another special area is that around the town of Lahti. The surface of the rock foundation is here remarkbly rugged, and the highest point of southern Finland, the quartzite ridge of Tiirismaa, elongated in a westerly direction, rises here to an altitude of 223 metres above sea level. It formed an island in the late glacial sea. This high place is traversed by the First Salpausselkä. But the halt marked by this moraine began here several decades later than farther east in Uusikylä. When the ice border halted in the last-mentioned locality, about year — 670, it was, in front of Tiirismaa, still 10 km. south of

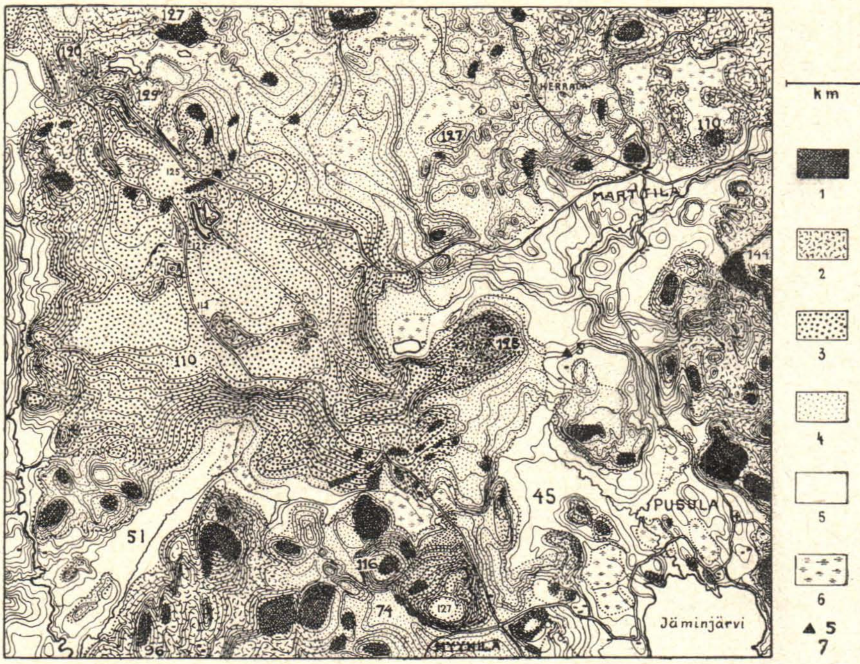

Fig. 16. Topographic map of the large plateaus in Pusula, Uusimaa (Nyland). 1 rock; 2 moraines; 3 stratified drift of the plateaus; 4 sand; 5 bog; 6 isohypses, equidistance 4.2 metres; 7 loc. 5 Pusula Marttila (see the special map Pl. VIII).

Salpausselkä, in loc. 137 Herrala. Thus the recessional moraine between these localities is not, in spite of its morphological continuity, synchronal, but analogous to the deposits of Hämeenkangas and those between Korpilahti and Jyväskylä described above. The local topography has here also played a decisive part, causing the deepening of the great bend of Salpausselkä during the halt. On the line here where the ice border was at the beginning of the halt, between Herrala and Uusikylä, there is a recessional moraine, called Renkomäki. West of this place the outer series of recessional moraines belonging to the Salpausselkä stage trends from Hausjärvi toward Herrala while the inner series continue in their former direction northeastward as a zone about 10 km. broad. Several rows of high rocky hills here run in the same direction.

As a third example may be described an area between the Second and Third Salpausselkä in Pusula, around loc. 5. (fig. 16). This area embraces two river plains in which the rock foundation lies at an altitude of 40 or 50 metres, while it rises, between these valleys and in the whole northern part, to an altitude of from 100 to 125 metres. Two esker plateaus mark halts of the ice border. The smaller southern deposit is situated on the high land between the valleys near the high rocks. The large northern recessional deposit proves that the ice border halted when it passed from deeper water to a shallower place and met with rocks reaching nearly to the water level of that time. The discontinous row of recessional moraines running in a northeasterly direction from the plateau also follows the northern slope of the river valley.

In other tracts, also, the recessional moraines display features similar to those described, for these areas chosen as examples represent general and by no means exceptional cases. Thus the Second Salpausselkä, in the central bow, follows the southern and southeastern edge of the big lake basins. Farther west, between Lakes Päijänne and Vanajavesi, it is situated near the local divide (see fig. 13). The First Salpausselkä, again, is situated where the ice border, on its retreat, met with the first rocks which reached nearly to the surface of the water and generally the outer margin of the shallows of the Salpausselkä belt.

On the western front, in the coast zone inclined southeastward, two long halts took place during the Salpausselkä epochs, and later there followed a third shorter halt. This Third Salpausselkä assumes the same topographical position as the Second Salpausselkä farther east, or on the higher country between the waters flowing west and southeast. The highest places between Tammela and Kisko here reached nearly to the surface of the late glacial sea (cf. the text map p. 112). Still farther southwest where the Third Salpausselkä is upon lower land, it still prefers the highest places. Thus, it traverses the large island of Kemiö (Kimito), and still appears in the Baltic in the small islands of Jurmo and Utö. — Toward lake Vanajavesi, the equicesses corresponding with this halt epoch spread to an increasingly broader zone as one proceeds farther northeast. East of L. Vanajavesi, no retardation is noticeable.

The Second Salpausselkä (Karjalohjanselkä) lies, on the western front, over somewhat lower areas than the third. In places its position is analogous to that of the First Salpausselkä on the central front.

In its southwest end, it also descends beneath the surface of the late glacial sea, still, however, like the Third Salpausselkä, choosing the highest ground. Thus, in the parishes of Karjalohja and Pohja, it marks the dividing line of two different landscapes: on the southeast side, a lower, clayey, well cultivated and densely inhabited tract, but on the northwest side a higher, meagre, wooded, and rocky land. Near the sea, the recessional moraine runs down the middle of the long cape of Bromarf, and still rises from the Baltic in the rocky islands of Hiitis.

The First Salpausselkä is situated upon a still lower area, having been formed under the sea all the way southwest of Hyvinkää. But it also shows a tendency to find the highest places, like the other recessional deposits. The railroad line between Helsinki and Hämeenlinna, which generally runs over very level country, has its only big rock sections in Hyvinkää and Riihimäki, in both places exactly under the recessional moraines. Southwest of Hyvinkää the First Salpausselkä keeps upon the highest ground. On the sea coast, the long cape of Hankoniemi is not merely formed of recessional deposits but has a rock kernel elevated above the average level.

In accentuating the fact that the halts have taken place upon a land-surface of a definite character, it is well to make two remarks. In the first place, these observations do not imply that the recessional moraines marking the halts would exist upon elevated ground only. In many places, they also traverse level ground. In the second place, it may be emphasized that topographical features similar to those connected with the halts also occur in places where no signs of halts of the ice border or retardation of its retreat are noticeable. Instead, the larger features of the land-surface seem to be much more important, especially with regard to the long halts. But still other remarkable relations are connected with these interesting phenomena, as will be discussed below.

Periodicity of recession. On a closer scrutiny of the retarding recession along a subaquatic slope inclined away from the ice sheet, we may note the following interesting observation: *The halts that repeatedly interrupt the recession are in themselves no independent events, but parts of larger series of events which repeat themselves during a longer period of recession.* The recession, in other words, is periodical. A period has the following general characters: The retreat becomes gradually slower long before the beginning of the halt and finally ceases entirely. After the stationary epoch, the recession starts again, and then with a sudden jerk, showing a maximum velocity immediately after the halt. Thereafter the pace again gradually decreases to the normal and still less, — toward the next halt (cf. Südfinnland, plate II). Thus each period has two epochs: a retarding recession starting with a sudden jerk, and the final halt. The halt is compensated by the subsequent quick recession, and the average pace is not affected by the halt.

The length of a period may be very variable; the larger halts only make themselves noticeable over wide extensions and give the recession a distinct rhythm. In our special area, in its northeastern part, there are four such periods: (1) starting from the Liljendal—Porneesi line and ending at the Artjärvi—Mäntsälä Hirvihaara line; (2) ending at the inner margin of the First Salpausselkä; (3) ending at the inner margin of the Second Salpausselkä; (4) is not concluded within our area, having not yet ended at the equicess of year 700. The following table gives a synopsis of these periods:

Period	Start year	End year	Length	Halt epoch[1]		Recession of ice border
			years	years	per cent	km.
1.	—1220	— 870	350	150	42	20
2.	— 870	— 435	435	270	63	20
3.	— 435	0	435	300	68	20
4.	— 0	700	700	100	14	120

With regard to the whole area, the periodicity is much more complicated. Even these large periods are not synchronal except in their big features. They include, moreover, several smaller periods of much local variation. The figures show anyway, first, the circumstance mentioned above that the number of years of the halts increases as the ice border reaches shallower waters in the southern coast zone. Secondly, the length of the periods increases in the coast belt and more especially in the lake district, as the grade decreases. A third very interesting fact is that the ice border moves, within the coast belt, a constant distance of 20 km. during each period, *notwithstanding the variation of the length of the period or the length of the halts. The halts, in other words are compensated by the quicker retreat and do not cause any decrease of the average rate of retreat.* This is especially apparent during the long-continued recession after the Salpausselkä epochs, when the whole of the lake district was freed from the ice sheet at a particularly quick rate. This result is also connected with the grade of the subjacent country: In the steeper coast zone the distance of recession, during a single period, is shorter, and in the level lake district much longer.

[1]) Including the lengths of the smaller halts during times of recession.

The southwest half of the special area differs from the other parts with regard to periodicity. There is one more period, 200 years long, ending with the halt at the Third Salpausselkä. This recessional moraine is, as mentioned before, located in the coast zone which inclines to the southeast. After this halt the recession has been uninterrupted and most rapid in the western coast zone which inclines toward the gulf of Bothnia, where the ice border, upon its retreat, met with successively deeper waters. This is another important difference from the eastern half.

Recession in the supra-aquatic area of Karelia. The largest part of the territory of Karelia north of Lake Laatokka, on both sides of the frontier of Finland, was supra-aquatic during the late glacial period. The recession therefore left no record except in the form of recessional moraines. In studying these, attention is drawn to the fact that *there are no moraines corresponding with the big Salpausselkäs.* As the geological mapping in Finnish Karelia has been done in the same way throughout, and even under the direction of the same geologist[1]), the difference can not be due to the method of mapping. The country east of the frontier is not as well known, *but many scientists have looked for Salpausselkäs in that district and not found any.*[2])

Local halts, on the other hand, have occurred in several places, especially farther north where the land was partly covered by shallow water, upon a special kind of land-surface: on the distal side of large lake basins in the rock foundation. Representatives of such recessional deposits are Jaamankangas south of Lakes Höytiäinen and Viinijärvi, Uimaharju south of Lake Pielinen, and Selkäkangas south of Lake Koitere. (See fig. 13 p. 132). On the far side of the frontier, Rosberg[3]) knows of similar deposits on the east (distal) side of Lakes Sumosero, Tuoppojärvi, Kuittijärvi, and the valley of the Tshirkkakemi River which is connected with the last-mentioned lake.

Near the boundary line between the subaquatic and supra-aquatic territory in Salmi and Suistamo there are many esker formations which, as far as the position of the ice border may be concluded from the striae, are similar to Hämeenkangas in Satakunta. Deposits related

[1]) Geol. Comm. Finland, The folios D2, E2 and E 3, Quaternary deposits, by H. Berghell.

[2]) J. E. Rosberg, Ytbildningar i ryska och finska Karelen med särskild hänsyn till de Karelska randmoränerna, Fennia 7, N:o 2, 1892.

J. E. Rosberg, Ytbildningar i Karelen med särskild hänsyn till ändmoränerna, II, Fennia 14, N:o 7, 1899.

[3]) I. E. Rosberg, op. cit. pp. 29—42.

to recessional moraines also occur on the Karelian Isthmus, in analogous positions.

Earlier data concerning the position of the ice border on land and in the sea. Mountain glaciers and the marginal parts of continental ice sheets, when ending on land, concentrate their largest masses in the lowest places and send out protruding ice tongues and lobes along the valleys. These forms are well known from existing glaciers and have also been described, as inference from marginal deposits, from the ice sheets of the Glacial period.[1]) It is of a special interest to us that examples of such an adjustment of the ice border according to the local topography are also known from Lapland, an area whose relief and relative altitudes are closely similar to those of southern Finland.[2])

An ice sheet ending in the sea is similar to that described above in that the motion of the ice depends upon the topography. The position of the ice-border, however, does not depend exclusively upon the supply and melting of ice in each place, but also upon a third factor, *calving*. The ice is buoyed up by the water and, at a definite depth, begins to float and breaks up to icebergs.

About 1/8 of a floating ice floe rises above the surface of water. So long as the portion above the surface is greater, the ice touches the bottom. The proportion of the thickness of the ice front and the depth of water, in some Alaskan glaciers is, according to Reid[3]), as follows:

Glacier	Depth of water feet	Height of ice front, feet	Thickness of the ice at end, feet
Muir	720	130—210	900
Carrol	540	100—200	700
Rendu	600	60—150	700

[1]) W. H. Hobbs, Characteristics of existing glaciers, New York, Macmillan Co., 1911.

R. S. Tarr, The Yakutat bay region, Alaska, U. S. Geol. Survey prof. Paper 64, 1909.

A. Penck u. E. Brückner, Die Alpen im Eiszeitalter, I, II, III, Leipzig, 1909.

J. G. Granö, Beiträge zur Kenntniss der Eiszeit in der nordwestlichen Mongolei, Fennia 28, N:o 5, 1910.

F. B. Taylor, The correlation and reconstruction of recessional ice borders in Berkshire County, Mass., Jour. Geol. Vol. XI, 1909, pp. 323—364.

[2]) V. Tanner, Studier öfver kvartärsystemet i Fennoskandias nordliga delar. III. Om landisens rörelser och afsmältning i finska Lappland och angränsande trakter. Bull. Comm. Géol. Finlande N:o 38, 1915, pp. 657—663.

[3]) H. F. Reid, Glacier bay and its glaciers, U. S. Geol. Survey Sixteenth Ann. Rept., pt. 1, 1894—95, p. 433.

These figures show that the portion rising above the water level is from 0.1 to 0.2 or, on an average, 1/7 of the total thickness of the ice front.

The investigations of von Drygalski on the glaciers of Greenland[1]) lead exactly to the same conclusion: Very homogeneous ice may move so far into the sea that only 1/7 or 1/8 of it rises above the surface of the water. More fractured ice does not reach that far. Depths which are four or five times as great as the thickness of the inland ice above sea level, have not been measured in Greenland in front of attached ice masses, because the latter become in that case broken up into bergs. The calving of bergs of the first class, in which case parts of the glacier break up along its whole breadth, occurs where the depth of the water has so far increased that the ice begins to leave the bottom and assume a swimming attitude. The buoyancy of the water is thus the true cause of the separation of the bergs.

Special emphasis upon the differences between glaciers ending on land and in the sea has been laid by Tarr[2]). — He writes: »It is a notable fact that the piedmont type of glacier extends much farther out from the mountain base than do those glaciers which are tidal. This is not in all cases due to an excess of supply from the glaciers which feed the piedmont expansions. In Hubbard Glacier, for example, the ice supply is unquestionably great, coming from numerous tributaries and from lofty mountains; yet its terminus is back well within the mountains, while some very small glaciers, like the Atrevida, extend beyond the mountain face and expand in moraine-covered, fan-shaped, piedmont areas.

It seems probable that the chief cause for this difference in position of the ice fronts of the two classes of glaciers is the action of the fiord water, which operates to cause relatively rapid recession in two ways — (1) by melting, breaking away, and removal of the ice front, and (2) by the prevention of marginal accumulations of protecting moraine, thus greatly accelerating ablation. A thin ice foot on the land may become covered with moraine and even with forest, and become so blanketed that it remains unmelted for half a century; but an ice cliff rising above fiord waters can develope no such condition.»

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[1]) E. von Drygalski, Grönland-Expedition der Gesellsch. für Erdkunde zu Berlin, Berlin, 1897. pp. 387—404.

[2]) R. S. Tarr and B. S. Butler, The Yakutat bay region, Alaska U. S. Geol. Survey. Prof. Paper 64., 1909, p. 37.

Cf. also: R. S. Tarr, Glaciers and glaciation of Alaska, Ann. Assoc. Amer. Geogr. 1912, II, p. 11.

Examination of the maps of Arctic countries proves clearly that the course of the ice border is determined by the distribution of land and sea. Even the largest glaciers flowing along valleys end at the head of the fiords and do not send out ice tongues into the sea. Upon more level ground, the land ice ends invariably as a vertical cliff.[1])

To sum up, the course of the ice border is greatly influenced by the position of the ice front — whether on the land or in the sea. On the land, the course is mainly determined by the rate of melting and the supply, which is greatest in the valleys. Ice sheets therefore always send out ice tongues along the valleys. In the sea, the supply being the same, calving, depending upon the depth of water, is a

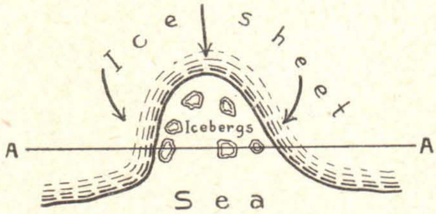

Fig. 17. Diagram showing an ice bay formed by calving, with icebergs. Arrows indicate the movement of land ice. A-A the cross section in fig. 18.

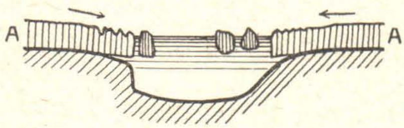

Fig. 18. Cross section of the ice bay along A-A. Arrows indicate the movement of land ice.

determining factor, and the ice front in deep water is likely to assume a concave line, or form ice bays.

Calving of the late glacial ice sheet. In the course of the equicesses in the area of our investigation — to return to them again — we recognize many features familiar from existing glaciers. In southern Finland the ice sheet, as a rule, extended farther upon high ground, or in shallow water, than in lower places, or in deeper water. This means that the water bounding the ice sheet has been the controlling factor determining the course of the ice-border. *The late glacial inland ice has calved.* In higher places the ice could form a cape, because it rested upon the bottom. In deeper water, in the basins, it could not extend as far, because it lost its support and broke up into ice

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[1]) Examples are quoted by W. H. Hobbs, Characteristics of existing glaciers, New York, Macmillan Co 1911: p. 107, map of the ice-capped islands in the eastern part of the Franz Joseph Archipelago; p. 60, picture of typical ice cliff of the coast of Prince Rudolph island, Franz Joseph Land; p. 124, fig. 75, map of the region about King Oscar and Kaiser Franz Joseph fiords, Eastern Greenland.

U. S. Grant and O. F. Higgins, Coastal glaciers of Prince William Sound and Kenai Peninsula, U. S. Geol. Survey Bull. 526, 1913.

floes and bergs. Thus were formed the ice bays in the basins. Figures 17 and 18, are intended to illustrate schematically the mutual relations of the inland ice, the sea, and the underlying land, in such a case.

The occurrence of calving of the Fennoscandian land ice has been early recognized by geologists from various phenomena: (1) The boulders embedded in the varve sediments having apparently been carried by icebergs. (2) The occurrence of rocks of known provenance as boulders in tracts to which they can not possibly have been carried by the land ice, e. g. of rapakivi from the Viipuri area in western Uusimaa). (3) The influence of calving upon the position of the ice border has been especially discussed by Frödin[2]) who describes, among other examples, a beautiful ice bay due to calving from the vicinity of Holmestad in Vestergötland in Sweden, which appears from the position of the annual moraines. These are situated upon a land-surface strictly analogous to that observed in similar cases in southern Finland. A concave course of the ice border due to calving in valleys has also been noted by Carlzon[3]). Further, acceleration of the recession in deeper water and retardation in shallower water has been proved by Antevs in his study of the clays in Scania.[4])

The thickness of the ice front. The fact that the ice sheet, in a large part of southern Finland, ended in the sea and calved there, *affords a possibility of estimating the thickness of the ice front.* This has certainly, as in recent glaciers, had from 1/5 to 1/8 of its thickness above the water level. At the south end of Lake Päijänne, for instance, the thickness of the ice front should have been some 35 or 50 metres (the surface of water having been about 160 metres above the present sea level and the average altitude of the land being 125 metres). The portion reaching above the water was therefore about 10 metres. In the southwest half, in the region of Tammela—Loimaa, the thickness of the ice was 80 or 90 metres, and near the present Baltic a little more than 100 metres. The thickness of the ice sheet behind the front naturally increased, though probably not very quickly.

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[1]) W. Ramsay, Finlands geologiska utveckling ifrån istiderna intill våra dagar, Helsingfors 1900, p. 58.

[2]) G. Frödin, Über einige spätglaziale Kalbungsbuchten und fluvioglaziale Estuarien in mittleren Schweden, Bull. Geol. Instit. Upsala, Vol. XV. 1916, pp. 149—174.

[3]) C. Carlzon, Inlandisens recession mellan Bispgården och Stugun i Indalsälfvens dalgång i Jämtland. Geol. Fören. Förhandl. Bd. 35, 1913, pp. 311—328, 343—360.

[4]) E. Antevs, Landisens recession i nordöstra Skåne, Geol. Fören. Förhandl. Bd. 37. 1915. pp. 360, 361.

The ice streams. The position of the particular ice streams that were formed in the marginal parts of the inland ice may be reconstructed from the topography and the striae. On the land they resulted in protruding ice lobes, in the water they usually ended at the ice bays, like recent glaciers flowing to the fiords. These larger ice flows have had a special effect upon the distributions of the sediments, quite independent of the location of glacial water streams. This has been verified by Leiviskä in different parts of the Salpausselkä.[1]) Other examples in the area are: Hämeenkangas, swelling out near the basins of lakes Kyrösjärvi, and Jämijärvi, and Muuramenharju near L. Muuramenjärvi southwest of Jyväskylä. The special accumulating effect of these ice streams is noticeable even in the distribution of the varve sediments. Thus in the coast zone east of the Kymijoki river, the clays occur in greater abundance south of the basins of L. Saimaa and the other larger lakes.

A particularly large volume of ice streamed through the valley of L. Vanajavesi to Southern Häme and Northern Uusimaa, toward the wide ice bay. The accumulation of varve sediments (uninfluenced by coagulation) and esker materials is conspicuously abundant in this region.

The thickness of the land ice was greatest in the basin of the Baltic, and the rate of its movement accordingly quickest. The land ice masses pressed through the basin of the Gulf of Bothnia were therefore probably larger than those moving over the higher zone of the divide of Pohjanmaa.

The course of the ice border, with its bends, is thus no indicator of the location of the particular ice streams. It may be specially emphasized that the two great lobe-shaped portions of land ice bounded by the bows of the Salpausselkäs in the southern coast zone, east and southwest of Lahti, do not mean the existence of two corresponding large ice streams.[2]) The course of the ice edge has here, as in the smaller details, been determined by the devastating effect of the sea.

The movement of the inland ice and the striae. Near its outer margin the inland ice turns nearly at right angles to the edge, thus converging in the bays and diverging in the capes, *as indicated by the striae.* Near the basin of Lake Päijänne, for instance, the striae turn toward the basin. The same is the case on the southwest side of Lake

[1]) I. Leiviskä, Der Salpausselkä, Fennia 41. N:o 3, p. 341.

[2]) The term Saimenloben (the Saimaa lobe) used by De Geer is therefore misleading, as it suggests the idea that an active ice stream should have formed the bow in question. (G. De Geer, Om den senglaciala isrecessionen inom den Baltiska dalen, Geol. Fören. Förhandl. Bd. 36, 1914, p. 217.

Vanajavesi, where the ice border formed a bend. The region of Tampere, with its complicated development of the ice border, exhibits more divergent striae than any other part of Finland. Here may be found, in a small area, striae in nearly all directions except from the east and south.[1]) Some of the observations deserve special attention. In South Pirkkala, south of Lake Pyhäjärvi, I met with roches moutonnées eroded and formed by ice moving from the northwest. Striae in this direction were found on the northeast side of the rocks.

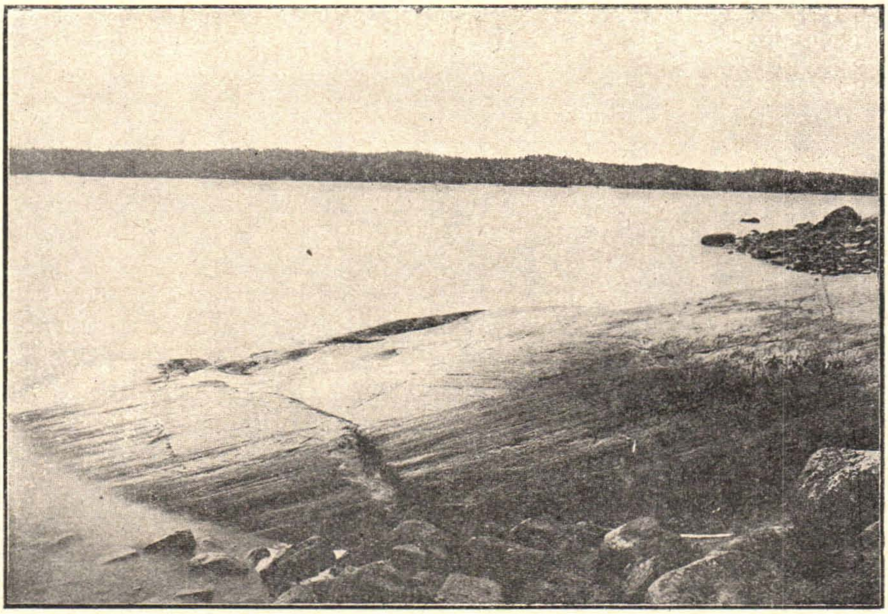

Fig. 19. Striae in two directions, the earlier from NW, the later, better developed, from N. North shore of Lake Kyrösjärvi, North Satakunta. Photo J. J. Sederholm.

On the opposite side, a later ice movement from the west (N80°W) has ground off the earlier striae and carved in it a new face, though not well developed. Thus the ice, at the last stage when the border was quite near, has moved from the west, or along the basin of Pyhä-

[1]) But a small part of the observations of striae collected by the Geological Commission or published (e. g. R. Herlin, Tavastmons och Tammerforsåsens glacialgeologiska betydelse, Geogr. Fören. Tidskrift, Helsingfors 3, 1891, pp. 88—113) are indicated on the special map. Some striae in the Tampere region have been noted by myself.

järvi, toward the ice bays formed in it. At an earlier stage, when the ice border was still farther southeast, the land ice moved from the northwest directly across the basin, which was here 50 or 60 metres deep.

A quite analogous observation has been made by Sederholm north of the basin of Lake Kyrösjärvi.[1]) Among two directions of faces and striae the earlier are from the northwest (see fig. 19), like those in south Pirkkala, representing the general movement of the inland ice, and the later from the north, at right angles to the last position of the ice border.

Fig. 17 and the text map, fig. 11 p. 112, are intended to illustrate a generalization from the above data concerning the movement of ice in different parts of the ice sheet. Far behind the front, the movement has a straight course at right angles to the general direction of the ice border and regardless of the small details of the relief. Near the margin, on the other hand, the movement adjusts itself to the local topography along basins, and tends to turn at right angles to the border in all details.

Observations of the striae connected with the subsequent courses of the ice border, as determined from the record of the varve sediments, throw light upon the well known fact that the striae most of which were formed when the ice border was not far distant, are no dependable indicators of the general movement of big ice sheets.[2]) By a critical use of the striae, on the other hand, the course of the ice border may be reconstructed even where no chronological investigations are available. This method has been practized by Tanner in Lapland[3]).

Causes of the varying rate of recession. Of the two opposite factors determining the position of the ice border, supply and wastage, the latter was dominant in the late glacial time. In supra-aquatic areas, wastage was exclusively due to melting. In areas covered with water, on the other hand, calving was another means of wastage, and recession might have taken place even without any melting at all, the supply being constant, if the water level had risen enough to keep the ice off the bottom. In southern Finland, however, the water was falling all the time (see pp. 105 and 114)[4]). Melting must

[1]) J. J. Sederholm, Atlas de Finlande 1910, map. sheet 5, IV.

[2]) Cf. for example: A. G. Högbom, Studier öfver de glaciala aflagringarna i Upsala, Geol. Fören. Förhandl. Bd. 14, 1892, p. 300; V. Tanner, op. cit. pp. 129, 654.

[3]) V. Tanner, op. cit. pp. 654—667.

[4]) For this reason, Astrid Cleve-Euler's hypothesis of sinkage of the land and a sudden disappearance of land ice after the Salpausselkä epochs is not at all in accord with the conditions in southern Finland. (Försök till analys av Nordens senkvartära nivåförändringar, Geol. Fören. Förhandl. Bd. 45, 1923, pp. 19—106.)

therefore have been an important factor here. But the manner of recession is clearly that characteristic of land ice facing the sea, *its pace being determined by the varying chances of calving, i. e. by the depth of water. Deep water in front of the ice border hastened and shallower water delayed the recession.* As a whole, the recession was retarded as the border met with shallow waters, at the northern margin of the southern coast zone and in northern Häme and Satakunta, while it was continually accelerating in the western coast zone, where the depth increased toward the north.

Even the opposite factor, the supply, is determined by the topography, but in a different way. The velocity of the movement of the

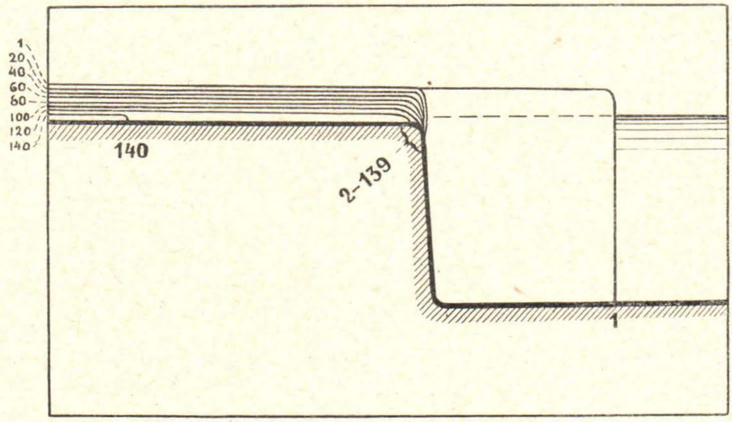

Fig. 20. Schematic and exaggerated diagram illustrating a halt of the ice border ending in the sea.

ice masses depends upon the character of the relief, not at the ice front, but behind it, the existence of basins and their position, whether parallel or transverse to the approaching ice border. These topographical features determine the amount and velocity of ice masses moving toward the front and counteracting the recession.

A special kind of balance between wastage and supply sets in at the halts. The exaggerated and schematic diagram fig. 20 is intended to illustrate the conditions causing a halt in a subaquatic area. The ice border retires gradually in consequence of calving so long as the depth of water is sufficient. But when a higher place is encountered, as all the places of halts actually are, the changed proportion between the thickness of ice and water prevents further calving. The ice masses, again, move at the same pace as before, but cannot effect any advance of the border toward the deeper sea, as the ice there breaks into pieces. The border therefore lingers in the same position. The halt continues until the marginal part of the ice sheet has grown thin enough by melting and evaporation to allow calving in that shallower water and the retreat may start anew. Thus the halt is caused by a lessened amount of calving.

This type of halt is represented on the northwest shore of Lake Päijänne, south of Iittala, in Kylmäkoski, and in Pusula Marttila (see fig. 16). Among the great halts in the area, those in Uusimaa at the First Salpausselkä and, in part, that at the Second Salpausselkä belong to the same type.

A halt in a supra-aquatic area is illustrated by the schematic diagram fig. 21. The ice border halts at the slope of a basin inclined

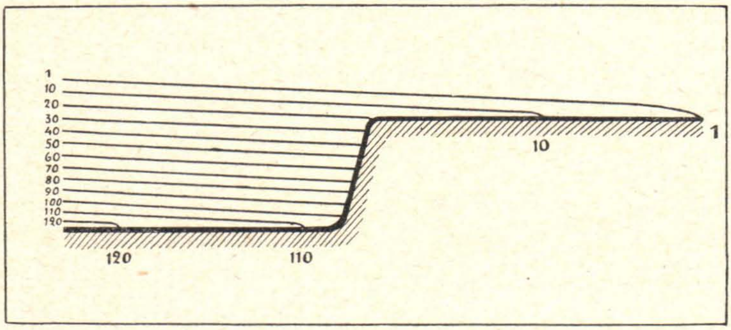

Fig. 21. Schematic and exaggerated diagram illustrating a halt of the ice border ending on the land

against the ice mass. It lingers there, because the ice in the basin is thicker than on both sides of it. The ice stream, flowing preferably into the basin, counteracts the wastage. Only when the ice masses in the whole surrounding area have very much diminished can the basin be freed from ice. The halt is therefore accounted for by a greater supply than usual.

Halts of this type have been described by Tarr from the receding glaciers of Alaska.[1]) In Finland, exactly the same case is represented by the local halts in the supra-aquatic area of Karelia.

Now, we may state that both these factors working to the same effect, namely, the decrease of calving and the local increase of supply, have combined their effects in the case of many halts that have occurred in areas of very shallow water. The halts at Jaamankangas on the south shore of Lake Höytiäinen and at Selkäkangas south of

[1]) R. S. Tarr, Glaciers and glaciation of Alaska, Ann. Assoc. Amer. Geogr. 1912, 2, p. 11.

Lake Koitere are good examples of this type. The same is the case at the Second Salpausselkä, as well as south of Lake Saimaa.

The southern plateau of Pusula (see map fig. 16), indicating a halt, is situated on high land and separated from the lower land in the south by still higher rocky hills, which have protected the ice from the attacks of the sea.

A fairly good illustration of the combined effect of increased supply and decreased calving may be found at Hämeenkangas in northern Satakunta. To the southwest, in the deeper water, recession was quick, but much slower in the shallower area northeast. A halt and even some oscillation took place at the southeast end of the basin of Lake Kyrösjärvi, to which the ice stream concentrated, while calving was inconsiderable, the basin being separared from the lower area by a rock threshold. Farther northwest the difference in the depth and in the supply of ice disappeared, and the rate of recession was therefore equalized.

The assumption of the combined effect of the two factors in question finally helps one to understand the periodicity of recession in the subaquatic area inclined away from the land ice. A halt takes place where calving in shallow water becomes ineffective in causing further recession. But the thinning of the ice sheet continues during the halt, until it reaches the point necessary to start a fresh recession. The start apparently is further delayed by moraines accumulating at the margin. In the case of the Salpausselkä, it is very clear that the moraines reaching to the surface of the water entirely prevented calving, and the conditions were the same as in an ice sheet ending on the land. Lack of calving is directly evidenced by the fact mentioned above (p. 119) that the varve sediments deposited during these halt epochs do not contain any boulders. In the case of the smaller and more undecided halts in Uusimaa the moraines, although they did not reach the water level, yet strengthened the effect of the topographical factor which originally caused the halts. It may further be considered that the ice near its edge, during halt epochs, became loaded with debris, and perhaps locally covered with drift (»ablation moraine»)[1]), and may therefore have been for some time prevented from floating and breaking up.

During this excessive delay the thinning due to melting continued as before. When the halt finally ended, the ice therefore decayed at a much quicker rate than usual as long as the thinned zone lasted.

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[1]) R. S. Tarr, Some phenomena of the glacier margins in the Yakutat bay region, Alaska, Zeitschrift für Gletscherkunde III, 1909, p. 85.

Later, when the recession had once more reached parts where the ice sheet was thicker, it reassumed its normal rate and then again retarded, until a new halt took place.

As the outer portion of the ice sheet after a halt is thinner than usual, the border is not likely to halt in places where it otherwise would do so. A thicker ice front, on the other hand, easily becomes stationary even when only some parts of it find a favorable position. Therefore the distance (but not the time) between two halts is about the same so long as the inclination of the underlying country and the velocity of the ice remain constant.

In western Uusimaa, the velocity of the ice movement was always greater than farther east, as the ice sheet was there thicker. Therefore the two great Salpausselkä halts take place here in a deeper part of the inclined land-surface, and on the upper margin there at a later epoch when the recession farther east had reached its maximum pace.

The lingering of the ice border in the southern coast zone was favoured by two other circumstances besides the factors mentioned, (1) the lowering of the water level and (2) the elevation of the land.

The drainage of the Baltic at the end of the First Salpausselkä epoch made the sea in the Salpausselkä belt, which was shallow before, still shallower.[1]) A slight retardation of the ice border, appearing in the absence of the usual fast retreat after the halt, may be due to this lowering of the water level.

The upheaval of the land (see p. 114) lowered the water during the great halts, causing a decrease of the calving. As, moreover, the upheaval was greater in the central parts of the glaciated area, the elevation was likely to accelerate the movement of the ice, thus working against the recession.

As we have seen, a halt during periodical recession does not affect the rate of retreat as a whole, being compensated by a subsequent rapid recession, (see p. 142). *This is due to the fact that the ice has decayed all the time by melting.* The long halts at the Salpausselkäs

[1]) If the lowering of water level had been, as Ramsay assumes, over 20 metres and had happened after the Second Salpausselkä, it should have had the consequence that the ice border, which before had receded by calving would have been left, in wide areas, upon dry land. This would necessarily have caused a halt and advance of the border. No signs of such events have been encountered, and far more, the rate of recession at this very time reaches its maximum in Central Finland. Such a consequence of a sudden lowering of the water level would by necessity occur even if the halts were mainly due to variations in climate. For the variations in depth of water has anyway a great influence upon the recession.

prepared the land ice for the rapid regional decadence all over the lake district. Before the Salpausselkä epochs the ice front, in Uusimaa, was about 100 metres thick, after them but 40 or 50 metres. The rate of thinning of the ice front, on the other hand, is an indicator of the progress of decadence of the whole ice sheet.

The continuous recession in the Supra-aquatic area of Karelia (See p. 143) *is also a consequence of the uninterrupted decay of the ice masses.* A very quick recession in the coast belt of Satakunta between the years 200 and 400 can not be explained as due to topographical factors, as the depth of water was about the same as on the southeast and northwest sides of this area. Another explanation in fact lies close to hand: *the accelerated recession may have been caused by the salinity of the sea water, which reached its maximum at that time.* As Tarr[1]) has been able to prove in Alaska, salt water has a much greater devastating influence upon ice than fresh water, probably owing to the depression of its freezing point, and to its greater density.

According to Leiviskä,[2]) the Salpausselkä halts were caused by the rock barriers existing under both series of moraines. The ice could not flow over these higher ridges, but remained stationary behind them. The ridge of *Tiirismaa*, especially, should have had a decisive influence owing to its great height. The following objections may be made against this interpretation:

(1) Only at the Second Salpausselkä, east of the region of Leppäkoski, did the land ice move against the incline, and even there not in all parts of the ice front. At the First Salpausselkä there was no continuous rock barrier, nor at the Second at the western front. Tiirismaa is a single exceptional place, but the study of the varve sediments shows that even *this high place did not start the halt but, on the contrary, delayed it.* As we have seen (p. 139), the halt started earlier on both sides of it. — The halts in Southern Finland have taken place in the opposite position, *upon a land-surface inclined away from the land ice.*

(2) If, as Leiviskä explains, the halt was due to the resistance of the rock barrier against the advance of ice, the recession should have been fastest immediately *before* the halt when the ice could no more slide over the barrier. Actually the rate of recession points to the contrary, being *slowest* before and fastest after the halts.

(3) The supposition that the variation in *supply* is a deciding factor as to the varying rate of recession is not consistent with the

[1]) R. S. Tarr, Glaciers and Glaciation of Alaska, Ann. Assoc. Amer. geogr. 1912, 2, p. II.

[2]) I. Leiviskä, Der Salpausselkä. Fennia 41, N:o 3, pp. 373—380.

results of the present investigation, which prove clearly that changes in wastage are more important in this respect, when the receding land ice ends in the sea.

Periodicity of sedimentation. The different manner of wastage during the epochs of halts and continuous recession explains, also, the differences in the sediments formed during these epochs (See p. 121). The great commotion caused by calving and melting of the icebergs (see above p. 119) ceased during the halts. Sedimentation took place under tranquil conditions, and coagulation was more efficient. Even the finest matter had an opportunity of settling near the ice border. During rapid recession and much calving, on the other hand, its deposition was checked by the general unrest of the sea and it was carried farther. Only the coarser matter, and especially the boulders carried by the icebergs, could accumulate and are in fact abundant in the sediments formed during those epochs.

The sudden start of the ice border after the halts is depicted in the sediments by the very sharp contrast between the horizons of the halt epochs and the subsequent times of recession. We need only remember the coarse grained sediments of H_1 — the rapid recession —, immediately superimposed on the fine clays of the IISs-horizon. Farthest to the southwest there is less difference between the sediments of the periods of halts and recession. This is apparently due to the fact that calving was there possible even during the halts.

Remarks on recession in other regions. As it seems to me from a study of the literature of the subject, relations between the recession of the ice border and the character of the underlying land-surface analogous to those described above from southern Finland may be found in some other countries. Attention may here be especially directed to southern Norway and central Sweden.

The recessional moraines, called Raer, on both sides of the Christiania fiord in Southern Norway, and the smaller moraines parallel to them, are situated on a slope inclined away from the ancient inland ice and, in the late glacial time, covered by the sea.[1]) They are parallel to the slope and, in the course of the subsequent ice border and the location of the halts, wholly analogous to the Salpausselkäs.

[1]) W. C. Brögger, Om de senglaciale og postglaciale nivaaforandringer i Kristianiafeltet, Norges Geol. Undersögelse N:o 31, 1901.

J. Rekstad, Kvartaere avleiringer i Östfold, Norges Geol. Undersökelse N:o 91, 1922.

P. A. Öyen, Nogle bemerkninger om ra-perioden i Norge, Norsk. Geol. Tidskrift, Bd. II, 7, 1911.

K. O. Björlykke, Norges kvartärgeologi, Norges Geol. Undersökelse N:o 65, 1913 pp. 134—152.

The Norwegian moraines have their analogues in Western Sweden.[1]) They are 4, in places 5, in number and situated upon a slope inclined toward the southwest. Those nearest the coast and at the lowest levels are more extended and discontinuous, while the upper moraines, during whose formation the ice border, according to the map, had partly reached dry land, are more continuous. In the neighbourhood of Lake Stora Le there is, according to De Geer,[2]) a rugged high rock plateau inside, and lower land covered by sediments outside the moraines. All these features are well known from southern Finland. The inner moraines continue eastward, running like a bow round the southern part of the great basin of Lake Wenern. A large ice stream thus had here the same effect as in the basin of the Gulf of Bothnia. The inner pair of moraines continuing farther east assumes a position analogous to that of the halts in Karelia, being situated upon a land-surface inclined toward the land ice and formed in shallow water, protected by high supra-aquatic land in the south[3]). East of Lake Vettern, in a subaquatic area, there are discontinuous local moraines only. The largest of them may be found on the north shore of lakes Boren and Roxen marked by a step-like fault.[4]) They represent a really ideal case of the subaquatic type of halts.

According to the chronological investigations of De Geer,[5]) the ice border has receded rather slowly in the southern part of this region, as far north as the Södertelje line, or from 70 to 100 metres in a year. The absence of great halts may be explained by the fact that the ice ended in the sea in the whole area.

Farther north, in the valley of Lake Mälar, the rate of recession increases to 200 and later to 300 metres a year. *This acceleration is apparently connected with the fact that the land ice here ended in deeper water which, moreover, was saline.*

To understand the reason of acceleration it is not therefore at all necessary to assume any so-called finiglacial amelioration of climate.

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[1]) Here I refer to the excellent map compiled by G. De Geer on the basis of the materials collected by the Geological Survey of Sweden: Das spätglaziale Südschweden, 1: 500,000. 1910.

[2]) G. De Geer, Dals Ed, some stationary ice-borders of the last glaciation. Geol. Fören. Förhandl. Bd. 31, 1909, pp. 511—556.

[3]) Hans W:son Ahlmann, Die fenno-skandischen Endmoränenzügen auf und neben dem Billingen in Vester-Götland, Schweden, Zeitschrift f. Gletscherkunde X, 1917, pp. 65—103.

[4]) Sten De Geer, Map of landforms in the surroundings of the great Swedish lakes, 1: 500,000. Sveriges Geol. Undersökning. Ser. B. 7. 1910.

[5]) G. De Geer, A thermographical record of the late-Quarternary climate, Postgl. Klimaveränderungen, Stockholm 1910, p. 305.

As set forth earlier, *the First Salpausselkä in Finland is somewhat later than the northern moraine in Sweden. All those still farther south, and the raer of Norway, must be still earlier.*

Features analogous to those in Finland also seem to exist in the manner of recession of the land ice in northern America. According to the results of the chronological investigations of Antevs in New England,[1]) in the valley of Connecticut river between Hartford and Northampton, the rate of recession decreases gradually, the subjacent land-surface having been subaquatic and inclined away from the ice sheet. Farther north in the same valley the recession is remarkably quicker, but west of this area, in the Berkshires,[2]) several recessional moraines occur in valleys.

South of the Great Lakes numerous large recessional moraines, investigated by Leverett and Taylor[3]), exist in the supra-aquatic area inclined toward the land ice. An answer to the problem of the causes of these halts which have no analogues on the Connecticut valley may probably be looked for in topographical factors. Their position seems in fact to be exactly that where halts might be expected from the point of view set forth above. They are therefore not necessarily synchronal with any recessional moraines in Europe, and the opinion of Spencer[4]), later adopted by Frank Leverett[5]), that the moraines in the Great Lakes region are considerably earlier than the late glacial formations in Fennoscandia is not in disagreement with our general conclusions.

General acceleration of the recession. Geochronological investigations in Southern Finland and, still better, in Sweden[6]) and northern America[7]) have proved the recession of large ice sheets to have pro-

[1]) E. Antevs, The recession of the last ice sheet in New England, Amer. Geogr. Soc. Research ser. N:o 11, 1922.

[2]) F. B. Taylor, The correlation and reconstruction of recessional ice borders in Berkshire County, Mass., Jour. Geol., Vol. II, 1909. pp. 323—364.

[3]) Frank Leverett, Glacial formations and drainage features of the Erie and Ohio basins, U. S. Geol. Survey Mon. XLI, 1902.

A later work by F. Leverett and F. B. Taylor, The Pleistocene of Indiana and Michigan and the history of the Great Lakes, U. S. G. S. Mon. 53, 1915, was not available to me.

[4]) I. W. Spencer, The falls of Niagara, Canada Dep. Mines. Geol. Survey Branch, 1907, p. 370 (G. De Geer, A thermographical record of the late-Quaternary climate Postgl. Klimaveränderungen, Stockholm 1910 p. 308).

[5]) H. F. Osborn and C. A. Reeds, Old and new standards of pleistocene division in relation to the prehistory of man in Europe. Bull. Geol. Soc. Amer., Vol. 33, 1922, 478, 479.

[6]) G. De Geer, A thermographical record of the late-Quaternary climate Postgl. Klimaveränderungen, Stockholm 1910. pp. 304—305.

[7]) E. Antevs, op. cit. pp. 75, 76.

ceeded at an accelerating rate. We shall try to elucidate this phenomenon with the aid of a shematic diagram (fig. 22). For the sake of simplicity, the ice sheet is here supposed to have the shape of a spherical calotte and the annual melting to remove from its superficies shells of uniform thickness. These shells cut, from the subjacent land-surface, concentric rings whose breadth increases toward the centre. In others words, the rate of recession increases although the rate of thinning be constant. It may be especially remarked that this diagram does not by any means show the actual conditions in ice sheets. These are known to be almost flat in their inner parts, and not

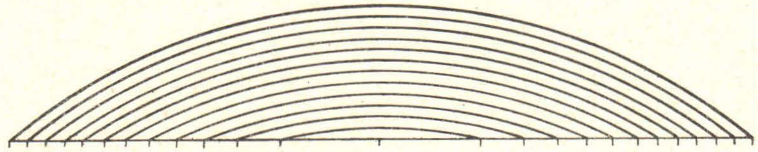

Fig. 22. Diagram illustrating the acceleration of recession of an ice sheet whose annual thinning is constant.

calotte-shaped. Nor is the melting uniform in the whole area; glacial conditions may prevail at least in some part of the ice-covered area, especially at those stages when the ice sheet is very extensive and high, but in mountainous regions also later. In other words, the amount of snow-fall may be larger than that of melting in the inner parts of a land ice area, at the same time as recession is in progress at the margins. Furthermore, the rate of recession is slow at the early stages when the ice sheet is thick, because of more rapid motion and larger supply than later.

All these factors are likely rather to intensify the normal acceleration of recession. It might be remarked that prevailing superiority of snowfall in the Scandinavian mountains during the late glacial time might have counteracted the acceleration, but the actual facts clearly point to the opposite condition, as the last remainder of land ice was situated on the east side of the divide and not on the high mountains where glaciers exist at present.[1])

The accelerating rate of recession does not therefore necessarily imply an increase of annual melting and rise of temperature, but may simply be due to the gradual thinning of the ice sheet and to the decrease of the rate of motion as the ice masses become smaller.

[1]) Cf. Fredrik Enquist, Die glaziale Entwicklungsgeschichte Nordwestskandinaviens, Sveriges Geol. Undersökning, Ser. C, N:o 285, 1918, p. 108—109.

The Changes in Climate.

The changes in climate — an unknown factor. While endeavouring to explain the varying rate of recession, I have directed attention exclusively to the dependence of supply and wastage upon the geographical factors. Supply and wastage, of course, also depend on the climatological factor with all its variations, but these variations are entirely unknown. It is only surprising that they, in the commonly accepted theory, have been supposed to afford a satisfactory explanation for the capriciously varying process of recession, while this very variation of recession has been considered as a proof of the supposed climatic oscillations. It may be well to examine whether the recession and the characters of the varve sediments afford any direct evidence of changes in climate.

Recession and the changes in climate. The recession and the changes in climate are commonly believed to be connected in such a way that rapid recession means an increase of melting or, generally, an amelioration of climate, and retardation and halt of recession, refrigeration of climate.[1]) The other factors have generally been little considered. But, as I have tried to show, several of them, as the varying rate of movement of the ice (on the land), or this factor combined with the chances of calving (in the sea), and the distribution of salt and fresh water, have a decisive influence. The position of the ice border, therefore, is the resultant of two or four factors and not of the climatological factor alone. The particularly important stages of halts are no exceptions. They do not imply any true balance between supply and wastage, for the real disappearance of the ice masses by melting and evaporation continues also during them.[2]) Nor does the general acceleration of recession mean any general amelioration of climate, for it may result even from uniform melting. Stated briefly, *the subsequent positions of the ice border do not afford any direct measure of the changes in climate.*

But let us suppose that I have laid too much stress upon the importance of calving and movements of the ice, and that the variations in climate are the true cause. Of what kind should these varia-

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[1]) G. De Geer, A thermographical record of the late-Quaternary climate, Postgl. Klimaveränderungen, Stockholm 1910, p. 305.

[2]) It is not necessary to assume that the thinning of the ice sheet during the halts would be mainly due to a particular increase of evaporation, as suggested by N. B. Wright (Review of M. Sauramo, Geochronologische Studien über die spätglaziale Zeit in Südfinnland, in the Geological Magazine, 1920, p. 15, and A Theory of the Marginal Drift, The Geological Magazine 1920. pp. 518—519).

tions be to result in recession, as it has actually taken place? In Karelia, no refrigeration of climate should have occurred. On the central front in southern Finland, there should have been two, and on the western front four, in places five, in eastern Sweden none, in central Sweden two, in western Sweden four or five, and in southern Norway two long and a great many shorter epochs of refrigeration. In other words, there should have been, in central Fennoscandia, a number of zones of varying climatological development parallel to the *meridians*. On the east coast of the Baltic, for instance, climate should have been very variable and on the west coast invariably mild. And the epochs of refrigeration, moreover, should have occurred in a various rhythm: In the east, the most considerable of them started, when those in the west had ended!

Furthermore, the refrigeration should have been exactly severe enough to cause a halt, but not a readvance of the ice border on its whole front. In subsequent times there occurred, as a rule, a remarkably sudden though regionally strictly confined amelioration of climate which removed the ice from wide areas. The periodicity of recession, of course, implies corresponding but still greater, repeated variations in climate, the large masses of inland ice naturally reacting but slowly to such changes.

Finally the changes in climate should have been dependent upon the grade of the subjacent land surface, the distribution of land and sea, of salt and fresh water, deep and shallow water, basins and level ground etc.

The changes in climate thus should have been of a kind to which it is not easy to find analogues in the conditions of the present time. They may be justly characterized in the words used by Tarr in his criticism of certain endeavours to explain the recession and readvance of the Yakutat Bay glacier: »Such a profound and sudden change in climate would of itself be more remarkable and more difficult of explanation than the phenomenon which it is called upon to explain».[1])

The varve sediments as an indicator of climatic periods. The annual variations in the amount of sediment, appearing in the varying development of the subsequent varves, undubitably, as De Geer has argued, depend upon the amount of melting which, in turn, is determined by temperature. Even the climatic peculiarities of individual years are depicted in the structure of the varves. The annual periodicity is the only periodicity indicated by these sediments. When the

[1]) R. S. Tarr and B. S. Butler, The Yakutat bay region, Alaska, U. S. Geol. Survey Prof. Paper 64, 1909, p. 91.

annual variations are eliminated, or the diagrams are rounded (see above p. 105), the diagrams show no recurrent variation of constant period. All variations longer than the annual are of such a nature that they may be interpreted as effected by some physicogeographical factors.[1]) The depth of the sea and the velocity of sea currents may influence the development of the sediments, and the differences in facies due to such varying conditions are in no relation to the changes in climate. Introduction of salt water causes coagulation and multiplies the varve thickness, but the swelling of the varves for this reason, naturally, does not mean any general amelioration of climate. Other differences between the varve series result from the varying chances of calving during the epochs of halts and retreat, and they are as local as the variations in the recession.

The above considerations help us among other things to a full understanding of the special characters of the sediments formed during the Second Salpausselkä epoch (the IISs-horizon, see pp. 118 and 156) which I could not at all explain in my earlier paper (Südfinnland). Brückner tried to find an explanation in exceptionally long winters,[2]) while Antevs saw in them an evidence for increased precipitation.[3]) Both these assumptions are now unnecessary: This horizon simply represents sediments deposited in salt water under the tranquil conditions of a halt epoch.

These results have some bearing upon the methods of investigation of the varve sediments. Correlation by means of the facies is not practicable over long distances, over areas where the characters of the sediments and the manner of recession are unknown. This is the necessary restriction of the facies method, as stated at the outset (p. 14).

The small annual variation in thickness is therefore the only means by which connection between far away localities is worth trying. The most reliable results may perhaps be expected from comparing whole lines of investigation with each other, »normalized» in such a manner as proposed by Antevs in his New England work.[4]) Thus it may be also possible to get an answer to the question, in how

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[1]) The question concerning the cause of the marked swelling of horizon S relatively to the underlying horizon H still remains open, until the investigation is continued farther north. (Cf. p. 117).

[2]) E. Brückner, Geochronologische Untersuchungen über die Dauer der Postglacialzeit in Schweden, in Finnland und in Nordamerika, Zeitschrift für Gletscherkunde, Vol. XII, 1921.

[3]) E. Antevs, op. pp. 87, 88.

[4]) E. Antevs. op. cit. pp. 45—63, Plates I—V.

wide an area the variations of varve thickness remain constant enough to allow reliable connections.

The reason for the failure of the connections so far tried between Finland and Sweden (p. 127) and between Northern Europe and America[1]) probably lies in the fact that this undoubtedly difficult operation has been based upon single sections only. Furthermore, as mentioned before, the first orientation has been apparently guided by the assumption that the great variations in recession are synchronal, an idea that finds no support in the present investigation.

The possibility of proving changes in climate. The conclusion that the rate of recession is no indicator of changes in climate does not imply the statement that no such changes have occurred, and that they have no effect upon the wastage of ice. The effect of this unknown factor can only be revealed by an analytical method, by eliminating all the known factors influencing the position of the ice border. In those discrepancies from the normal that may then still remain should the influence of general changes in climate be sought. Local discrepancies, however, can not be used for this purpose. It is true that they could be explained by assuming desirable changes in climate, but these in themselves then remain as problems very difficult to solve.

An unobjectionable evidence of changes in climate favourable to decreased wastage would be provided by a general advance of the ice on a wide front. This might be inferred from an abnormal sequence or disturbances of the strata. It may be remembered, however, that disturbances in the sediments do not always mean any advance of the ice but may result from dragging icebergs, or later slidings etc.[2]) Nor do all advances of the ice mean any period of general change in climate in such a direction. A single winter, more severe or longer than normal, may cause an advance of the ice, especially during the halt periods. In general, the present state of knowledge does not afford any means of determining the quantitative importance of all the varying and geographical factors in estimating the part played by changes in climate.

The climate of southern Finland most probably varied during the late glacial period and in different parts of the area, but even this may have been effected by geographical factors. It is well known that

[1]) E. Antevs, op. cit. pp. 48, 49.

[2]) Cf. the special descriptions of sections 24 Lepaa, 117 Kokemäki Ristee, and 132 Nakkila.

the distribution of land and water, and especially of land ice, influences climate. The great importance of land ice has been especially emphasized by Otto Nordenskjöld.[1]) Near the edge of land ice ending on the land, climate may have been mild, as in Greenland, and vegetation may have spread at the margin of or even upon the ice, as in Alaska.[2]) Great ice masses ending in the water, and icebergs, on the other hand, may have kept temperature low, as much heat was needed to melt the ice. It is probable that during the Salpausselkä epochs, when icebergs in the waters of southern Finland were very scarce, temperature was higher than during the times of rapid recession. It is also clear that temperature may have risen in the late glacial times, as the melting ice masses decreased in quantity, and gradually less heat was consumed in the melting. But even this change, like all the others, is no proof of general changes in climate on the earth globe, or changes in the amount of heat supplied to the earth from internal or external sources.

Tracing of general changes in climate from the varve sediments is no easy task, and the influence of the different elements of climate, as varying precipitation, temperature, and evaporation, is entirely hypothetical. These difficulties, however, should not discourage but rather stimulate continued research. Much may be achieved by a more efficient application of results won by the study of existing glaciers. Investigation of the varve sediments should be carried out in greater detail than before and, at the same time, be extended to large areas and not confined to certain lines from the mere chronological point of view. Future research no doubt will help to a better understanding of those factors influencing the recession of ice sheets emphasized in this paper, which are in my opinion very important, but have so far been little considered.

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[1]) Otto Nordenskjöld, Studien über das Klima am Rande jetziger und ehemaliger Inlandeisgebiete, Bull. Instit. Upsala, Vol. XV., 1916, p. 35—46.
Otto Nordenskjöld, Polarnaturen, Stockholm 1918.

[2]) R. S. Tarr and B. S. Butler op. cit. pp. 138—141.

2264—23

a

b

Fig. 1. Part of the clay section of the Kolsa Brickyard near Jokela. The uppermost dark series (to *a*) is IISs, the ligther middle series (*a* — *b* is iSs, the lowest series (below *b*) is ISs.

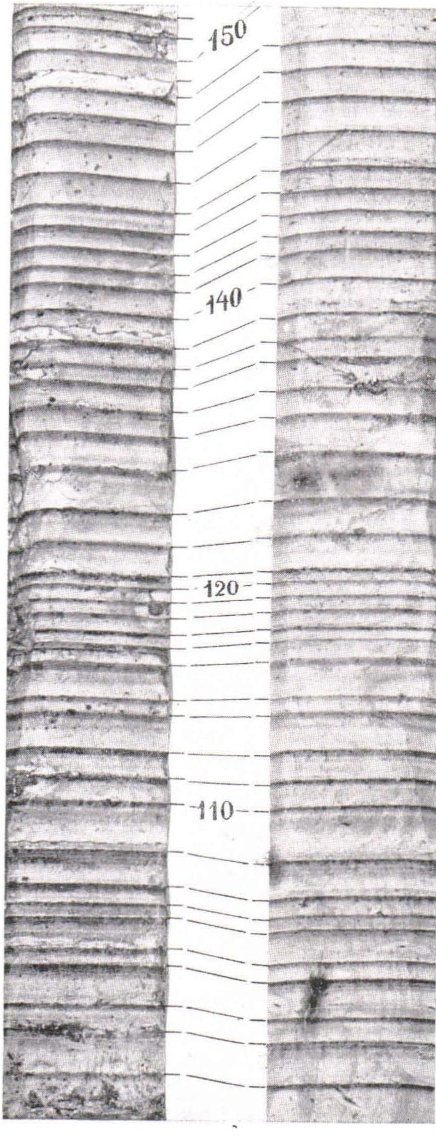
Pl. II.

a

b

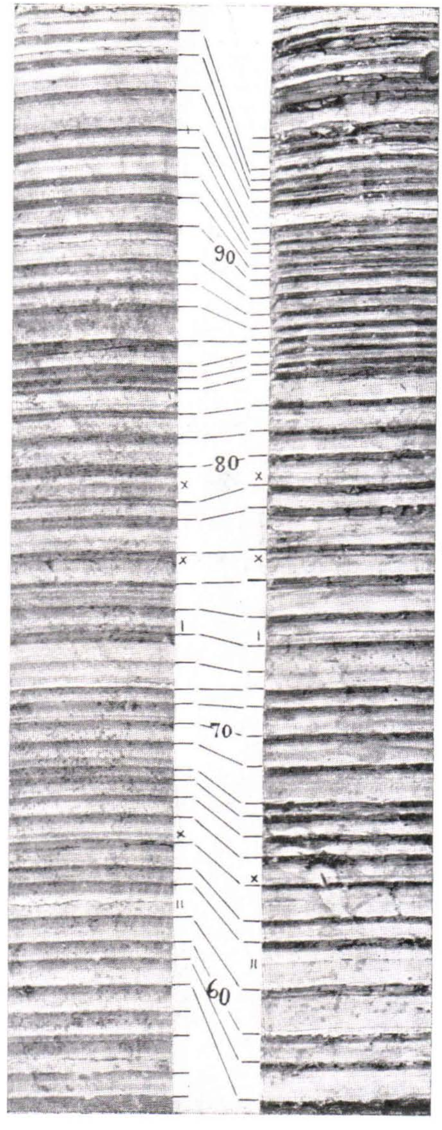
Fig. 2. A detail of the section shown in Pl. I. The uppermost dark part (to *a*) is IISs, the ligther middle series *(a — b)* is ISs, the lowest series (below *b*) is ISs. The thick varve visible near the letter *b* is a sandy varve of exceptional thickness, supposed to indicate the drainage of the ice-ponded Baltic Sea.

Pl. III.



a *b*

Fig. 3. Varves of a part of H_1 from Sipilä *(a)* and Rauhaniemi *(b)* connected with each other. Loc. 1 Leppäkoski. $^1/_2$ nat. size.



a *b*

Fig. 4. Varves of part of H_1 from loc. 1 Leppäkoski *(a)* and 2 Högfors *(b)* connected with each other. $^1/_2$ nat. size.

Pl. IV.

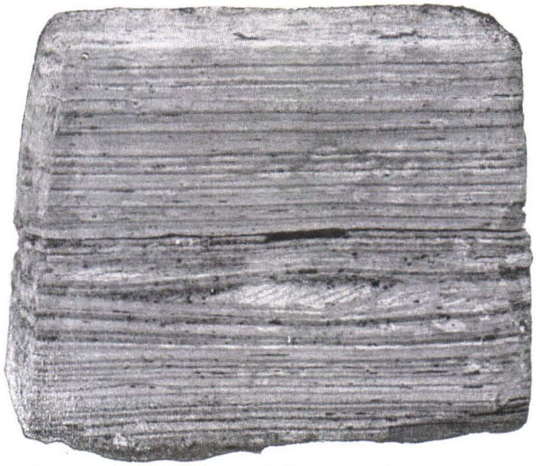
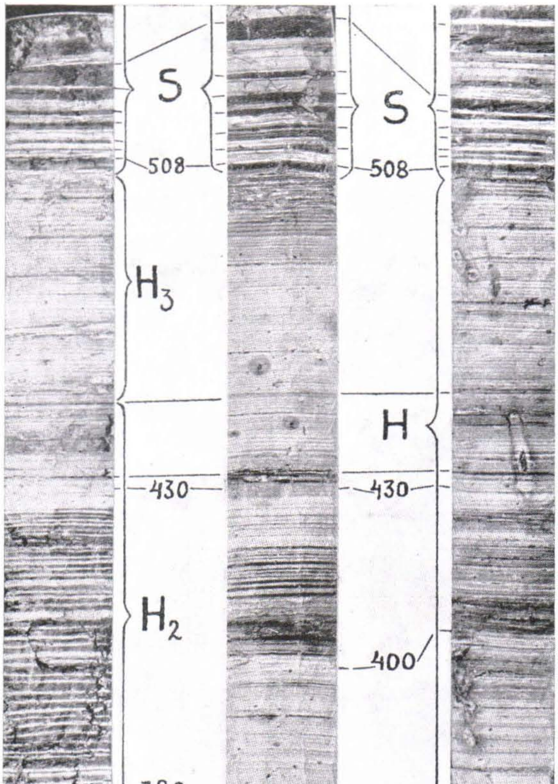


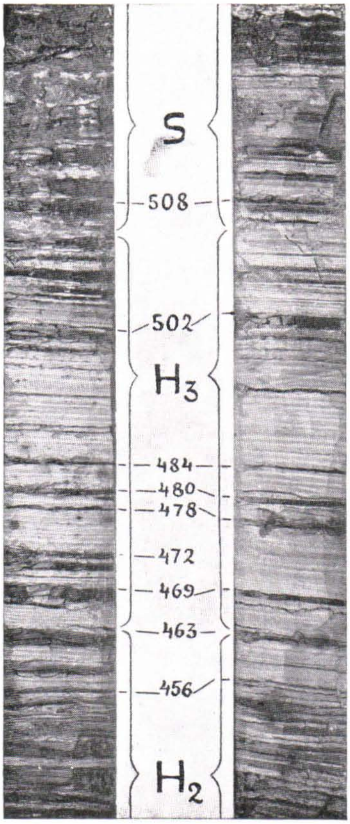
Fig. 5. Lenses of sand between the varves of horizon S in loc. 1 Leppäkoski. 1/2 nat. size.



a *b* *c*

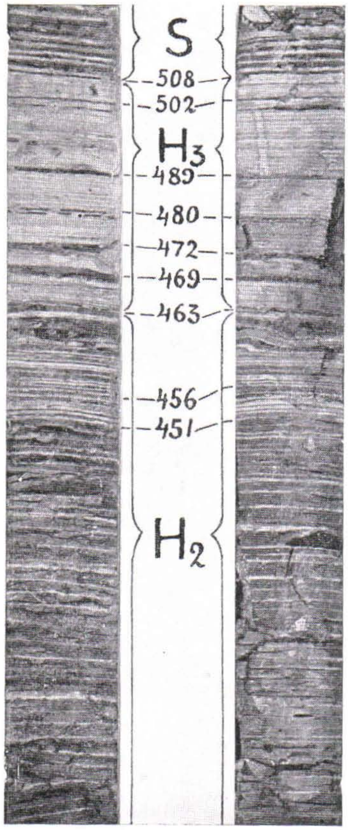
Fig. 6. Connection between sections 36 Pälkäne Pintele *(a)*, 16 Pälkäne Kukkonen *(b)*, and 17 Luopioinen Aitoo *(c)*. 1/3 nat. size.

Pl. V.



a *b*

Fig. 7. Connection between sections 38 Toijala *(a)* and 78 Viiala *(b)*. $^1/_3$ nat. size.



a *b*

Fig. 8. Connection between sections 32 Iittala *(a)* and 31 Lammasmäki *(b)*. $^1/_3$ nat. size.

Pl. VI.

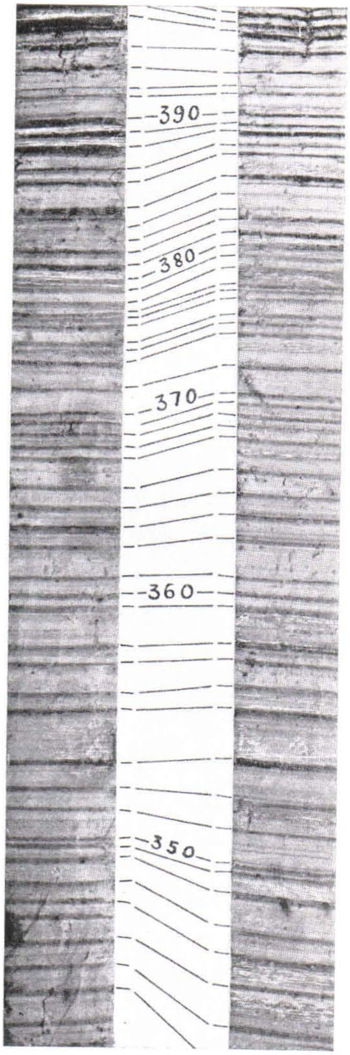


Fig. 9. Connection between sections 98 Messukylä *(a)* and 100 Tampere *(b)*. $^1/_3$ nat. size.

Fig. 10. Two symmict varves from loc. 59 Loimaa. $^1/_2$ nat. size.

Pl. VII.

Fig. 11. Thin sections of a diatactic varve from loc. 1 Leppäkoski, subhorizon H_1. Magnified 12 diam

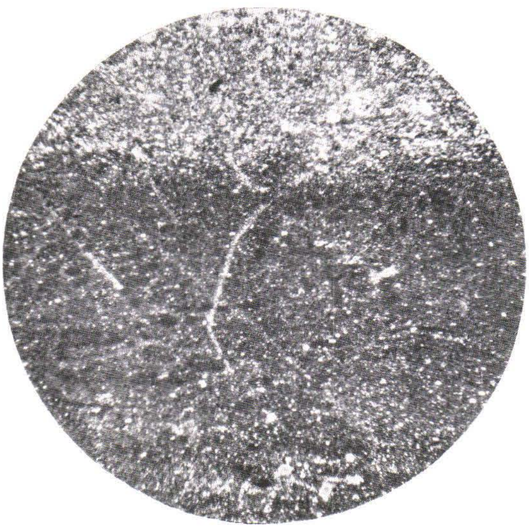
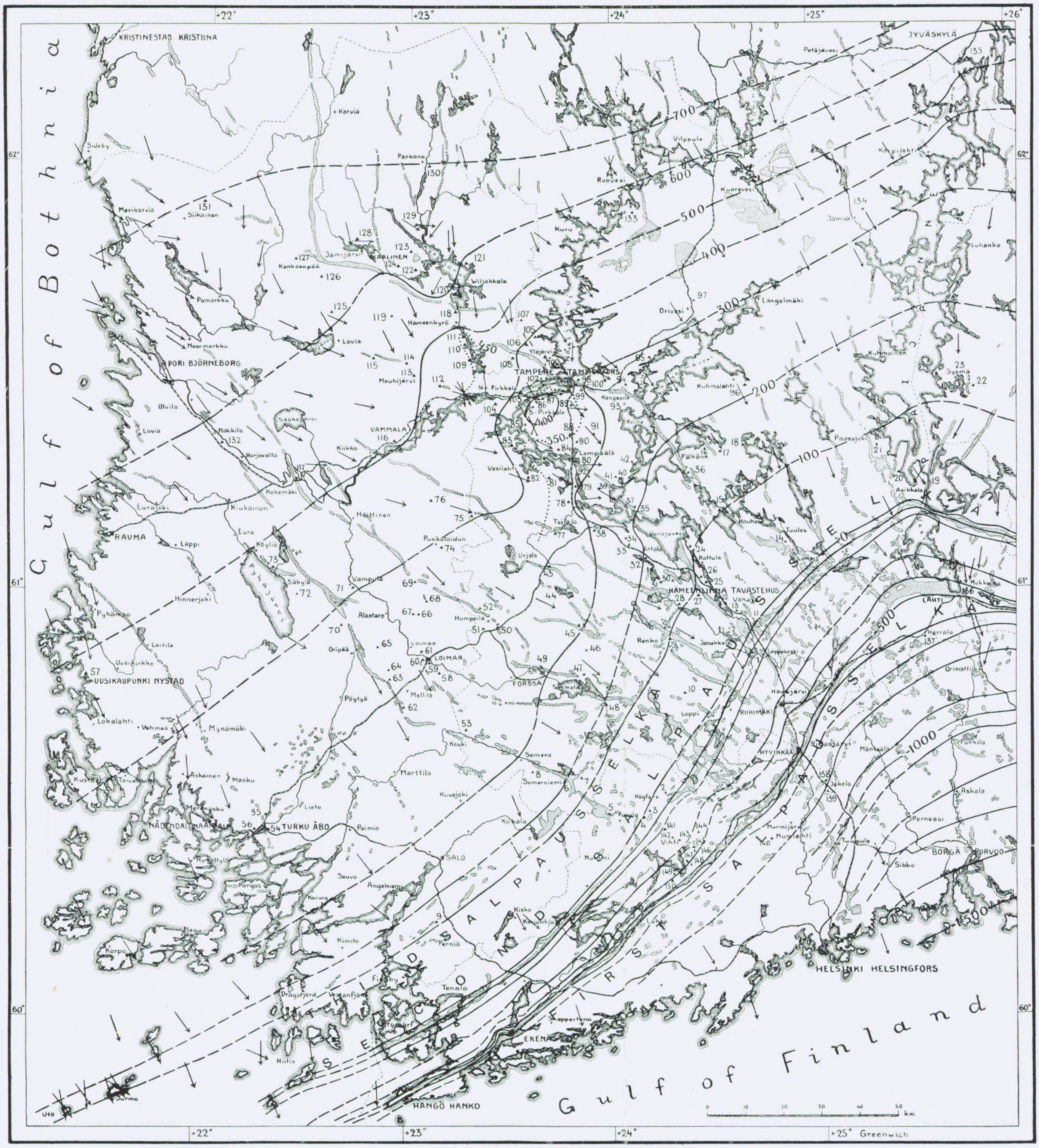


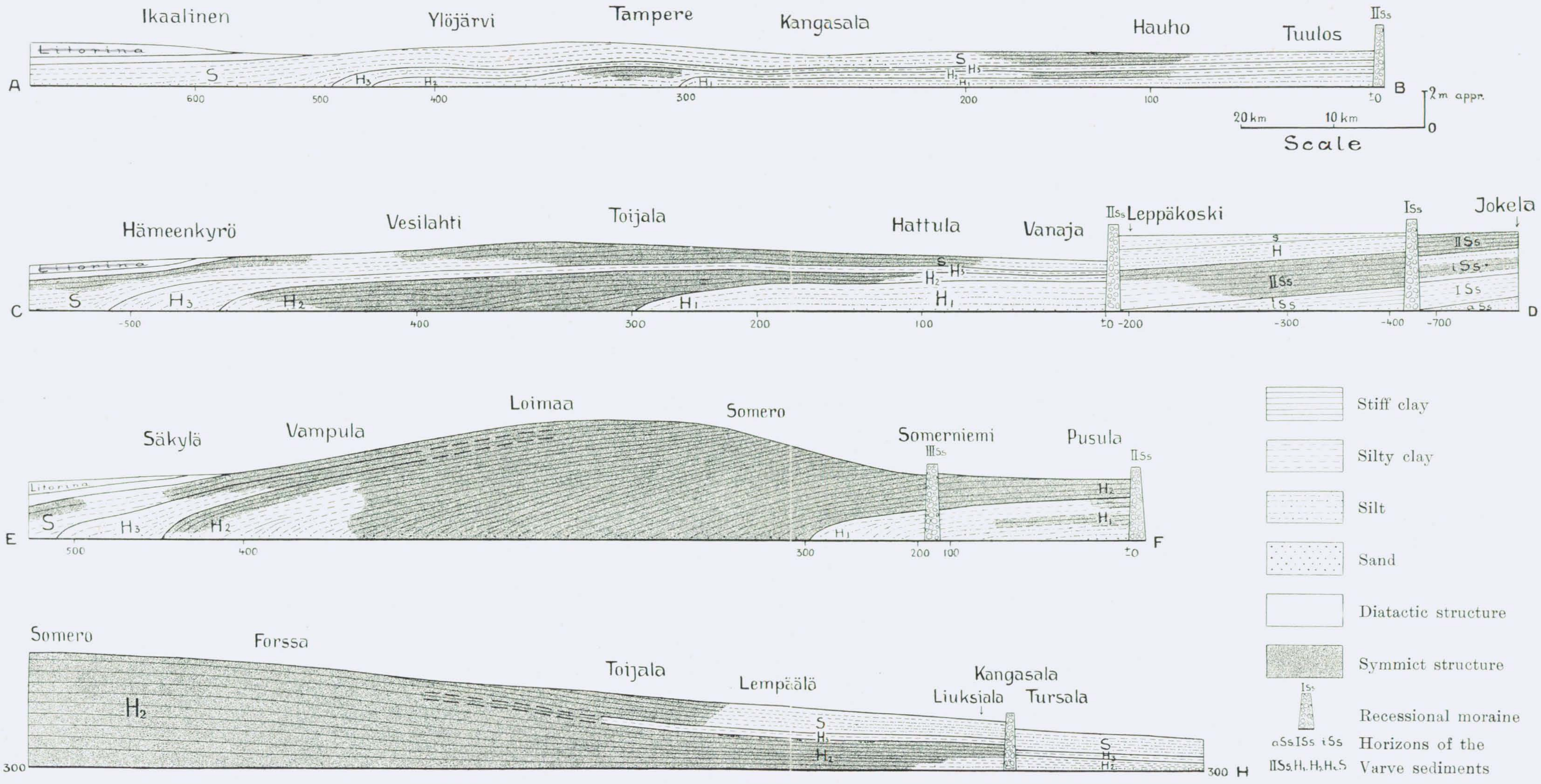
Fig. 12. Thin section of a symmict varve from loc. 79 Mattila, subhorizon H_2. Magnified 12 diam.

MAP OF SOUTHWESTERN FINLAND.



Eskers and recessional moraines — Striae — Localities investigated — Proximal lines for every 100 varves

Cross Sections through the Varve Sediments in Southwestern Finland.



Diagrams showing the Varves in Sections through Laminated Sediments in Southwestern Finland

Northwest of the Second Salpausselkä

Scale 1: 5

N:o 40. On the Petrology of the Orijärvi region in Southwestern Finland, by Pentti Eskola. With 55 figures in the text, 27 figures on 7 plates and 2 coloured maps. October 1914 .... 26: —

N:o 41. Die Skapolithlagerstätte von Laurinkari, von L. H. Borgström. August 1914. 5: —

N:o 42. Über Camptonitgänge im mittleren Finnland, von Victor Hackman. Aug. 1914. 5: —

N:o 43. Kaleviska bottenbildningar vid Mölönjärvi, af W. W. Wilkman. Med 11 figurer i texten. Résumé en français. Januari 1915 .... 6: —

N:o 44. Om sambandet mellan kemisk och mineralogisk sammansättning hos Orijärvitraktens metamorfa bergarter, af Pentti Eskola. Med 4 figurer i texten. With an English Summary of the Contents. Maj 1915 .... 12: —

N:o 45. Die geographische Entwicklung des Ladogasees in postglazialer Zeit und ihre Beziehung zur steinzeitlichen Besiedelung, von Julius Ailio. Mit 2 Karten und 51 Abbildungen. Dezember 1915 .... 15: —

N:o 46. Le gisement de calcaire cristallin de Kirmonniemi à Korpo en Finlande, par Aarne Laitakari. Avec 14 figures dans le texte. Janvier 1916 .... 6: —

N:o 47. Översikt av de prekambriska bildningarna i mellersta Österbotten, av Eero Mäkinen. Med en översiktskarta och 25 fig. i texten. English Summary of the Contents. Juli 1916 .... 14: —

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N:o 49. Om en prekalevisk kvartsitformation i norra delen af Kuopio socken, af W. W. Wilkman. Med 7 figurer i texten. Résumé en français. Oktober 1916 5: —

N:o 50. Geochronologische Studien über die spätglaziale Zeit in Südfinnland, von Matti Sauramo. Mit 4 Tafeln und 5 Abbildungen im Text. Januar 1918 10: —

N:o 51. Einige Albitepidotgesteine von Südfinnland, von Aarne Laitakari. Mit 5 Abbildungen im Text. Januar 1918 .... 4: —

N:o 52. Über Theralit und Ijolit von Umptek auf der Halbinsel Kola, von Th. Brenner. Mit 4 Figuren im Text. März 1920 .... 5: —

N:o 53. Einige kritische Bemerkungen zu Iddings' Classifikation der Eruptivgesteine, von Victor Hackman. Mit 3 Tabellen. September 1920 .... 5: —

N:o 54. Über die Petrographie und Mineralogie der Kalksteinlagerstätten von Parainen (Pargas) in Finnland, von Aarne Laitakari. Mit 3 Tafeln und 40 Abbildungen im Text. Januar 1921 .... 11: —

N:o 55. On Volcanic Necks in Lake Jänisjärvi in Eastern Finland, by Pentti Eskola. 4: —

N:o 56. Beiträge zur Paläontologie des nordbaltischen Silurs im Ålandsgebiet von Adolf A. Th. Metzger. Oktober 1922 .... 4: —

N:o 57. Petrologische Untersuchungen der granito-dioritischen Gesteine Süd-Ostbothniens, von Heikki Väyrynen. Mit 20 Figuren im Text und 1 Karte. Februar 1923 .... 8: —

N:o 58. En train de paraitre ....

N:o 59. Über den Quarzit von Kallinkangas, seine Wellenfurchen und Trockenrisse. Nach hinterlassenen Aufzeichnungen von Hugo Berghell zusammengestellt und ergänzt von Victor Hackman. Mit 19 Figuren im Text. April 1923. .. 5: —

N:o 60. Studies on the Quaternary Varve Sediments in Southern Finland, by Matti Sauramo, with 22 figures in the text, 12 figures, 1 map, and 2 diagrams on 10 plates. September 1923 .... 15: —

N:o 61. Der Pyroxengranodiorit von Kakskerta bei Åbo und seine Modifikationen, von Victor Hackman. Mit 2 Figuren und 1 Karte im Text. April 1923 .... 5: —

N:o 62. Tohmajärvi-konglomeratet och dess förhållande till kaleviska skifferformationen, av W. W. Wilkman. Med 15 figurer och en karta. Deutsches Referat. 6: —

N:o 63. Über einen Quarzsyenitporphyr von Saariselkä im finnischen Lappland, von Victor Hackman .... 4: —