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DESCRIPTION TO ACCOMPANY THE MAP OF THE QUATERNARY DEPOSITS OF SWEDEN

BY

G. LUNDQVIST

With one map in three separate sheets
in the scale 1:1 000 000

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STOCKHOLM 1959

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CONTENTS

The distribution of the soil regions of Sweden is illustrated by Fig. 29, p. 51.

Preface

The present map is the first complete one for the Quaternary deposits of the whole of Sweden. A rather homogeneous picture is the result in spite of the very heterogeneous map material described in greater detail on p. 112. Thus we understand why south-west Skåne (SW of a line Höganäs—Simrishamn) is the most fertile part of Sweden; it is due to the boulder clay, which is more distributed here than in other districts. Only Central Jämtland (N of 63° N latitude) has about the same area of such deposits. There is a very sharp difference between these districts and the exclusive rock districts in south-west and south-east Sweden. The land round Lake Mälaren (W of Stockholm) is an entity and in some degree the same is applicable to the environs of the large Lake Vänern. But in spite of such great differences, the general feature is one of fundamental uniformity over the whole country. The fact is that moraine is the most important deposit and this applies from the extreme south to the extreme north of Sweden. It is the forest clad deposit whilst clay gives arable soil. Both are vital for our livelihood.

The map should be able to speak for itself but some description is not superfluous. The arrangement is as follows. Firstly, the different factors in the legend (moraine, glacifluvial deposits etc.) are described. Each chapter is introduced by some general remarks concerning the mode of formation of the soil. Then follows a chapter about the main features which catch the eye. Finally comes a chapter about the different soil regions based on the distribution of the soils. The southern districts are only briefly described because detailed map sheets (in the scale 1 : 50 000) exist with explanations. The northern districts are discussed in more detail. From here we have the descriptions of some counties but they are not so detailed as for the ordinary map sheets. In general I have often included descriptions of more interesting details as in the chapters on southern Sweden. Other authors would probably have done it in another way.

This description was first published in Swedish in 1958. The present English version is a more or less literal translation though a few sentences have been slightly altered. It has often been difficult to translate effectively certain words since no exact English equivalents exist. I have myself done the translation but Dr Peter Padget of the Geological Survey of Sweden has afterwards corrected the English of the manuscript. I am very much obliged to him for his assistance in this way.

G. Lundqvist

Bare rock ground

Bare rock ground includes partly completely exposed bed rock, partly districts with so thin an earth or soil cover that the bed rock is locally visible. It is a matter of experience that it is often nearly impossible to decide the boundary of the types.

The map picture of the bare bed rock is based on very heterogeneous material. In southern Sweden, where we have combined maps of rock and soil, I have used them. In other regions the map of the General Staff — the old type with a designation for bare rock — is used. But geologists and topographers have not the same meaning as regards the use of the term bare rock. Therefore it has been necessary to modify the rock picture of the geologists with the guidance of the topographical map from the same area. For the purpose of the map in this scale — 1 : 1 million — the differences are of no importance.

The variable distribution of the bare rock ground in the country is at once clearly shown by the map. The cause can be partly the difference between the geological and the topographical maps, but this is not the whole truth, as is seen by an analysis of the gradual changes between the districts rich and poor in exposures in Västergötland, Småland and Östergötland. Thus the great differences do mark a reality. This can also be appreciated in corresponding relationships in northern Sweden, where all map material is drawn from the topographic map.

The following may be observed by a general study of the map. In Skåne (the most southern part of Sweden) the rock ground is very insignificantly exposed. It is mainly in the Romeleåsen, Söderåsen and the other "åsarna", i.e. the mountain ridges, that bed rock is visible, however, in small areas. Deeper into Småland (e.g. Växjö—Emmaboda) north of the latter, the rock area is no more extensive, as any traveller can see.

Quite otherwise is the picture in Blekinge (between Karlshamn—Karlskrona). There the bed rock is extensively exposed, particularly in the coast zone. The nobs of rock are often high and rounded. The rock area diminishes progressively towards the north in the moraine terrain.

The bed rock on the big isles in the Baltic Sea is quite extensive, especially on Öland where the Ordovician limestone is exposed over a wide area, as on Stora Alvaret. Noteworthy is the fact that the strata are nearly horizontal, but in other districts it is the rock hills which are bare. On Gotland there are small "alvars" (=exposed limestone) too, but of special interest is that on the southern part of the isle. Silurian mudstone and shale are widely exposed. On digging it is found to be just like a soil.

In the coast regions of Östergötland, Västergötland and Bohuslän the bare rock ground dominates 55 % of the land area. As the rocks in these districts are profoundly cracked and fissured the terrain has a character all its own. In Bohuslän there are two types of fissure, namely, coast fissures along the coast, and fjord fissures extending about SW—NE (see fig. 35). In Östergötland (the vicinity of Västervik etc.) the NW—SE fissures dominate and determine the direction of the fjords, bays and sounds. The moraine is of very insignificant area in these counties; the soils are mostly clays lying in depressions and fissure valleys. We do not find such an exceptional area elsewhere, except in Södertörn (south of Stockholm) where it is 50 %.

In the districts north of the previous one the rock area shows a successively diminishing area up to Värmland, Dalarna and Norrland. The coast regions alone have a greater rock area. Often the forms of the rock hills give the landscape a certain characteristic appearance. Especially is this the case in the region round the Lake St. Gla (NW of Lake Vänern) in Värmland, but unfortunately it is not so distinct on the small scale of the map fig. 61.

The coast strip in Norrland is a distinct zone with a big area of rock, 10—20 %. Distinctly rich in rock is the tract in Ångermanland where the area is 20 %.

In the inner part of Norrland bare rock ground is distinctly uncommon. The rocks are here small areas. One exception to this rule is the region SE of Jämtlands Storsjö (N of 63° N lat.), that is characterized by numerous small and sharply emergent knobs of rock. Certainly the appearance of the district is not so marked on the map but the rock percentage is still about 20 %. In the field this landscape is so distinct that one notices it even in passing.

It is much to be regretted that the topographers who made the old topographical maps did not mark the bare rock ground above the timber line. Within certain regions there are great areas with such exposed bed rock and others which are completely soil covered. Unfortunately it is yet quite impossible to get a fairly correct picture of the situation. But quite clearly much greater rock area is exposed on the other side of the frontier in Norway. This is very distinctly seen from the air.

The cause of the varying area of bare rock ground has been much discussed but a comprehensive solution of universal application has not emerged. Marine abrasion, the effect of the breakers, ice erosion and earth flow have all been proposed. The widespread distribution over the country shows that no one of these can be the only factor. In certain regions the marine abrasion must have been of very great importance, e.g. Bohuslän (between Göteborg and Strömstad), Östergötland (east of Lake Vättern) and Södertörn (S of Stockholm). But if that is right we may ask: why did not the marine abrasion give the same result in Halland (south of Bohuslän), NE Uppland (north of Stockholm) and so on? I think that a necessary assumption for the discussed effect is the form of the knobs. They must rise quite abruptly through the Quaternary deposits. A help to the solution of the problem is to be seen in the exposures one sees in front of the recent glaciers in Sweden and Norway. They are commonly quite bare without any moraine cover; here and there occur small areas covered with gravel. This also applies to the valleys. Most striking is that the knobs often have a pronounced streamlined form which is probably one of the causes for the inability of the land ice to loosen boulders from the rock or to deposit the moraine on the rock surface. The ice sweeps it into the hollows and unevenesses of the terrain, mostly in the bed rock.

It must be about the same with the marine abrasion and its effects. Tanner was the scientist who specially emphazised the earth flow as one factor, but his investigations were performed in northern Scandinavia and Labrador. In these regions there is an additional factor, namely, a climate that is favourable to earth flow. One can of course argue that such a climate prevailed also in previous times in southern Sweden which now is very rich in exposed bed rock. This is so but such districts were then under water. Thus my opinion is that land ice and breakers are the agents while the reason for their strong effect lies in the form of the outcrops which are largely shaped by the land ice erosion. As Sahlström pointed out in discussions, the low relative relief of the land surface in certain districts may be advanced as an explanation for the absence of exposed bed rock. This can best be seen by a comparison with the map of 'Landytans brutenhet' (The relative relief of landsurface, map sheets 3—4) in 'Atlas över Sverige' by Magnus Lundqvist. An example of such a region is northern Uppland (north of Stockholm) the surface of which probably coincides with the subcambrian peneplain. The latter emerges out of Kalmarsund (W of Öland), where it is very clear south of an E—W line through Oskarshamn. Further inland it intersects the Cretaceous peneplain at a shallow angle (Asklund 1928). The great surfaces lacking in outcrops in the region south of Lake Vänern (except for the rock ridge Kållandsö) also belong to it. This too is the sub-cambrian peneplain that is visible west of Kinnekulle at Lake Vänern (A. G. Högbom and Ahlström 1924).

The preceding examples were from districts where agreement may be found between low relief and exposed bed rock. But there is no difficulty in finding examples to the contrary. Quite special examples are parts of Öland and Gotland, the great limestone islands in the Baltic, where the bed rock consists of Silurian or Ordovician shales. These are very unconsolidated and one will therefore suspect this to be the explanation. These rocks are very easily crushed and the end product is a fine-grained and mobile earth layer. Therefore in such a condition the soil is very easily washed away by the breakers. The contact zone between bed rock and moraine has possibly been such that it particularly facilitates the process by being a good loosening surface.

In the high mountains we find extensive rock surfaces which are, as yet, not shown on the map. This is especially the case in districts with mica-schists which are often exposed due possibly to earth flow, landslides and the like. Of particularly great importance in the afore mentioned regions is that it is just the easily crushed mica-schists which give a fine-grained, easy-flowing type of moraine. This easily becomes mobile on the smooth and slippery schist surface, especially when wet.

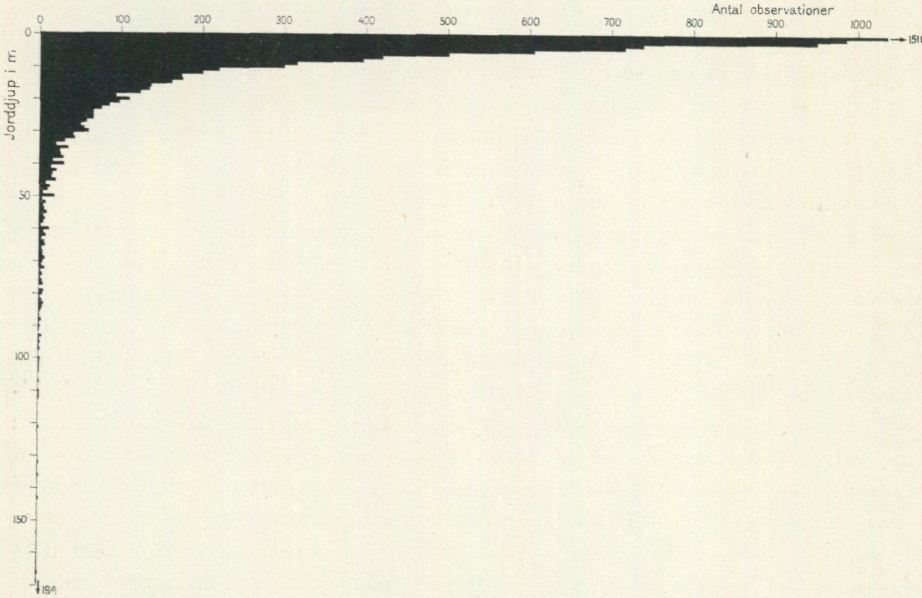


Fig. 1. The thickness of the Quaternary deposits according to reports in the "Brunnsarkivet" (= the well records) of the Geological Survey of Sweden. In this material small diggings are also recorded. In the diagrams earlier published by me, only drillings are recorded and therefore the information from the shallower depths is lacking. More observations will certainly not alter the form of the curve. Jorddjup i m = Thickness of earth cover in metres. Antal observationer = Number of observations.

The thickness of the earth cover

Concerning the earth cover the best would be to give an account of the thicknesses of the different types of earth, but unfortunately it is only in exceptional cases possible. One must therefore be satisfied with total thickness of all layers at each locality where drillings are performed. The minimum value is 0 m, that is where the bare rock ground is met with. The maximum value is of course almost impossible to determine. It is only possible to say that a particular value is one of the largest we know. This value is relatively unimportant, being only a record; much more important is the average value we can expect in drillings. Such a figure we find at first through a summary of all known drillings in the country, and the result is shown in the diagram fig. 1. The material, yet not published, is obtained from the well records of the Geological Survey of Sweden ("Brunnsarkivet") and is here collated by Miss Lydia Jürisson.

It is necessary to remember on studying this diagram, that the thickness is dependent on the locality of the drilling. The picture on a larger scale when compared with a topographic map, will show that the exposed bed rock is met with on the heights and summits etc. In the river valleys on the other hand, the earth cover has considerable depth. Thus we here have the two extreme values. The average value must be met with on the slopes. According to the diagram this is 5—15 m, broadly speaking. It varies of course upwards and downwards according to the surface forms of the bed rock.

In spite of the incomplete material the diagram shows a very elegant curve and I do not think it will be otherwise even if the number of observations increases. The curve will only be displaced in the direction of the abscissa, that is, to the right. That means that the most important part of the curve will keep its position between 5 and 15 m. This value is thus valid as an average for the whole of the country. In the different parts of the country, however, this section of the curve is certainly quite different.

Deposits of the land ice

The deposits of the land ice, that is moraine, are developed when the ice or a glacier glides over a district, in the course of which the knobs are worn down on the side facing the direction of ice-flow, that is, the stoss side. On the opposite side, the lee side, plucking by the ice occurs (Sahlström 1914). This is possible through the variations of temperature which are caused by the variations of pressure under the ice surface. The water that remains in the rock fractures freezes and melts alternately, by which means rock fragments of different size are loosened and are transported by the ice (Hamberg 1926). The material is crushed and worn down to finer and finer fractions during the transport. This type of earth is moraine. It is always characterized by an irregular mixture of fragments of very different sizes.

Moraine is deposited in all districts traversed by the land ice, even to its extreme limits, except the areas of uncovered rock, described on p. 5. The moraine, however, in great parts of the country is covered by younger deposits such as gravel, clay, peat and so on.

On our map the blue colour covers the greatest part; this colour marks the moraine, the deposit of the land ice. It includes many different types. These types are unfortunately not distinguished for the whole country and therefore it has not been possible to mark them on this map. They are marked only on some maps, namely, in Bergslagen (about between Filipstad and Avesta in southern Sweden), on the county maps of Värmland (north of Lake Vänern), Kopparberg (around Lake Siljan etc.), Västerbotten to the "cultivation limit" (i.e. a line between Ormsjön—Storvindeln) and the province of Norrbotten (northwest of the Gulf of Bothnia). They are also shown on the newly mapped parts of the counties of Jämtland and Gävleborg (from Gävle to Östersund). But on the older maps, before 1930, all are united in one type. This brief summary makes it clear that it is not possible to give a picture of the distribution of the moraine types over the whole of Sweden. It is, however, possible to get some guidance as to what is available in different parts of the country.

The concept moraine was used for the first time in Swedish literature by A. Erdmann in 1868. The older words for moraine were 'krosstensgrus' or 'krossgrus', which when translated mean approximately crush stone gravel or crush gravel. These words describe quite well the fundamental point in its development. The material is in fact crushed and smashed rock, but there are also parts influenced to some extent by water, that is to say, sand layers, clay layers etc., kneaded into the matrix.

Grain size and boulder content

Earlier descriptions paid most attention to the surface forms (terminal moraines, drumlins etc.). But these morphological types are not of the same practical importance as the nature of the material, the earth or soil, that is to say, the soil type. This determines such properties as the capacity to take up water, sources of nourishment etc. Most important for determining the total mechanical composition are the grain fractions, from the biggest boulders to the smallest fractions of the size of clay. But such a method is not of practical use, being too unwieldy. It is therefore better to take notice of boulders on the one hand and the smaller fractions on the other. This method is useful at the stage of geological mapping after which we separate on the geological maps (see above) moraine with big boulders, boulder-rich moraine, moraine with median or low boulder frequency and afterwards the finer fractions: gravelly, sandy, with fine sand, silty and clayey types.

This classification according to the content of boulders is not logical, because the basis of the classification is changed. On the other hand, it is easy for unexperienced persons, who commonly perform the geological mapping, to use. Commonly, the moraine types can be described from the boulder content in the following manner. In an area with moraine with big boulders a great part is covered with boulders of more than 1 cubic metre. Often such an area is very broken and hilly. When the moraine is rich in boulders it is very difficult to traverse. In a moraine with low frequency of boulders they are small, sparse and rarely visible. In the two first types, moraine with big boulders and moraine rich in boulders, the boulders are sharply angular, they lie superficially and are so loose that a great many of them tilt when trodden on. The rock type in these boulders is for the most part local, from the underlying or adjacent bed rock. In moraines with normal or low frequency of boulders these are in greater or less degree rounded, and are so deeply embedded in the soil that only a very little part of them is visible above the surface. Where the vegetation is rich, it is often nearly impossible to see the boulders without digging.

The separation of moraine types from boulder frequency gives in some degree a different distribution where the country is more or less rugged. The coarser grained types, that is those with large boulders or with high frequency, are met with extensively in valley bottoms and sides (fig. 3 and 4) and especially on slopes in the lee of ice movement. Often they lie on breaks between terrains of different sorts where the slope alters. The types with normal or low frequency occur on the heights and on the proximal sides of the heights and hummocks in relation to the ice movement. What here is said about the distribution of the

G. Lundqvist 1953.

Fig. 2. Stone "fence" in Urshult, Småland, indicating the boulder frequency in the moraine. The older part is built up of smaller boulders; the large boulders have been collected by means of a new and much improved technique. This has made it possible to cultivate many more areas which before were covered by the boulders.

From the moraine district of South Sweden (3 e).

moraine types classified from boulder frequency is of course not an invariable rule, but quite a common principle is demonstrated nevertheless.

According to boulder frequency, the types of moraine are very different for practical use. Those with large boulders or high frequency can be suitable as arable soils but on the other hand, they make it difficult to transport the forest products (timber, firewood etc.). It is worth mentioning here that moraine with a superficial stone layer is "warmer" than one where the surface has no or few boulders (T. Troedsson 1956). The types with low frequency of boulders are good arable soils: in certain parts of Sweden they are the only soils that are suitable for cultivation. In extreme cases it is possible to put the plough directly into the ground without any clearance whatsoever.

The classification of the moraine from the smaller fractions, the fine grain part of it from gravel downwards, is, as previously mentioned, gravelly, sandy, fine sandy, silty or moraine clay. It is convenient in this connection to state the grain size fractions, their names and sizes, especially as the same classification recurs in other soils. Because the fractions on detailed examination are more subdivided than described above I give the full classification below (to make a

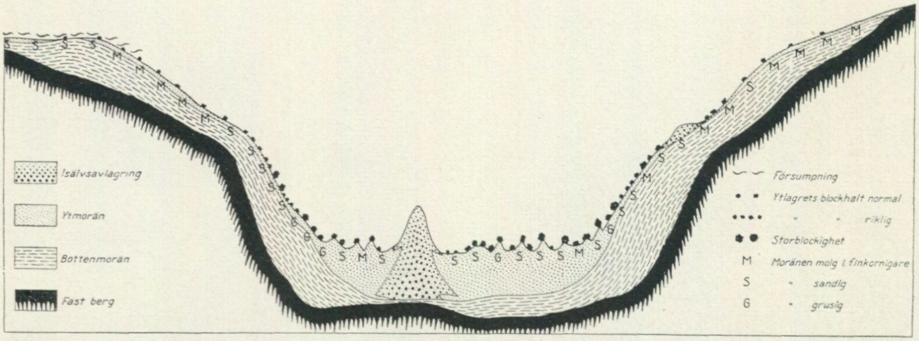


Fig. 3. Schematic profile across a flat-floored valley in Bergslagen (middle Sweden) with different types of moraine and an esker. — Isälvsavlagring = glacifluvial sediments; ytmorän = surface moraine; bottenmorän = bottom moraine; fast berg = bedrock; försumpning = thin layer of peat; ytlagrets blockhalt normal = normal frequency of boulders in the surface layer; .... riklig = ... rich in boulders; storblockighet = with large boulders; moränen moig l. finkornigare = the moraine with fine sand or finer; ..... sandig = ... sandy; ...... grusig = ... gravelly.

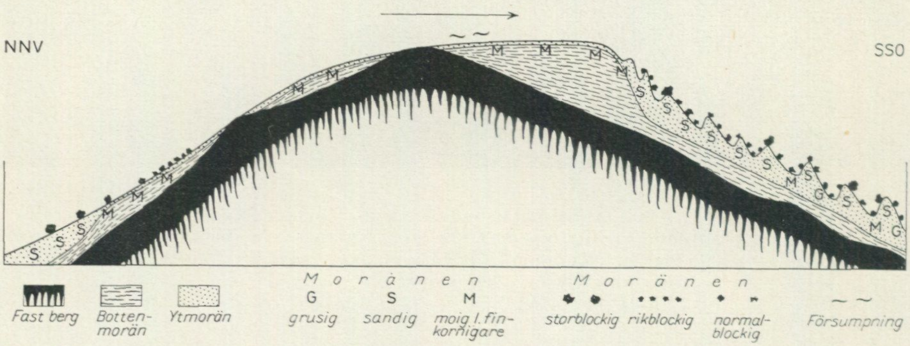


Fig. 4. Schematic length profile through a great moraine height in Bergslagen (middle Sweden) showing the relation between the surface forms of the substratum and the moraine types. — Fast berg = bedrock; bottenmorän = bottom moraine; ytmorän = surface moraine; grusig = gravelly; sandig = sandy; moig l. finkornigare = fine sandy or finer; storblockig = with large boulders; rikblockig = rich in boulders; normalblockig = normal frequency of boulders; försumpning = thin layer of peat. The arrow = direction of the ice movement.
After Sv. geol. unders. Ser. C. Nr 433.

From the moraine and mire district of the interior of Norrland (13 a).

connection with Swedish literature and maps more easy I give the Swedish names in parenthesis):

Boulders (block)	have	a	particle	diameter	greater than 2	dm
Stones (sten)	»	»	»	»	20—2	cm
Coarse gravel (grovgrus)	»	»	»	»	20—6	mm
Fine gravel (fingrus)	»	»	»	»	6—2	»
Coarse sand (grovsand)	»	»	»	»	2—0.6	»
Medium sand (mellansand)	»	»	»	»	0.6—0.2	»
Fine sand (grovmo)	»	»	»	»	0.2—0.06	»
Very fine sand (finmo)	»	»	»	»	0.06—0.02	»

Coarse silt (grovmjäla)	have a particle diameter	0.02—0.006 »
Fine silt (finmjäla)	» » » »	0.006—0.002 »
Clay (lera)	» » » »	<0.002

For certain work it is necessary to divide the clay fraction < 0,002 mm, still more, but this is of no interest for the map in question. Therefore it is sufficient to combine the fractions in pairs, e.g. course gravel and fine gravel. In doing so we get the more simple classification:

Gravel (grus)	has the particle diameter	20—2	mm
Sand (sand)	» » » »	2—0.2	»
Fine sand (mo)	» » » »	0.2—0.02	»
Silt (mjäla)	» » » »	0.02—0.002	»
Clay (lera)	» » » smaller than	0.002	»

The finer fractions of the moraine are divided according to this classification which is also used to name the types. It seems quite easy to make such a classification according to the dominating fractions present but it is seldom that one of them is markedly dominant. Instead gravel and clay can be of nearly equal frequency. In such a case one must use the name gravelly—clayey moraine. In certain districts all fractions are represented with about the same frequency and it is more difficult to name any dominant one. Granlund (1943) used in these cases the term "normal moraine". Such a method is certainly convenient but the name is not good because the "normal moraine" differs in various districts. In some districts it is the very clay-rich moraine, boulder clay or moraine clay which is to be regarded as the normal one. The most common type in the whole of Sweden where the bed rock belongs to the Archean, is the sandy—fine sandy type.

The usefulness of the moraine varies according to the boulder content; the grain sizes are nearly as important for practical purposes. The more coarse types are useful for gravel if no better is to be found. The finer types are good arable soils, the finer the better, and best of all are the boulder clays. Most important too, is that moraine types with a high frequency of very fine sand or silt are strongly influenced by the frost action. They flow easily and it is therefore very difficult to construct roads in such districts.

Finally, it can be said that a relation exists between the structure of the moraines, their frequency of boulders and grain sizes, at least in some districts. It can be illustrated in the following manner:

Moraine with large boulders is gravelly moraine,

Moraine rich in boulders is gravelly-sandy moraine,

Moraine with medium boulder frequency is sandy and sandy—very fine sandy moraine.

Moraine with low boulder frequency is very fine sandy, very fine sandy—clayey or boulder clay.

In reality the above means a continuous development from the most coarse to the finest fractions, that is, from boulders to clay. From this it is clear that the simple terms which are used above illustrate the successive crushing and diminution of the material. It means too that a gravelly moraine with large boulders represents the start of the development while a very fine sandy or clayey moraine with low boulder frequency is the termination stage of the moraine type in question.

It was stated earlier that the type with large boulders or high frequency includes material from the local rocks, whilst the others have more far-distant material. This suggests that there is a certain connection between moraine type and rock type. It is also evident that some rocks which are more difficult to crush owing to hardness, fissures, structural conditions and so on give coarser moraine types, while others give moraines with finer grained material. Examples of rocks, which give a relatively coarse moraine — the differences are often quite small — are quartzitic sandstones and porphyries. Fine grained types are developed from limestones, loose shales and similar rocks. A special type of moraine is one which consists of both coarse and fine grained components as for instance some mica-schists with quartzite knobs e.g. the rocks of the Larsbo series.

The moraine clay or boulder clay, as it is called, is a special type deposited by the land ice and having a higher frequency of clay. But this occurs in many forms which are not differentiated in the laboratory nor systematically described. The best material with most forms is from the county of Jämtland and has been provisionally investigated by G. Lundqvist and Jan Lundqvist. The most common type of boulder clay from this county is a very heavy and stiff earth with a clay content of more than 20 %. The stone content is variable, but the content of boulders is mostly very low. This type is very compact and does not easily fall to pieces. Another type on the contrary disintegrates to small cubes on drying. The spaces between these cubes are filled with fine sandy or sandy material. The mechanical analysis of this earth gives a relative high frequency of the above mentioned fractions. Yet we do not know, if this material, sand and fine sand, that fills the fissure system is a sediment or a constituent of the body of the moraine that has been dried out of it. Thus the manner of formation is not known.

A remarkable type is one which is possibly a local moraine of shale. It consists completely of small pieces of shale and a mechanical analysis shows it to be mostly gravel. But if on sieving and so on the material is handled more energetically, the fine particles must surely increase successively in quantity. The question then is, which grain fraction is of the most significance in this connection and consequently which soil type designation should be given? Gravelly moraine is completely misleading as is clayey moraine or boulder clay. But the last names correspond most closely with the situation.

A variant of the above mentioned local type is one in which the shale pieces appear to have a stratigraphic orientation, that is to say, they are practically *in situ*. Then the deposit is very similar to a weathering soil. But such an interpretation is surely false; it is more probable that such a shale hummock has been moved as a whole by the land ice and during this process somewhat crushed. In such a case it is not improbable that it has slid on a looser layer that has served as a lubricant. The alum shale moraines, recognized by their deep black colour, belong to this type of shale moraine.

It has already been mentioned that the boulder clays discussed above are to be found in Jämtland. In addition to them there is a type that at least in the southern Cambro-Silurian parts of the country, is quite common; it is developed from the Ordovician limestone. When the rock is red limestone the whole of the moraine mass is intensively dark red in colour and in certain lighting is much like the laterite soils of the tropics. It is heavy and stiff and the content of boulders and stones very different. On the isle of Öland there are areas with boulders of Orthoceras limestone 20—30 cm across, and a short distance away areas where the boulders and stones are less than 10 cms across (fig. 5). The matrix between them is intensively red.

In Skåne (the most southerly part of Sweden) the boulder clay has been studied by Ekström (cf. fig. 23) especially with regard to the primary rock material. From this study it is clear, among other things that their grain sizes vary considerably from gravelly to heavy clay types. The latter belong especially to the Baltic moraine clays, which are largely formed of unconsolidated rocks, mainly Cretaceous in age. They are commonly very poor in stones and contain only boulders and stones of the hardest rocks. The most common and characteristic types are small nodular flint fragments or "rullflintor". Their colour is black or dark gray, the diameter about 5 cm and the rock is a chalk. For the rest the reader is referred to fig. 23 (after Ekström 1936).

The stratification of the moraine

The moraine generally lacks a differentiation into separate layers, but some special peculiarities in structure and composition are often to be seen. The irregularities that are to be found in the beds concern sand layers which vary from about one centimetre to about one metre in thickness and have a horizontal extension varying from about one decimetre to many metres. These sediment layers, or rather lenses, were probably sediments deposited in front of the land ice and then ploughed up by the advance of it. At the time the sediments were often frozen, the ice tearing them to pieces. In this way they enter into the unsorted morainic matrix. Another feature in the structure of this mass is a certain foliation or structure resulting from pressure (G. Lundqvist 1940). In exceptional cases one can find a certain type of varve, about a decimetre thick, which constitutes the bedding. All the different structures, which show various forms, are formed in conjunction with movements of the ice and the moraine mass which result in the successive crushing down of original material. This seems to occur preferentially on more or less obvious schistosity planes that demonstrate the stratification of the ice-cover, planes of thrusting and so on. In sections there are seldom more than a few metres to be seen but certain signs suggest, that quite large slices of moraine can be transported as units. Especially is this valid for boulders of the Cretaceous of Skåne (e.g. Holst 1903).

G. Lundqvist 1952

Fig. 5. Area with boulder clay southwest of the ancient castle of Gråborg on Öland. The earth is formed from red Orthoceras limestone, and shines dark red in the sun like the tropical earth laterite.

From the limestone isle Öland in the Baltic (2).

Finally I wish to point out that in the previous description no reference is made to layering which surely represents different beds of moraine. Such are principally characterized by different boulder contents, different structures etc. (fig. 6). There are many causes for the occurrence of such beds (G. Lundqvist 1951) including: 1) different glaciations, 2) changes in current direction, by which various rocks are eroded, 3) the erosion reaching down to a new type of rock (the current direction is not altered) etc.

A special type of moraine is the so-called Kalixpinnmo (Beskow 1935) or Kalix till. This name is given to a special type of moraine, first described from the environs of Kalix (on the map Nederkalix) in northern Sweden (west of Haparanda). Later it has, however, been found in many parts of Sweden. Kalixpinnmo consists of stratum packs of sand and fine sand, which are congested and folded. The boulder content is commonly insignificant; in many cases boulders are lacking altogether.

The surface forms

The surface forms of the moraine may be various, but it is unfortunately impossible to give a map of the distribution of the different types. Some can be

G. Lundqvist 1930.

Fig. 6. "Double moraine" $1^1/_2$ km NW of Ingasäter on the eastern side of Mount Billingen. The upper bed contains a greater percentage of far-travelled boulders than the lower. After Sv. geol. unders. Ser. Aa Nr 172.
From the Cambro-Silurian district of Västergötland (6 a).

distinguished on the topographical maps but often the same form can have various expressions. Neglecting the even level form which does not show any special morphological features, it is immediately easy to distinguish the three following types: 1) ridges extended in the ice movement direction, 2) ridges perpendicular to the latter, 3) irregularly orientated ridges.

Ridges extended in the ice movement direction are drumlins (fig. 7) and radial moraines. Both of them have variants which are not discussed here. Drumlins appear as swarms, and are made up of bottom moraine, the boulders of which are firmly pressed down into the moraine mass and very often scratched by the ice. They are mostly orientated in the direction of the striae, but in certain cases a relatively high percentage of them may lie crosswise. The drumlins are formed by the interplay of erosion and accumulation.

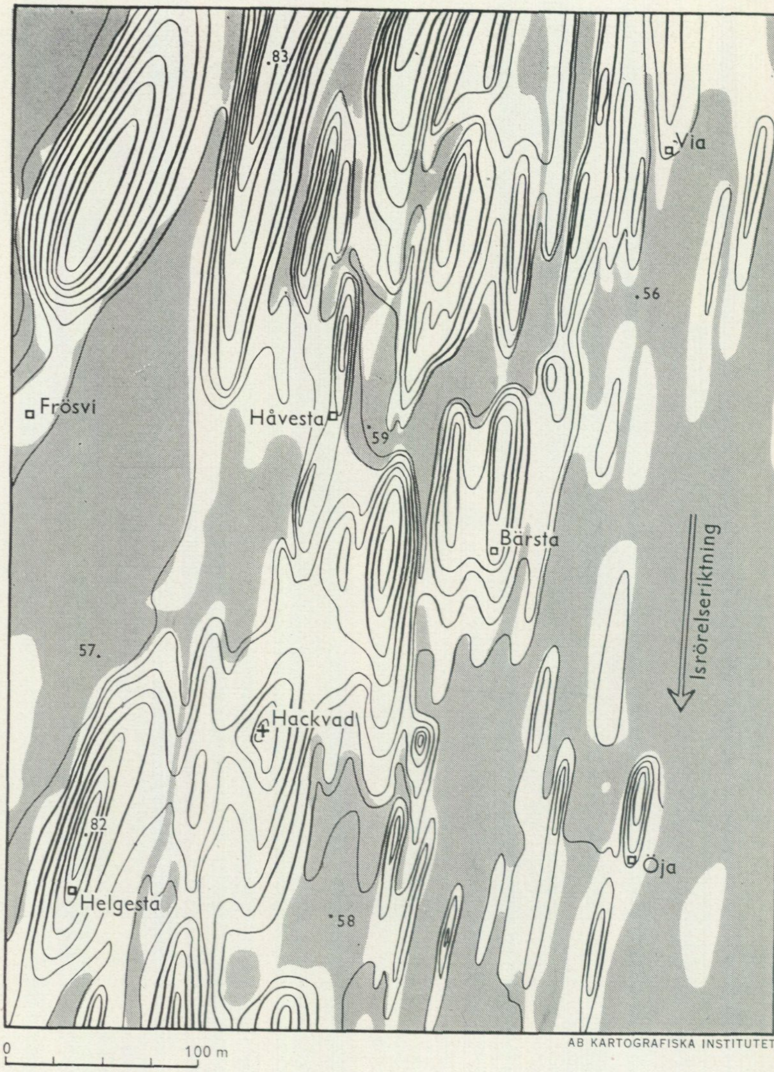


Fig. 7. Drumlins on the clay plain of central Närke. The whaleback form is typical: slender and elegant ridges orientated in the direction of the ice movement (indicated on the map by the arrow and the word isrörelseriktning). The map is constructed by K.-E. Sahlström 1913 and published in Sveriges geologi 1957.

From the Cambro-Silurian district of Närke (6 c).

Radial moraines consist of surface moraine and often have a high frequency of large boulders. The boulders lie loose and are superficially without any distinct orientation: the rock types are local. The development of radial moraines is conditioned by fissures in the ice. The difference between drumlins and radial moraines was pointed out by Tanner (1914) but is commonly overlooked.

Ridges extending crosswise to the ice movement include, among other things, the smaller terminal moraines (fig. 8) or push moraines, and the great end moraines of the Salpausselkä type. There is really no other difference between these two types than their height and extent. The terminal moraines are smaller, only a few metres high and relatively short; the composition is more homogeneous. They occur in groups and the boulders are orientated crosswise to the ridge, whilst in front of and behind the ridge they lie parallel to it. The cause of this must be that the moraine material is shovelled forward by the ice a short distance, during which the "shell" only is influenced, causing the boulders or larger stones to turn into a crosswise position. In the main body there is no distortion. Specially conducive to the development of these smaller terminal moraines is the existence of only a thin moraine cover when the soil is very easy to shovel forward on the hard rock surface. The end moraines are larger; they mark a longer pause than the smaller ones. As good examples of this moraine type may be mentioned the great Middle Swedish or the large Fennoscandian end moraines of Salpausselkä type. They contain often large clay embankments or glacifluvial material.

A moraine form of great importance in a morphological respect is, as was mentioned above, the one with irregularly orientated ridges: ablation moraine or, to use the common Swedish term, "dödismorän", that is, dead-ice moraine (figs. 9—10). Of this type it is possible to distinguish some variants to which it is better to come back later. The ablation moraine is developed during the melting of the ice, when the latter is divided into immense ice blocks which are successivly embedded in the gravel exposed on melting. During the continued wastage of the ice relics a further disturbance of the stratification of the moraine material occurs when it slides down into the hollows left behind after the melting of the ice boulders. The irregular ridge and hummock morphology has been formed by this reciprocal action. The irregular orientation of the boulder material is also obtained in the same way. In some cases the moraine boulders can be quite distinctly orientated with regard to their long axes. Finally, it must be pointed out that no theory free from objections has yet been put forward for the origin of ablation moraines, despite many attempts.

The ablation moraine is found in great parts of the level lands in supra-aquatic positions of Sweden, that is above the HK line (= highest marine limit or shore line). On the map, the districts with ablation moraine are readily detectable due to the richness in small lakes. See, for example the topographic map-sheet Hakkas (NW of Murjek in Lappland).

The following must also be remembered in connection with the problem of the ablation moraine. Locally districts are found where the ridges are less irregularly arranged and instead are aligned more parallel to each other. These districts therefore resemble a terminal moraine landscape and the ridges have often been interpreted as terminal moraines, developed in front of an ice front and pushed together by it. However, ridges of this type are formed behind the ice front and within the outer zone of the land ice. Their development does not require any movement of the ice though it may be asked why one dares to make such a statement. One reason is that this moraine form is found as far

G. Lundqvist 1952.

Fig. 8. Terminal moraines in the Åråsviken bay, Lake Vänern. The shallow bay with an even bottom is now largely overgrown by vegetation. The ridges rise from parallel courses of moraine parallel to the ice movement.

From the moraine and mire district of the interior of Norrland (13 a).

as the last ice divide where the movement must surely be supposed to have been nearly non-existent.

The glacifluvial deposits

Everyone who has walked on a glacier, irrespective of its extent, has surely observed the many melt water rivulets on its surface. Within fissures in the ice too, as well as beneath the ice, the melt water rushes along, and one hears a continuous roaring and rattling sound. It is produced when the moraine, the deposit of the land ice, is transported by the melt water streams. Then the boulders and stones of the moraine are rolled along the bottom during the course of which they are worn to nearly globular forms. Such boulder material has been widely used for the cobblestone streets of older times. During the erosion of the material it is also sorted by stream washing. The smaller the grains, the farther they are transported by the stream. They are taken with it until the speed of the stream, and hence its carrying capacity, diminishes so that the material drops to the bottom.

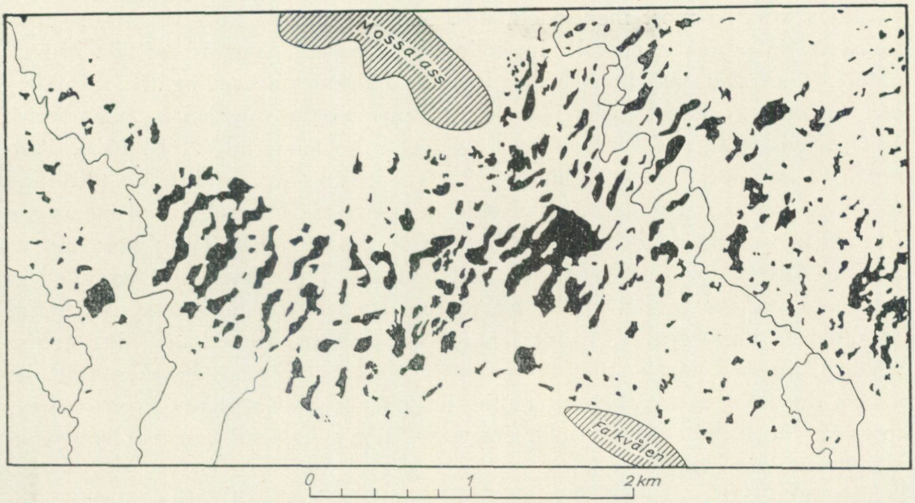


Fig. 9. Lakes Falkvålstjärnarna NE of Ljungdalen, Härjedalen (after an air photo by Airborn Mapping Ltd.). The whole of the district is rich in moraine ridges, ablation moraine, often with large boulders, perpendicular to the last ice movement. Mossalass and Falkvålen are mountain ridges.

From the district of the high mountains (15).

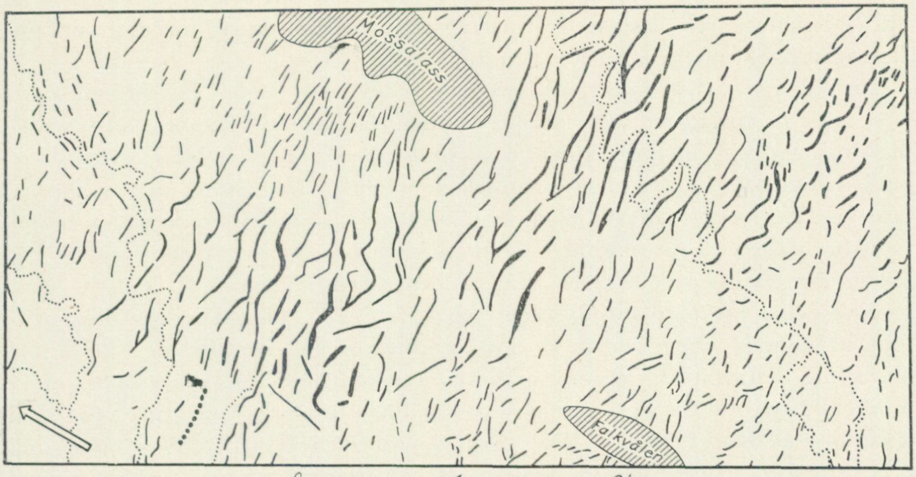


Fig. 10. The area of the lakes Falkvålstjärnarna: the same district as the previous picture. The crests of the ridges are drawn from the same air photo. The whole of the flat lands between the hills is rich in ridges perpendicular to the ice movement (the arrow, left), but they are lacking on the hills. The ridge pattern is similar to the crevasses of glaciers. The dotted lines indicate recent brooks (cf fig. 9).

The glacifluvial deposits are eskers (fig. 11), deltas (fig. 12) and lateral terraces of different types. On the maps — as on most Swedish geological maps — are included such coarse-grained deposits as those reworked by the glacifluvial, extra-marginal rivers or their successors, possibly even of recent date.

Eskers are the most mentioned, and one can indeed hear the term "rullstensgrus" (= esker gravel) in colloquial language instead of glacifluvial gravel. The eskers are not divided like the moraines according to grain sizes etc. but on a genetical basis. The chief groups are the subglacial (Strandmark 1885, Davis 1892, and G. De Geer 1897) and the subaërial (Holst 1876, Tanner 1914 and other years, Halden 1942). Yet it is often very difficult to decide to which type a particular esker should be assigned. The subglacial eskers are formed in tunnels on or near the bottom of the land ice. The water and its load are driven forwards by hydrostatic pressure. The material is deposited in the mouth of the tunnel at the ice margin so that the most coarse material (boulders, stones, gravel) drops first. There is thus formed an esker centre which is the first part of the deposition during any one year. Farther from the ice all the finer material drops to the bottom, broadly speaking from coarser to finer, that is, the sand to clay fractions. The subglacial eskers follow principally the large valleys.

The subaërial eskers are deposited in large crevices and fissure channels in the ice, the directions of which are quite independent of the forms of the land surface. A subaërial esker often runs straight across a large valley or lies on a height. This type is distinguished from the subglacial, by the absence of the esker centres and its angular course among other things. Finally, there is one more difference between the two esker types. The subglacial consists of well-washed material that is mostly transported a long distance, for example 100 km, whilst that of the subaërial is quite local e.g. 5 km.

An attempt to distinguish both esker types regionally is not possible but each case must be considered individually. It might be said that Tanner in his works has lead the way in this respect: a scrupulous measurement both of the esker and its environs, makes clearer the development of the district during the ice wastage. Everyone understands how much time this works requires and in this lies the reason why so few investigations have been done. In later pages, the eskers are discussed collectively, independent of their genesis.

The deltas are of many different types. In reality the eskers are deltas too but a boundary between them and ordinary deltas is very hard to draw. Terminal deltas are in any event the largest and most impressive. They were built in front of the ice when it was standing still for a long time. Classical examples of this type are "Dals Ed" described by G. De Geer 1909, and "Brattforsheden" described by Hörner 1927. Variants of these are the proximal deltas, whose material is coarse grained and rich in boulders, and the rand eskers, which constitute a transition type to the terminal moraines—marginal moraines. One can perhaps say, that the marginal eskers are a glacifluvial end moraine type, if such an inconsequent term is permitted.

Kame is properly a morphological conception, and can be briefly described as a round hilly area built of glacifluvial material. Another of these concepts is esker net, that is, a district rich in eskers aligned in all directions. Finally kettle fields or deltas with ice hollows (kettles) developed in one way or other during the disintegration of the land ice (fig. 12).

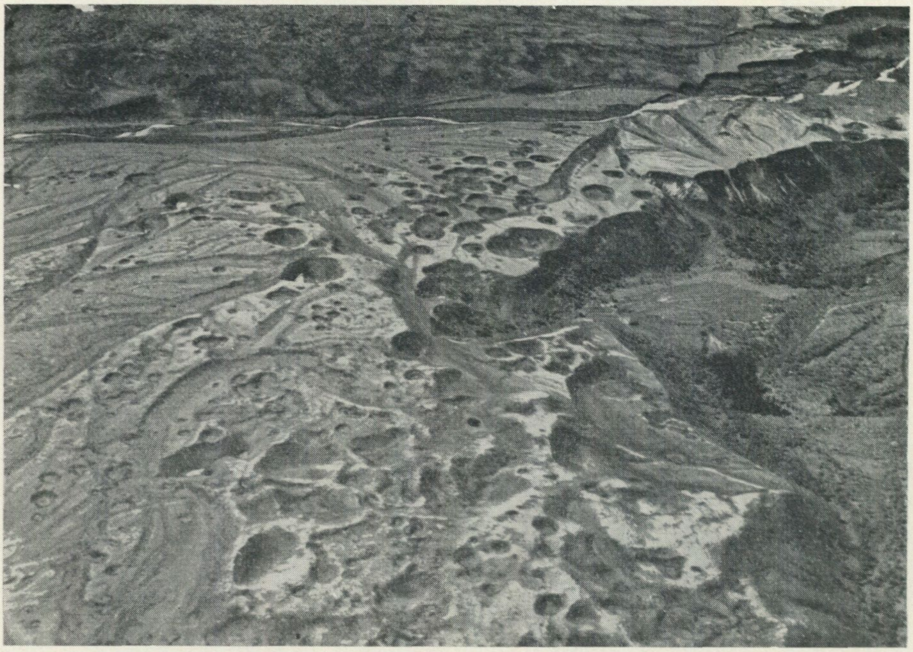
G. Lundqvist 1949.

Fig. 11. The Hedesunda esker, a southern part of the Gävle esker, here crossing Hedesunda bay in the river Dalälven. The foreground is moraine, which is clear from the large boulders on the open surface in the forest.

From the coast zone of Norrland (12 a).

Lateral terraces are a special form of delta. They accumulate between the ice margin and the steep slope of a hill or mountain. Therefore they can be described morphologically as gravel shelves on a slope.

All these sediments, which were deposited more or less directly in conjunction with the land ice, are marked in the same way on the map. So also are the gravel fields which were worked over and washed by rivers, glacifluvial rivers and such like. They are thus more or less erosion relics or material redeposited from other, more typical glacifluvial sediments. They have been built up when the glacifluvial river changed its course over the delta and cut down locally into the sediments in the swinging way that is characteristic for



G. Lundqvist 1949.

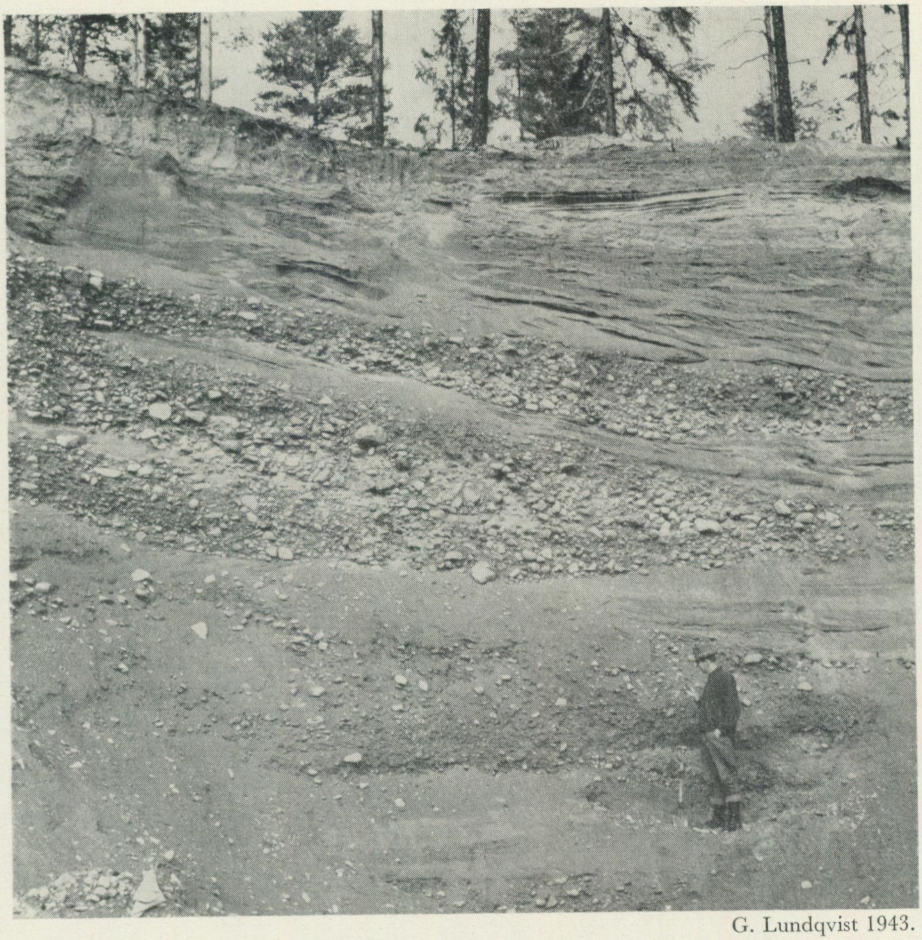
Fig. 12. The kettle field (pitted outwash plain) at Gröndalen in Jämtland. The river flowed from the lower left corner of the picture and swung in a curve to the upper right corner. The kettles are formed where ice blocks were embedded in the glacifluvial sediments or by the action of the stream around the ice blocks. The stream prevented the burial of the blocks. In the foreground ablation moraine. The contours of the Gröndalen valley to the right are sharpened by solifluction, which is demonstrated by some of the dry brook furrows (dark lines) beginning immediately at the margin of the large valley to the right.

From the district of the high mountains (*15*).

rivers. Through these processes it has been possible in such gravel fields to find rock or the moraine floor exposed. But without more detailed studies it is not possible to see if the field has, in fact, development in this way. For absolute certainty it is necessary to examine the type of stratification and the attitude of the layers in each field. The short description just given shows that these deposits are stratified drifts in front of the ice and it must be quite clear that in regional studies based on map material it is quite impossible to separate these different types, hence all of them have been marked with a green colour on the map.

From the preceding it can also be realized that the stratification in the glacifluvial deposits must be very variable. It is completely dependent on the strength of the stream in the deposition area. Therefore the grain size can rapidly vary from boulders more than metre large down to clay particles (fig. 13). Veritable continuous clay layers are certainly not met with in the normal, primary glacifluvial sediments, but material as fine as fine sand is not at all uncommon.

Most characteristic for the strata belonging to this category is the abundance



G. Lundqvist 1943.

Fig. 13. Section through the glacifluvial delta Styrsjöplatån in Leksand southwest of Lake Siljan, Dalarna. The rapid changes in the grain size of the material, from sand to cobbles, distinguish these large deposits.

From the moraine and mire district of the interior of Norrland (13 a).

of discordances. Certainly one often finds a great persistence of the layers but abruptly these are broken by a discordance. But it should be noted that below the highest shore line there is a very important discordance between the glacial and post glacial part of the succession, but it is not this one that is meant here. The above mentioned discordance on the other hand indicates a change in the course of the melt water stream and this, in its turn, can be caused by opening of new fissures in the ice cover or shutting of others for some reason or other. Under favourable circumstances the differences in the stratification appear along the length of the deposit in such a way that the coarser fractions are met with upstream. Theoretically, the most coarse fractions, the large boulders, should be so placed that they mark the first of all deposits during any one year. Therefore an esker should be like a long gravel

G. Lundqvist 1956.

Fig. 14. Cobble field on the island of Gran in the Gulf of Bothnia. The effect of the breakers has here been very strong. This picture is rather characteristic for numerous isles in the Gulf of Bothnia and along its coast.

From the coast zone of Norrland (12 a).

string with these esker centres spaced along the ridge. In practice that is not always the condition.

Most of the sections of glacifluvial layers are from eskers below the highest marine limit. But a great part of this sediment is redeposited by sea breakers. Under certain circumstances it is impossible to decide how deep the wave-washing and redeposition have reached. There can be a seemingly quite normal glacifluvial deposit, but suddenly one finds shells of post glacial molluscs or simply a shell bed. Then it is quite clear that at least the layers over these shells are redeposited and post glacial. However, there are examples which show that the entire esker was redeposited and displaced perpendicular to its main extension. Meanwhile, of course, the original form has changed, but the end-product appears at all events as a gently rounded ridge.

G. Lundqvist 1940.

Fig. 15. Shore gravel in the vicinity of Hedemora, Dalarna. The material is of boulders and sand. In this stratification the stones and boulders increase in size towards the bottom; this is characteristic of strata when the breakers have worked up and down, instead of in a horizontal way.

After Sv. geol. unders, Ser. Aa Nr 184.

From the coast zone of Norrland (12 a).

Fine grained sediments

In this group are united many sediments with very different developments. Common to them all is, however, that they are deposited in standing or running water. The grain size is quite dependent on the deposition milieu so that in flowing water soils with coarser grain sizes are deposited. Therefore the shore zone and running water are characterized by coarser sediments. The more fine grained sediments are found in the seas or the deeper parts of the lakes. Somewhat coarser sediments are found in fjords and bays. The type is different in salt and fresh water. Therefore the time for the deposition (Ancylus or Litorina time) is of importance. On the map it has not been possible to take all these factors into consideration. For the map the mechanical composition of the soils is the main consideration.

The map of the different fine grained sediments largely shows, as must be clear from the above, the former distribution of the sea or more exactly, the incidence of the different stages of the Baltic Sea. But the sediments in question are also found, though more seldom, above the limits of these stages thus giving evidence of the occurrence of earlier ice lakes or similar lake systems.

The fine grained sediments marked on the map are sand (orange), light clays, silts and clay (yellow). Certainly these sediments in the field present a greater variation, but corresponding sub-division on the map is not possible with the material yet known. In reality, it does not make possible the above-mentioned rough sub-division of the clays. Not even fine sand and very fine sand are distinguishable. On the map therefore the fine sand has been united with sand, and very fine sand with silt and clay. The reason is that such a sub-division is good for practical purposes, as a very important mechanical limit lies between these groups. It is in fact the limit between non flowing and flowing earths; the last is characteristic for the finer types.

The sand often lies in rather extensive areas. In such cases these are more or less associated with the glacifluvial deposits and are as a matter of fact, redeposited portions of the latter. It is not surprising then that some of the glacifluvial deposits, the green marked areas, have sand of the same grain size as the areas shown with orange. The difference between these two sediment types is their mode of formation. The green areas are mostly influenced by ice rivers, the others by the breakers of the sea. The last named type of deposit is thus washed from the glacifluvial deposits or from moraine. Therefore they are more common below the highest marine limit (MG or HK) or in ice lake districts. It might be reasonable to use different designations for the sand areas in both of these principal districts, but because the position of the MG (or HK) in important parts of Sweden is still under discussion, it is more suitable to differentiate the sand from a petrographic rather than a genetic point of view.

The sand has affinities with the gravel but it has seldom been possible to distinguish the latter on the map. It is found partly as large areas, partly as narrow 'strings' on the slopes. Genetically these sand and gravel areas are somewhat different. The large gravel areas are moraine, completely redeposited and transformed with regard to its grain size frequency by the breakers. The finer fractions are often quite washed away (fig. 14), and the remainder is coarse gravel and rounded cobbles (fig. 15). This is especially well seen where the areas are met with in connection with flat heights in open positions and with rather boulder-rich material.

The narrow gravel strings on the slopes are similarly washed from the moraine but on account of the form of the terrain there is no width to them. They constitute only the coarse proximal parts of the extensive sand areas lying below.

Both of the gravel fields described above are, as already mentioned, developed by the effect of the sea-breakers. Often, however, this is shown by their surface forms, beaches being characteristic at least of more open situations. Therefore one speaks about beach gravel or shore gravel. Mostly our interpretation of the land elevation is founded on these phenomena.

The above mentioned sediments, sand and gravel, are certainly not to be included with the fine grained types, but the groups grade into one another. The coarser types consist of shallow water sediments whilst the finer are deep water sediments. To the last mentioned belongs very fine sand, silt and clay. On the map it has unfortunately been impossible to give each one its symbol, because the geological observations have been quite heterogeneous. Over large districts of Sweden they have in our primary material quite simply been denoted as clay. Despite the fact that on the map this includes very fine sand—clay, that is to say, a mechanical classification (compare tab., p. 12), it has also been convenient to use a classification based on the time when they were deposited. Broadly speaking, the clays can be summed up under the chronological terms glacial and post glacial. The first mentioned type was deposited to a great extent in connection with the land ice. It is in certain districts varved, or seasonally stratified: a special type is the plateau clay (see p. 54).

The post-glacial clay (fig. 17) on the contrary is not varved being commonly a heavy clay with a varying content of organic matter (mud substance, diatoms etc.). In any case the organic percentage is here much greater than in the glacial clay, where it is always low and, as it seems, nearly always associated with the winter layers (G. Arrhenius 1947). The post glacial clay is often intensely blue-black when first dug up due to iron sulphide FeS_2. But it turns pale quite rapidly in the air, when the iron sulphide is oxidized to sulphuric acid and ferric compounds. Then the clay generally turns light grey.

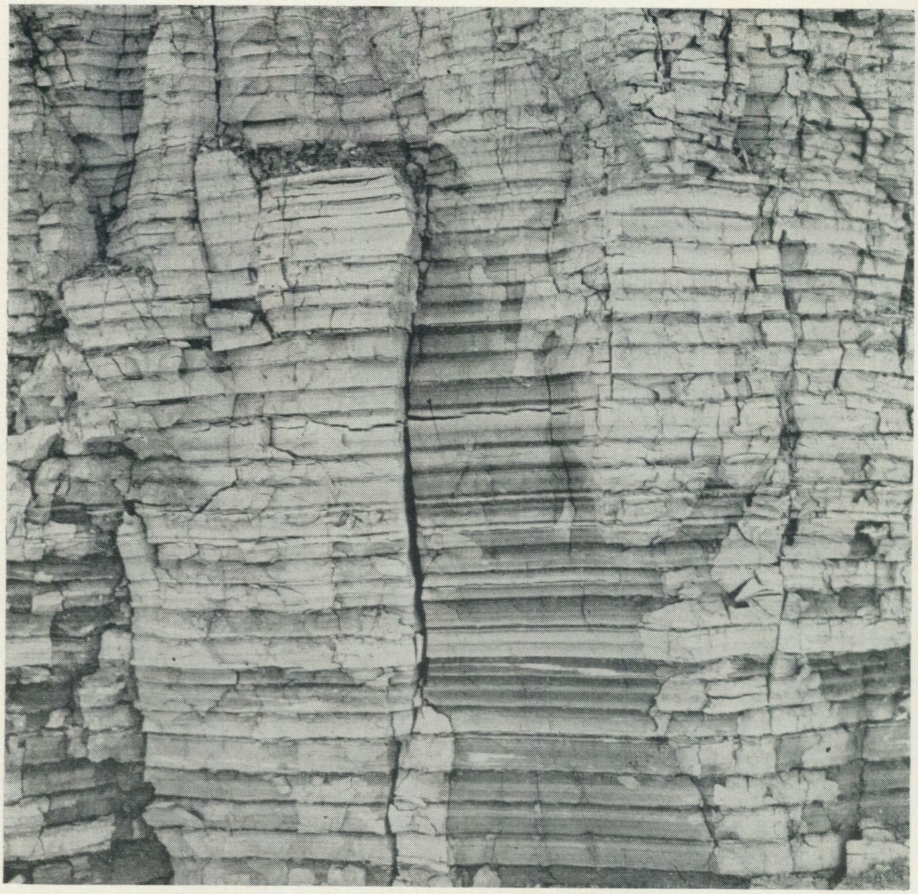
The mud clay too is grouped with the fine grained sediments; it is the youngest in the succession. It is distinguished from the above mentioned post glacial clay by a higher percentage of organic matter. Furthermore it falls to small pieces on drying and is therefore called by Swedish country people "grynlera", meaning approximately 'grain-clay'. Another characteristic trait is a richness of limonite precipitate in all the fissures. The mud clay is deposited in rather shallow water among luxuriant vegetation.

River sediments

The fine grained sediments described above include also deposits laid down in running water. These deposits are the river sediments, which are developed at very different times. They are distributed along the river courses usually as narrow strips which are impossible to mark in the scale of the present general map. On the latter they therefore are included in the fields marked with an orange colour (gravel, sand etc.) or yellow (clay etc.).

From this it is clear that the river sediments are partly sand or gravel, partly silt, clay and the like. To the first group, the more coarse grained one, belong mostly the deposits situated along the rivers Klarälven and Dalälven. Characteristic for the sediments of Klarälven, are the morphological types described by Sten De Geer (1911). The rivers meander very distinctly. Between meander bows, the head-lands develop down-stream, their surfaces sculptured by the current. The most important forms described by Sten De Geer are the point bars.

The river Dalälven has quite another style: there are no meanders, but instead along and near the river, the sediments are developed as levées, on which the roads, at least in ancient times, were laid.



G. Lundqvist 1954.
Fig. 16. Glacial clay from the vicinity of Uppsala. On this picture the varves are very distinct, but on closer examination it is often a problem to determine the limits between the laminae. After Sv. geol. unders. Ser. Aa Nr 199.
From the moraine district of Uppland (10 d).

Fundamentally, the river sediment plains along the rivers in Norrland are built up in the same manner, that is to say, as ridges. This was described long ago by A. G. Högbom. But the sediments are in these districts more fine grained. Fine sand, very fine sand or silt, are the most important sediments near the coast zone. On higher levels the sediments are more coarse.

Especially within the Norrland part of the country the river sediments are built up as 'mouth' deltas. Down-stream these deposits change into fjord sediments. Their grain size is mostly that of very fine sand or silt. Clay is seldom found as a surface layer; it is deposited between more coarse-grained sediment packs.

G. Lundqvist 1952.

Fig. 17. Post-glacial clay from the vicinity of Uppsala. The direction of some fissures, shades of colour etc., suggest the presence of a stratification not visible to the eye. This picture illustrates the great difference between post-glacial and the glacial clays (cf. fig. 16).
From the moraine district of Uppland (10 d).

Eolian deposits

In the chapter on the fine grained sediments, sand was also mentioned. But it is natural to ask: where are the eolian deposits, the wind-blown sand and fine sand in that account? In actual fact only water-lain sediments were discussed. The mechanical composition of the eolian sand is very similar to the sand deposited in water, the difference being only in the distribution of the finer grain fractions. The cause of the difference is that the sorting by the wind is much more efficient than by the water. Possibly this is the reason, why the eolian sand is certainly often overlooked, especially as the limit between the

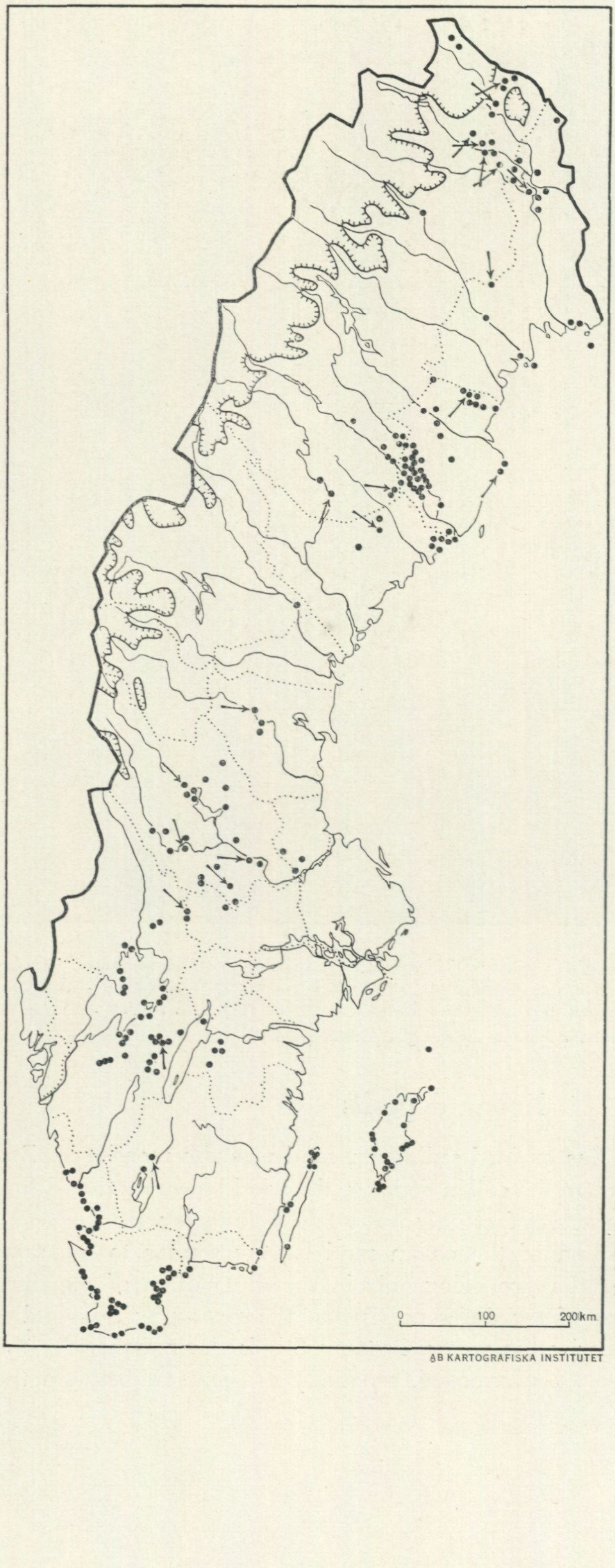


Fig. 18. Distribution of eolian sand in Sweden. The arrows show directions of the form-giving winds. The age of the different fields naturally differs widely, and therefore the main directions vary.
After Atlas över Sverige, map sheets 15—16.

two types, the wind-blown and the water-deposited, is rather hard to determine. Therefore the morphology of eolian deposits gives a better distinction. In their extreme development, dunes with more or less gentle wave-like ridges occur. In certain districts they are substituted by gently rounded hills which are really dunes partly destroyed by variable winds. The reason for this supposition is that it is often possible to see the characteristic feature of the dune: a flat windward face sloping at about 10° and a more precipitous lee side, inclined at 20—30° to the horizontal plane. In sections — but such are rather seldom in areas with eolian deposits — one can see the characteristic stratification. This is hard to describe but consists essentially of thin layers very rich in discordances.

The other type of eolian deposit is the eolian fine sand or, in Swedish, "flyg-mo". Its mechanical composition is very peculiar: there is almost only one grain size, fine sand or very fine sand, 0.2—0.06 or 0.06—0.02 mm. It was described by Hörner (1927) as "eolian mo" and may be compared with loess. It has no special surface expression but fills up small depressions on other deposits, mostly moraine or glacifluvial deposits. Eolian fine sand is very rare in Sweden, but has possibly only been overlooked.

Eolian deposits are locally met with in sand districts in all parts of the country, but the distribution is such that it is not possible to place them on the present general map. On a map on a smaller scale it is easier (fig. 18) to give their localities more precisely. On the smaller map are marked also the wind directions and these have been of fundamental importance in shaping the different fields. The manner in which the wind direction is determined is clear from the previous description: particularly decisive is the inclination of the slopes. When studying the picture it is necessary to remember that the fields are not of simultaneous origin. The fields up country at least, can be assumed to be older than the present-day shore fields. Exceptions in this respect are the fields in the most southern part of Sweden (Skåne) where the rise of the land has been very insignificant for thousands of years. Possibly a determination of the age of the different fields could give an idea of the older wind directions in the country. Long ago such an attempt was made (G. Lundqvist 1920).

Peat lands

The dying cover of vegetation, in Swedish "förna", decays with the assistance of the oxygen of the air. Under certain circumstances, foremost under water, however, there are no such processes of decay and peat appears. Therefore the water supply is of the greatest importance not only for starting the peat development but also for determining which soils, that is to say which peat types, grow. There is a great number of peat types distinguished, but this is a subject which lies beyond the scope of the present study. Various combinations of peat types or stratification are decisive for determining the peat-land types that develop. Popularly two types are distinguished, namely, bogs and fens; this is a very simple classification. The former are characterized by peat mosses, *Sphagnum-*

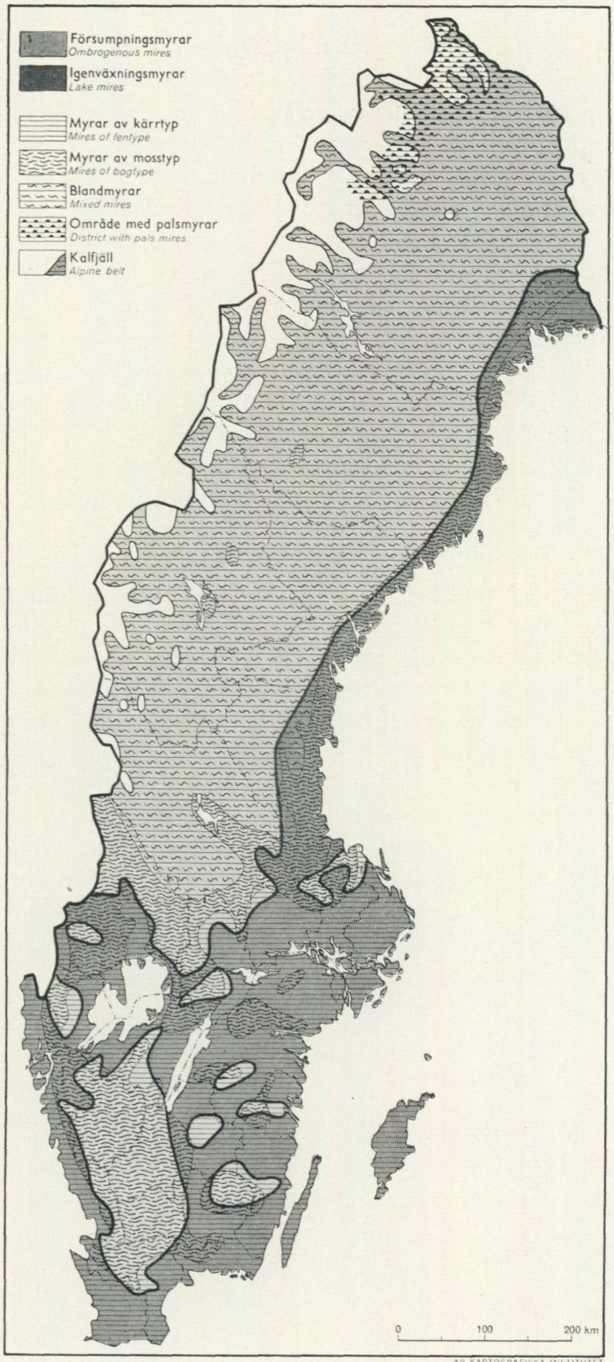
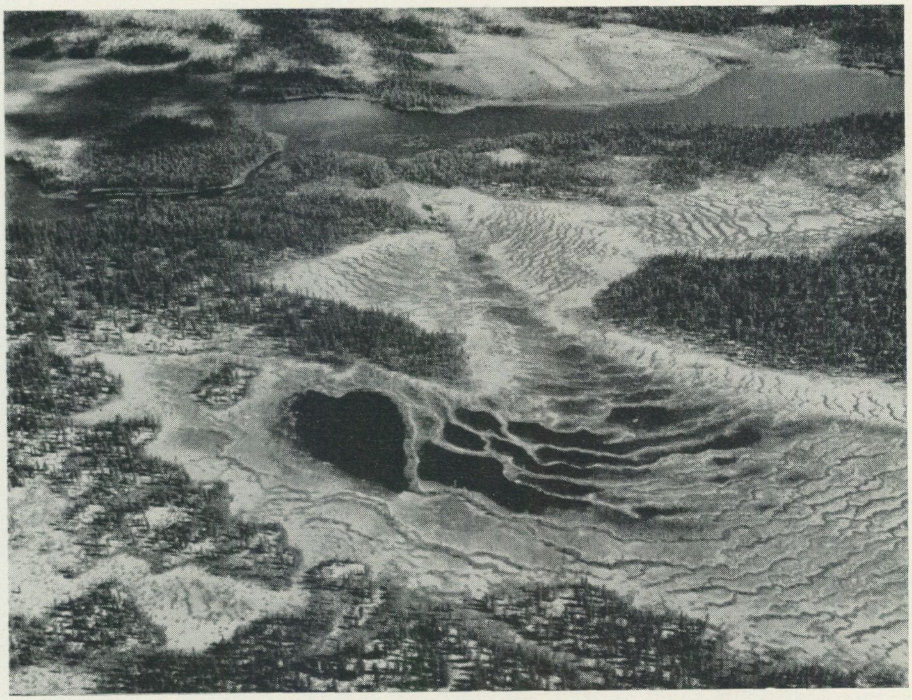


Fig. 19. The distribution of the various types of mire in Sweden. The vast district of Norrland (about numbers 12—15 on fig. 29) is too insufficiently known to allow greater differentiation.
After Atlas över Sverige, map sheets 41—42.



G. Lundqvist 1957.

Fig. 20. Mires at the river Lofsån below Lake Lofssjön west of Sveg in Härjedalen. The valley is occupied by big mire complexes in which ribbed mires of different types and wetness dominate. This type of mixed mire is characteristic for the greatest part of Norrland.

From the moraine district of the eastern marginal zone of the mountains (14).

species, in the bottom layer and the fens by sedges and certain brown mosses (*Amblystegium* etc.). But not even such a simple differentiation is possible to realize on the map without visiting nearly every mire. Only a glance at the map or at "Atlas över Sverige" map sheets 41—42 is enough to show that this work is impossible. Therefore one must reduce them for cartographic purposes to one type only called mire. But it is in such a manner that nearly all of the different types are distributed throughout the whole of the country. The important point is however, that the percentage of the types is quite variable. That is to say, in one district the bogs dominate, in another certain fen types and so on. With this experience as a basis it has been possible to make a small general map that gives a hint of the real conditions.

Figure 19 is the result of such a generalization. When studying this map it is necessary to remember that it is not to be understood that everywhere in the various districts one will find all the stated types. Certainly the types dealt with are given in the text figure but some comments are possibly necessary.

There are two main groups marked with light and dark tones: soligenous mires and lake mires. The latter are developed from lakes becoming filled with growth. Sometimes the growth is in the form of a springy turf, that is stretched over the lake surface. Most common, however, is that the lake is progressively filled up by vegetation, and the fen associations disperse over the lake floor during the summer when it is dry. The soligenous mires on the contrary are developed when formerly dry land has become wet. Such land includes slopes, flat levels etc. Their stratification begins with sedge peat or moss peat in the bottom whilst the lake mires have mud, lake dy, lime mud or other lake sediments.

The mire classification described above is thus based on the mode of development, especially the initial phase. But on the map there is also a classification according to the vegetation, in which fens, bogs and mixed mires are included (fig. 20). A special type is the 'pals' mire occurring farthest north in the country. The fen mires are level or gently sloping but they are not vaulted or convex in any way. They can be open, as for example sedge fens, or in a greater or lesser degree wooded. The bogs are raised above the prevailing level, their surface like a cupola or merely flat or sloping. Their most important vegetation in the bottom layer is peat moss, *Sphagnum*. Such a type or at least certain species of it are lacking in the fens where they are replaced by the brown mosses. The bog surfaces are either open (though often overgrown with small stunted pines about 1 m high = "martallar" in Swedish), or support pines and forest bogs. The boundary zone between these bog surfaces and the surrounding land is very wet and has a vegetation like the fens. In Swedish this part is called "lagg" whilst the slope between the lagg and bog proper is called the "rand" (or margin in English).

The mixed mires indicated on fig. 19 are often extensive, more fen-like mires with large bog tussocks or larger flat-lying stretches of bog. The map shows that they are most common in northern Sweden.

Finally the palses may best be described as small, cupola-shaped parts of the tundra on extensive fen surfaces (fig. 21). The peat in the pals knobs is frozen hard and partly intersected by thin ice strata. The height of the palses in Sweden is commonly one to several metres, but they are also found as high as 7 metres. The diameters vary between 1 m and 100 m or more. The largest pals surfaces are formed from the growing together of two or more palses.

The distribution of the different mire types is largely determined by the climate (precipitation, temperature, humidity etc.). Thus the raised bogs require a precipitation of more than 460 mm a year according to Granlund (1932). But there can clearly not be too high humidity, because they then should be very common in northern Sweden, where the precipitation is mostly very favourable for the development of raised bogs. The vaulting of the bog surface is entirely dependent on the precipitation and increases with increasing precipitation. But development of raised bogs is not realized if there should come a nutritious supply of water. For this reason the raised bogs are very seldom found in districts with lime. If such water, rich in nutriment, does reach the bog, or more correctly, its "lagg", the horizontal extension of the raised bog is halted. This is one of the reasons why the surface is vaulted and forced upwards.

G. Lundqvist 1950.

Fig. 21. Palses in close-up. These are old and eroded on the surface, thus exposing the peat. The peat growth is then stopped. The development of fissures is characteristic of this stage. These palse mires are found only in the northernmost part of Sweden.

From the district of the high mountains (15).

The ombrogenous peat condition, the moistening of the surface, requires low evaporation in combination with high humidity. In some cases it is regarded as primary, while moistening of formerly dry ground occurred in connection with development of raised bogs at RY V and RY III. It should be mentioned that this problem is not yet cleared up.

From their distribution, palses require for their development at least — 10° C for not less than 120 days of the year. Moreover it must be low winter precipitation, strong wind and bitter cold.

The frost earth

Under the concept frost earth can be included all soils which in a greater or lesser degree have had their primary structure changed by influence of the frost. The changing of the structure, is not always distinguishable. But on the other hand it is often possible to see on the surface if the stratification is so influenced. Then the surface presents quite special forms indicating that flow or some other sort of movement has taken place (fig. 22). Under certain circumstances not yet understood, it happens that the surface is quite even and without any indication of change of shape. The stones and boulders show that

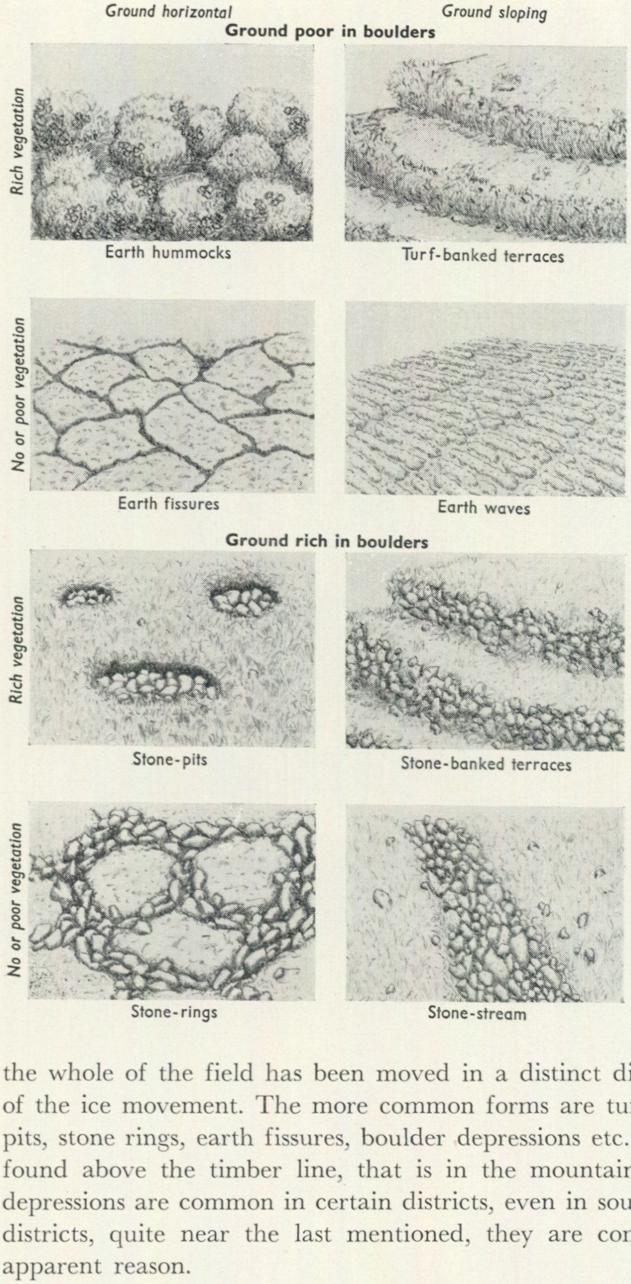


Fig. 22. Schematic picture of some types of frost ground forms and their relation to inclination, vegetation and boulder content. These are the most important geological factors determining the small forms characteristic for the high mountains. After G. Lundqvist in Geografiska Annaler 1950.

the whole of the field has been moved in a distinct direction other than that of the ice movement. The more common forms are turfbanked terraces, stone pits, stone rings, earth fissures, boulder depressions etc. Most of these are only found above the timber line, that is in the mountain belt. But the boulder depressions are common in certain districts, even in southern Sweden. In other districts, quite near the last mentioned, they are completely lacking for no apparent reason.

Of course one asks which factors cause these various types of frost earth to develop. It is especially the mechanical composition of the soil, the density of the vegetation and the conditions of slope of the ground which are of most importance. Under one set of conditions one factor is more important, under another set, one of the others. One can illustrate the relationship between these factors and some of the common ground forms by a schematic picture (fig. 22). But to these forms must be added a number of others which are not given in the figure. They have not yet been satisfactorily studied.

All these forms are to be found in the mountain belt, above the timber line. Only in exceptional cases are they found below this limit. Therefore one can say that the high mountains from the point of view of soil, can be called the region of redeposited earths or the frost earth region.

Striking features in the distribution of the Quaternary deposits of Sweden

A first glance at the map shows certain striking features. These include the distribution of the boulder clay in Skåne (most southerly Sweden) and Jämtland (middle Sweden), the extended bare rock ground in Bohuslän (the West Coast), the general distribution of the mires etc. A short and rapid survey is appropriate and is best begun in southern Sweden.

Striking is the diagonal structure in Skåne: boulder clay in the southwest, normal moraine in the northeast. This distribution depends on the fact that the landscape is traversed by displacements which have in their turn determined the distribution of the rocks. The boulder clay district is, however, not so uniform as the map would suggest. In the southwest we find the "backlandskapet" (meaning approximately "hilly landscape") which is an ablation district with knolls, ridges, depressions etc. giving rise to a chaotic relief. In the depressions there are small lakes or mires, on the hills luxuriant leafy woods, mostly of beech. North of this district the surface is more even or has rounded hills. But it is rare that Skåne is so flat as most Swedes imagine. "Det platta Skåne" is a common expression meaning flat or even Skåne. Out on the cultivated ground there are often small, water-filled pits, the marl pits, from which country people formerly took the lime-rich earth for nutritive purposes. One part of this district is occupied by the Baltic moraine while the other part of the county is covered by the northeast moraine (fig. 23). The composition of the moraine depends on the nature of the rock ground and is very variable in this seemingly uniform district. Noteworthy is the great difference in the distribution of the glacifluvial deposits: in the southeast, extensive areas occur whilst in the northwest they are quite absent in certain parts. This fact, together with their 'angular curve' in the southeast was an argument in the discussion as to whether one or more glaciations had taken place. Moberg and Holst examined this difference in distribution and stated ("De sydskånska rullstensåsarnas vittnesbörd i frågan om istidens kontinuitet." Lund 1899; possibly their own publication), that the course of the hills quite decidedly speaks for only one glaciation. They wrote as follows: "From the northwest the eskers from Småland come down to the Blekinge border, but the influence of the Baltic ice stream begins to assert itself in such a way that several of the eskers depict a wide semicircle, the convexity of which is directed towards the east.

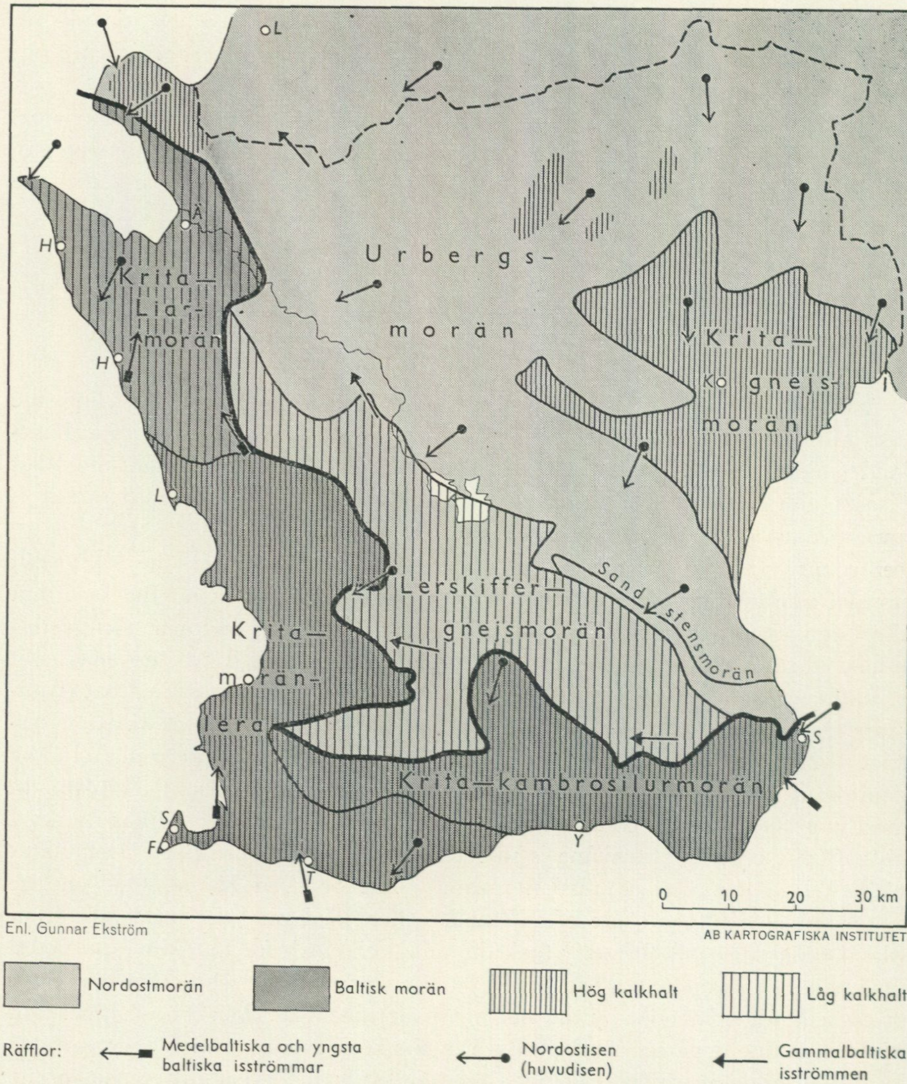


Fig. 23. The moraine district of Skåne according to G. Ekström. Explanation: Nordostmorän = Northeast moraine; Baltisk morän = Baltic moraine; Hög kalkhalt = High lime content; Låg kalkhalt = Low lime content; Räfflor = striae; Medelbaltiska och yngsta baltiska isströmmar = Middle Baltic and youngest Baltic ice streams; Nordostisen (huvudisen) = Northeast ice (principal ice); Gammalbaltiska isströmmen = old Baltic ice stream.

From these facts about the two esker systems it is not possible to conclude otherwise than that both of the ice streams as well as the two esker systems, must have been simultaneous. In any case the Baltic ice current could not have changed the northern esker systems direction, nor could both of the esker systems flow together as we have here proved that they really do.

This evidence against two glaciations we consider quite conclusive. It is up to the geologist or those geologists who still wish, regarding Sweden, to vindi-

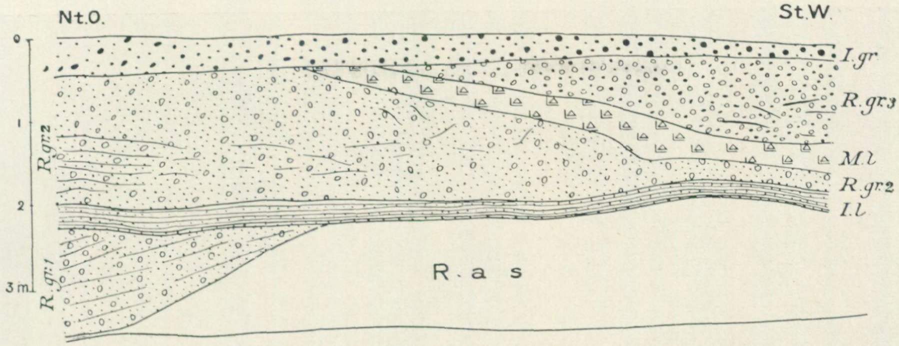


Fig. 24. Schematic section N of Bjäresjö kyrka, Skåne. Most important are the strata of ice lake clay (I.l) and boulder clay (M.l). — R. g. = glacifluvial gravel. This stratification is common in the districts of the Baltic ice stream in Skåne, that is, broadly speaking, the dark grey area on the previous figure.
After Sv. geol. unders. Ser. Aa Nr 142.
From the district of southwestern Skåne (1 a).

cate the inter-glacialistic interpretation, to indicate clearly how it can escape being disproved by this argument." (I have quoted so much in detail, here translated from the Swedish, because the paper by Moberg and Holst is very difficult to obtain.)

The descriptions to several of the map sheets from Skåne mention that glacifluvial gravel is interbedded in the boulder clay or, more cautiously stated, they are overlain by the latter. A section showing an example of such a stratification is fig. 24 from the map sheet Ystad but published in the adjacent map sheet Sövdeborg (north of Ystad). Regarding the numerous glacifluvial deposits in the last mentioned area Munthe (1920) writes, after pointing out that the land ice passed over the "Klingvallsslätten" (the Klingvall plain) etc.: "The mentioned appears to demonstrate, that a connection once existed between the small plateaux on the Klingvallsslätten and the extended gravel plains with about the same stratification on both sides, in particular Våmb-Sjöbofältet to the north and the widely spread gravelly-sandy fields to the southwest: or in other words, these larger fields have earlier continued over the Klingvallsslätten with its small plateaux, and their isolation has thus taken place later as a consequence of a considerable erosion." (The whole of this section is printed in italics.) If I do not misunderstand this text it means that the mentioned gravel fields at Ilstorp, Everlöv and others are erosion remnants of a very large delta (the places mentioned are situated on the map sheet Sövdeborg).

This supposition appears rather improbable, if one is unacquainted with the geological details of the district. But I have discussed the problem with two Skåne experts, the geologists Ekström and Mohrén, both of whom have local knowledge, and according to their conception it is not possible to explain it in any other way because the layers wherever one can observe them, go horizontally out into the air. Therefore it is necessary to submit to the facts, but then the next question must be: where is the source of these enormous quanti-

G. Lundqvist 1949.

Fig. 25. The vicinity of the well known waterfall Forsakar, Skåne. The area of the picture is situated on the northern side of Mount Linderödsåsen and is strikingly hilly.

From the moraine district of southern Sweden (3 *e*).

ties of gravel and sand of which the maps in reality give only an incomplete picture? A study of the general map shows that large parts of Småland (north of Skåne) are very poor in glacifluvial deposits and sand, but in the northern part they are much more abundant (see p. 43). Therefore it is not unreasonable that the mentioned material was transported out into the Baltic off the coast of Blekinge (east of Skåne) etc. It there came under the influence of the Baltic ice streams which conveyed it to southeast Skåne and was redeposited by the glacifluvial rivers. This is also indicated by the fact that the Baltic material is rather sparse in the southeastern part of the county.[1]

The district northeast of a line between about Stenshuvud in southeastern Skåne and Hallandsås in the northwest is mostly covered by northeast moraine. The constitution of this varies according to the proximity to the Cretaceous area of the Kristianstad region in the northeast.

[1] These very complicated phenomena have in recent years, again been taken up in discussion. In this connection, another Skåne geologist, H. Möller, has given me the following summary: "Observations from the late years show, that the gravel and sand deposits cannot be erosion remains. Wennberg (1949) states among other things, that if there has been an erosion the stone quantity must be greatest on the lower niveaux, but this is not the case. Referring to the morphology, Johnsson (1956) interprets the limit of the Sjöbofältet as an ice contact slope. Woldstedt remarked on a journey in Skåne in 1955, that the Sjöbofältet is not an open built delta, because delta stratification is lacking. In the Vomb basin the land ice must have been lying a long time as dead ice and the glacifluvial deposits have probably been deposited in connection with a dead ice, rich in crevasses (Johnsson). Later erosion has been of very limited extent, except in the narrowing northwestern part of the Vomb basin as drillings recently carried out there by Ekström show.

The main part is, however, Archean material, since the Cretaceous material is crushed very rapidly. It is remarkable how the district is traversed by deeper or shallower valleys running SW—NE (fig. 25). They are very prominent on the geological map on the scale of 1: 50 000, because mires and glacifluvial deposits often occupy them.

The large islands in the Baltic, Öland and Gotland, are very distinctive standing out on the map beside the adjacent district of Småland by a lack of the blue moraine colour. On the islands, the moraine is all developed as more or less distinct boulder clay. Further more, the bed rock is to a large extent uncovered giving rise to the characteristic "alvars". In southern Gotland the landscape in one zone is quite otherwise: cultivated ground and leafy meadows ("lövängar") often lie directly on the bare rock of the map. This is, however, Silurian mudstone and shale that can be so loose that it is often similar to the boulder clay. These differences in the bed rock and the consequences of it, account for the great differences between northern and southern Gotland.

The great uncovered rock area on southern Öland is called "Stora Alvaret". The earth layer is there commonly extremely thin or, more accurately, concentrated in the often rather deep fractures in the rock ground. Therefore the species-rich vegetation is mostly attached to these fractures which gives the red surface a green checkered aspect. The origin of this "Alvar", as far as it concerns the absence of forest and such like, has been intensely discussed. It has been guessed that earth flow, the blowing away of the soil by wind etc. has been responsible. But the most important cause is surely browsing by animals; a good indication of this is that nowadays when browsing (by horses and sheep) is very insignificant compared with former times, the vegetation shoots up to a height. It has been mentioned that this district should be a nature reserve as exemplifying a Swedish "alvar". In this case it is absolutely necessary that the browsing should continue.

One of the most striking features in south Sweden is the appearance of the inner parts of southeastern Småland, the counties of Kalmar and Kronoberg, in relation to adjacent districts. The counties mentioned are very poor in big glacifluvial deposits. The existing ones are short and narrow esker stumps. Sharply limited against this esker-free or in any case esker-poor district, follows the esker-rich area to the north. In this small scale too, 1: 1 mill., the eskers and the other glacifluvial deposits show an appreciable width. Of course one may wonder what the cause of these great differences is and suspect that there is a fundamental divergence in the genetic conditions. The district poor in eskers is very flat; it has been interpreted as the Cretaceous peneplain which after a small break in slope continues into Småland as the sub Cambrian peneplain at Kalmarsund (Asklund 1928). The surroundings, however, in which the glacifluvial deposits play an important role, are deeply dissected. This is especially striking, for example, in the zone Vetlanda—Vimmerby. The cause of this connection namely, flat surface forms and insignificant eskers and vice versa is as follows. In the more broken terrain the ice becomes more fractured into pieces and in the ice crevasses between these pieces large ice streams bring with them immense masses of gravel. One experience from the mapping of the moraine types is that particularly in the big valleys, the moraine cover, that is to say the initial material for the glacifluvial deposits, is thickest. Therefore the statement that the greater the valleys are, the greater the glacifluvial may be is by no means absurd. And the converse is also true that the less marked the surface forms the more insignificant are the glacifluvial deposits.

In connection with these problems must be mentioned the immense deltas outside the valleys at Målilla and Hultsfred (east of Vetlanda). They give the impression that they are deposited in the front of an ice margin. The height above the sea is about 120 m and therefore they should mark a strand-level at that elevation. But as far as we can now estimate this elevation is somewhat too low for the development that is now supposed. HK is namely, here determined to be about 125 m above sea level (E. Nilsson).

In the continuation of the Lake Vättern depression towards the south, which is partly in the Lagan valley, extensive sand areas are found. It is undeniable that the areas are made up of sand but locally, where sections are more deep, one can see that the material is coarser and seems like glacifluvial gravel. Therefore it is not unreasonable to suppose that these fields originally were glacifluvial deposits. In certain parts of this district the material is of such a grain size that it is blowing away or, more correctly stated, has blown away, before being bound by the vegetation. Such eolian sand districts are Slättösand, north of Lake Bolmen or the district around Store mosse (a large raised bog) north of the mentioned lake.

The district east of Halmstad down towards Hässleholm (in the SE) is distinguished by a great abundance of mires. The peat land area, as a percentage of the total land area, is there 20—40 % or more. Among the better known areas in this district is the "Tönnersjöheden" which is so richly overgrown with heather that it is nearly impossible to distinguish the mineral ground from peat land. Even at this stage it may be remarked that this mire-rich district continues as similar but isolated districts to the north through southern Sweden and to the inner parts of Norrland even beyond Kiruna north of the Polar Circle.

A feature that really brightens up the map is the large rock area in the western and eastern parts of southern Sweden, that is, Bohuslän and its surroundings on the west coast, and the vicinity of the plain in Östergötland down to Västervik on the east coast. In general both of these districts are characterized by rather flat rock areas traversed abruptly by fracture valleys. Commonly there is clay, more seldom sand or mire, on the bottom of these valleys. The directions of the fissure valleys, especially in Bohuslän is in the main (two-fold): NNW—SSE and NE—SW. Ljungner, who especially busied himself with the morphology of Bohuslän, divided them into coast fractures and fjord fractures. Along the coast, at least in the northern part, there is a dike of rhomb-porphyry that continues into Norway. By its relation to the stratigraphy in the Oslo field (an internationally known petrographical dis-

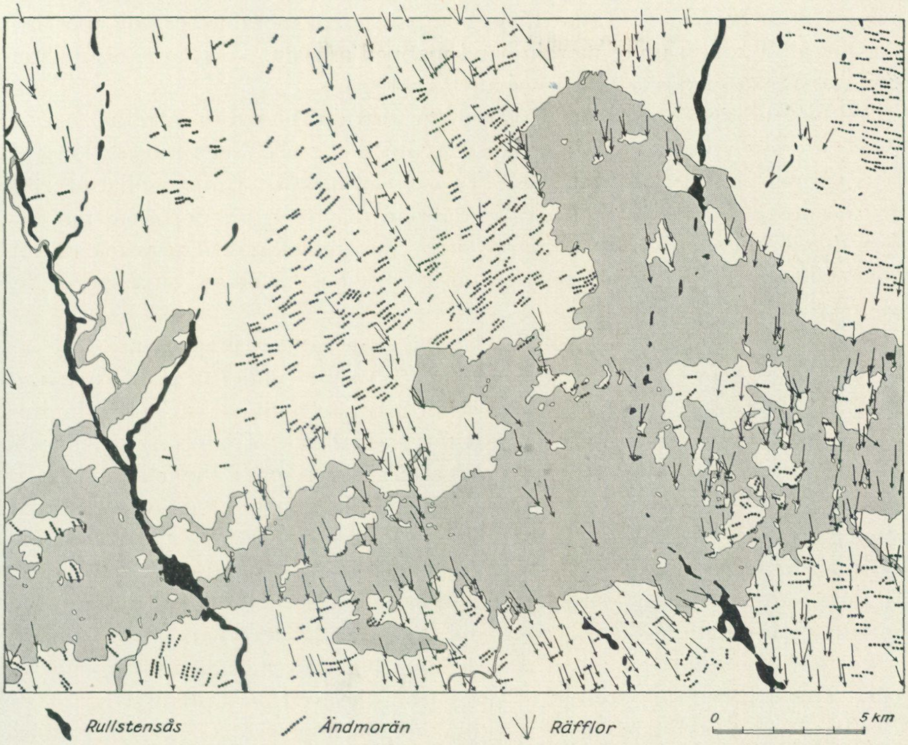


Fig. 26. Terminal moraines (ändmoräner), eskers (åsar) and striae (räfflor) on the geological map sheet Västerås. The moraines swing parallel to the eskers while the striae are orientated at right angles to them. In this way the estuaries along the eskers become visible on melting and therefore the area along the eskers is exposed first.
After Sv. geol. unders. Ser. Aa Nr 196.
From the clay and moraine district of the Mälar basin (11).

trict), it is possible to determine its age as Permian. The fjord fractures appear for certain reasons to be of post-Permian age.

Within the Östergötland part of the district the fractures belong to two age groups according to Asklund (1923), namely, horizontal fractures of sub-Jotnian age and fault fractures of Devonian age. The Östergötland district too is distinguished by extensive rock surfaces traversed by the clay-filled fissure valleys. From a scenic point of view there is a certain difference between these districts because Bohuslän is more bare and the forest type, where there is any forest, is quite different.

Large clay plains in Västergötland (between the lakes Vänern and Vättern) and Östergötland are also prominent in South Sweden. But unfortunately one of their characteristic features is not visible on this map: the largest clay areas lie in front of or, in any case, in connection with the great Fennoscandian moraines. These extend in general through Dals Ed—Ödsköldsmoar—Hindens udde (a cape in Lake Vänern)—Skövde—Motala—Norrköping. The continuation is not yet satisfactorily determined. From the point of view of the map it must be remarked that these Fennoscandian moraines or end moraines are not always built up of moraine and mapped as such. To a large extent they are glacifluvial deposits with associated sand tracts.

Within the above mentioned clay plain districts, bed rock is rather scarce. The outcrops appear as flat surfaces on which the clay rests directly, though it is seldom possible to check this. The cause can be that this oscillation zone has been exposed to such a strong ice erosion that even the deposited moraine was dug up again and taken charge of by the ice streams. The whole of this zone in front of the mentioned ice sheet must be the object of a special investigation.

The Mälaren basin (west of Stockholm) is a rather comprehensive, if not to say vague term but despite this its scope is easy to understand. It is characterized by extensive clay plains with small moraine hummocks, low rocky hills and eskers. Nowhere else in Sweden is this special type of landscape met with: high and narrow eskers which purposefully sweep over the clay plains in nearly a N—S direction. What is not seen on this map but only on the glacial geological map (e.g. Atlas över Sverige map sheets 21—22), is the broad zone of small terminal moraines which are met with on both sides of Lake Mälaren in the north and south. These terminal moraines are seldom higher than a few metres, their length less than 100 m and their breadth less than 10 m. In many cases they are visible only as a row of large boulders sticking up through the clay. This is very nicely seen in the area from the west of Västerås (fig. 26) to Ekolsund (east of Enköping). It is this moraine type that G. De Geer called annual moraine and Hoppe calving moraine. Probably one of them is correct in certain cases and the other in others. A general solution to the riddle seems to be very difficult to find.

The mentioned district, the Lake Mälaren basin, is in the east bounded by one rich in rock exposures that extends through Södertörn (south of Stockholm) and into Uppland north of Stockholm. It passes without a definite boundary into the archipelago ("skärgården") which eastwards disappears beneath the Baltic, only smaller and smaller knobs of rock emerging above sea level.

North and south of Lake Mälaren the eskers, which are so characteristic for this district, continue often 100—150 km, while at the same time the clay plains diminish and become of much less significance in the area. Towards the north the clay surface is covered by large flat peat lands.

Norrland, or better the district north of the limit of the Norrland terrain ("Norrlandsterrängens gräns"), a morphological limit between the southern district with low hummocky terrain and the northern with large hills, is to a great extent more uniform than South Sweden and this depends not just on the degree of accuracy of the map. One immediately observes three elongated zones: the coast zone, the interior land and the mountain range. Within the inland parts there are, however, three smaller and more distinctly bounded districts: the Hedemora—Borlänge plains, the Siljan environs and the boulder clay district in Central Jämtland round Lake Storsjön. An important feature

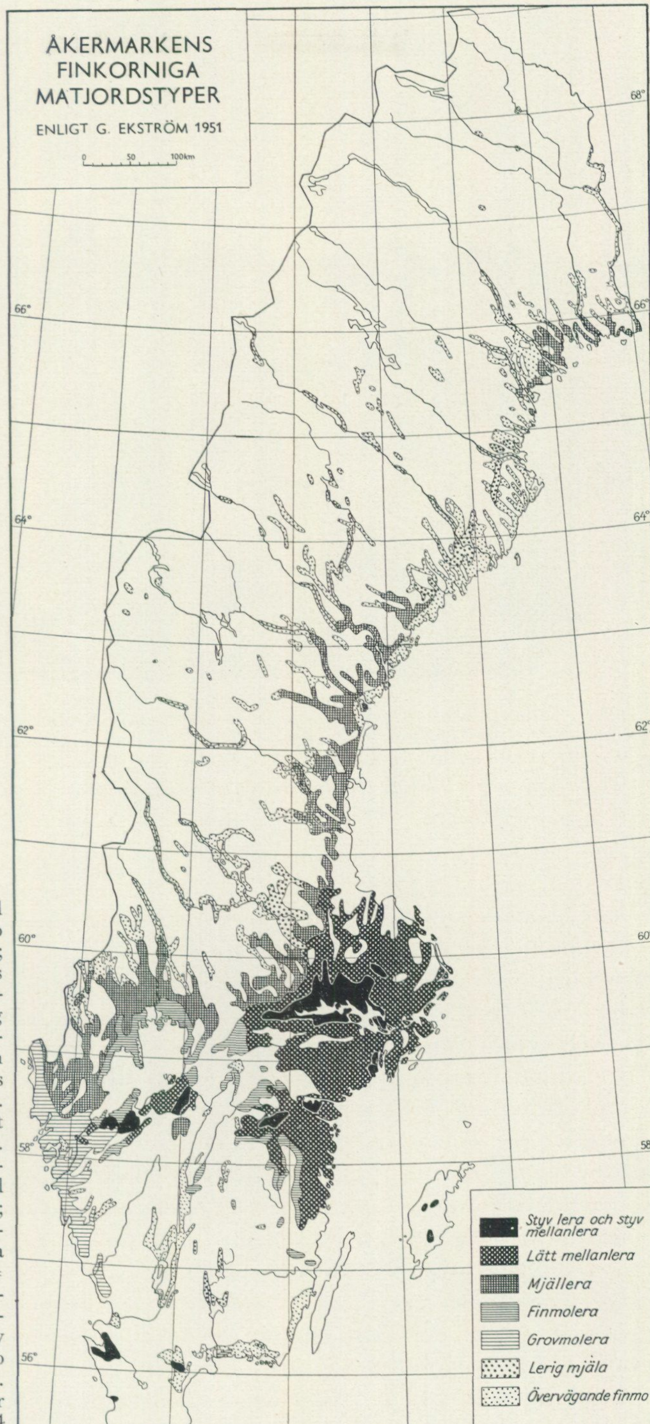
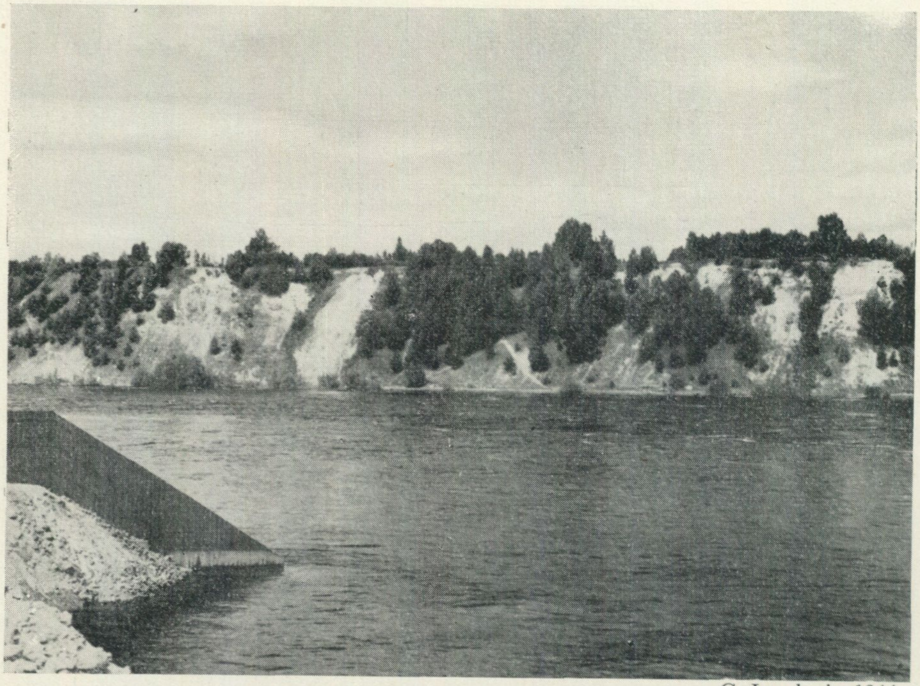


Fig. 27. Map of cultivated soils (surface soils). The map illustrates only the top soil; a map of the subsoil types would be somewhat different. The main governing principle that the most heavy clays occur in southern Sweden and the light soils in Norrland, is unchanged. The zonation along the coast of Norrland is very distinct. — Styv lera och styv mellanlera = heavy clay and heavy intermediate clay; lätt mellanlera = light intermediate clay; mjällera = silty clay; finmolera = very fine sand-clay; grovmolera = coarse fine sand-clay; lerig mjäla = clay silt; övervägande finmo = mainly very fine sand. According to Atlas över Sverige, map sheets 63—64 (G. Ekström).



G. Lundqvist 1944.

Fig. 28. Sediment cliffs (nipor) at the river Dalälven opposite to the Avesta ironworks. The sediments here are very fine sand and silt. The clay strata are very thin. These formations are characteristic for many of the large rivers in the shore zone of Norrland.

From the clay and moraine district of the Mälar basin (11).

of the rest is that the very heavy clay is lacking within Norrland or occupies only small areas (fig. 27).

The coast zone is distinguished by deep valleys, often of fjordlike type, with sediment fillings. These sediments are mostly sand, very fine sand or silt. A consequence of the great depth of the valleys and the great quantity of the sediments is that the river banks are high and steep, often vertical. These are the well known "niporna" which distinguish a strip inside the Norrland coast. Their situation is determined not only by the steep slope but by a certain grain size of the sediments, a size that makes solidarity possible to a certain degree. This grain size zone is also dependent on the situation in relation to the highest marine limit or better, the highest shore line (HK) farthest up the valley floors, that is to say, the former fjord bottoms. To some extent connected with these "nipor" (fig. 28) are also ravines, more or less branched small valleys of "Säterdal" type (fig. 49). The clay plains are also found within this coast zone but they are commonly flat with relatively thin sediment covers. They are to be found nearest the coast, that is, outside the silt zone, inland from Umeå (south of 64° N latitude) and in Norrbotten.

Other districts are, as shown on the general map, rich in sand or gravel. These sediments occur partly as wave-washed gravel, sand or cobbles on the great slopes, or as sand fields, either distal to the above mentioned or as outwash from glacifluvial deposits. Examples of the latter are to be found NNW of Söderhamn, at Sidensjö (W of Örnsköldsvik), north of Skellefteå, Piteå (all of them towns along the coast) and other localities.

Within this coast zone there are terminal moraines in many places but only as small groups. These occur in the neighbourhood of Skog, Gnarp, Offer (north of Härnösand) etc. and at numerous localities in Västerbotten. Therefore it is peculiar that the terminal moraines are so extremely common in the coast zone of Norrbotten (compare the glacial geological map of Sweden, "Atlas över Sverige" map sheets 21—22). Judging from the investigations of Hoppe and Fromm they are of about the same order as those in the Lake Mälaren basin but their length is greater. The cause of this is possibly that they are not always covered with young sediments in the same degree as in the Lake Mälaren basin. Therefore their whole development is clearly visible.

Another feature of the coast zone by which it may be separated from the inland strip is the relative abundance of bare rock surfaces. This is especially striking in the environs of Örnsköldsvik (north of 63° N latitude). One gets the impression there, as in Bohuslän, that the form of the rocks — high, abruptly steep knobs — is of great importance in determining whether the rock ground shall be exposed over such a large area or not.

The interior land is rather uniform, as mentioned above. The most important earths are moraine, glacifluvial deposits with very different grain sizes, and mires. The variations are mostly caused by the changes in the area of mire excluding the more extensive districts previously mentioned. Most striking is the very mire-rich zone that extends from western Dalarna through the middle part of Jämtland, the environs of Vilhelmina, Muddus, Sjaunja (both at about 67° N latitude) to east of Torneträsk. We see on the map that the mire-rich areas in this zone are not connected along the total distance but concentrated around certain centres. The cause of this distribution is not known but it is surely of great importance that these mire districts are very flat. The drainage must therefore be very insignificant, the water partly sinking into the mineral ground, partly evaporating. It is also striking that the zone to the west is so extremely poor in mires.

The most southerly of the local districts of the interior land contrasting with the common monotony is the sediment plain Krylbo—Borlänge. It is found immediately adjacent to the Norrland limit ("Norrlandsterrängens gräns") which here, fjord-like, breaks into the morphology of Norrland. Therefore it may just as well be included with the southern sediment district. Characteristic of this "fjord district" is, however, the silty sediment which often has an exceptionally distinctive constitution. It is very seldom that silt is so pure as here, the grain sizes 0.02—0.002 mm completely dominating. This earth is certainly distinctly varved, but the clay layers are very thin in the often immense silt beds.

The neighbourhood of Siljan is strikingly rich in glacifluvial deposits within the nearly circular valley Mora—Orsa—Ore—Boda—Rättvik. They are mostly deltas with a very complicated stratification and this is especially the case for the large field northeast of Orsa. There the material varies from rolled boulders a metre or so across down to eolian sand. Of course the last sediments are of quite another period of deposition, another generation, than the glacifluvial ones. Also the stream ridges which traverse the delta and mark the stream directions towards the southwest and southeast, are very characteristic. In the eastern part of the circular valley, that is in the Boda valley (south of Ore), occur Silurian deposits (especially limestones and shales etc.). In connection with these occurrences small areas of boulder clay are met with. A somewhat larger area is however, to be found east of Rättvik (southeast of the village of Ingels west of Lake Ljugaren). The Silurian material disappears very rapidly towards the southeast (more than half way to Falun). That means that the crushing down of the boulders is rapid but the tendency is, however, noticeable in the pH-values on the map sheet Falun (Kulling 1948, fig. 31).

The boulder clay district in Central Jämtland (round the Lake Storsjön) is in certain respects restricted to the Cambro-Silurian rocks. This is not uniform but broken up by means of fine sandy moraine areas where the moraine, however, can be made up, to an appreciable degree, of only Cambro-Silurian material such as Silurian shale (concerning this comp. p. 14). Regarding this district, it ought to be mentioned that there is often found an easterly moraine or boulder clay sometimes resting on a westerly one. Both types are identified by their boulder material.

In this district there are two further details of interest. First of all, the glacifluvial deposits which are elongated in two directions, SE—NW and NE—SW. Probably these correspond to different directions of movements of ice streams. These eskers are especially striking in the area north of Lake Storsjön. The other feature is represented by the mire richness in the district southwest of Strömsund (south of 64° N latitude). Here, considerable mires may be found both on the flat valley bottoms and on the moraine slopes. They are cultivated to some extent.

Soil regions of Sweden

Of course the country may be divided into a number of districts or regions characterized by different soil types. This was first tried by A. G. Högbom (1906) in "Norrland". Even if his boundaries are not so sharply determined, there are no difficulties in understanding what he meant by them.

"1. The high mountains and region of long lakes.
2. The Silurian region.
3. The moraine slopes and the large mires region.
4. The river and sea deposits region.
5. The coast and archipelago region."

The classification is not quite consequent as the basis of it changes many times. It is thus both geologic and geographic. One ought, to be completely

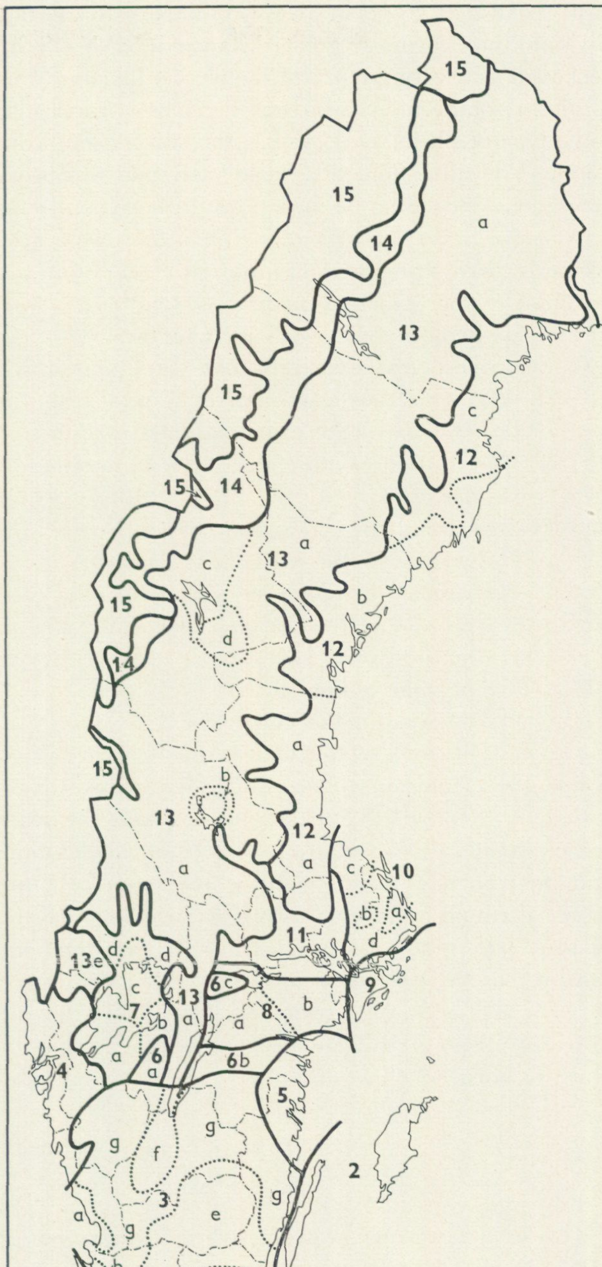


Fig. 29. Division of Sweden into soil regions. The numbers and the figures refer to the districts described in the following text. The same applies to the photographs and some other pictures.
According to Atlas över Sverige, map sheets 15—16 (G. Lundqvist).

just, recall that Högbom gives prominence to the fact that in such a strip-like division that covers a great distance in a N—S direction, climate must be reckoned as a very important factor. To illustrate this one may remember that a silt in southern Dalarna has far more practical significance than just the same type of silt in, for example, the district south of Pajala north of the Polar Circle. The silt is namely a "cold" soil, and this property becomes more or less prominent depending on variations in the type of climate.

A more strict geological sub-division, even applicable to Norrland has formerly been attempted (Lundqvist 1943), but not even in this is the importance of the climate apparent.

The sub-division mentioned is as follows:

"A. The zone of the secondary soils (the mountains).
B. The district of the supra-aquatic deposits (the interior of the land).
   a. The district of the coarse grained moraines.
   b. The district of the fine grained moraines ("Silurian moraines" and boulder clays).
C. The district of the sub-aquatic deposits.
   a. The district of the ice lake sediments.
   b. The district of the ice sea sediments (the coast region).
      1. The zone of the marginal deltas and the eolian deposits.
      2. The quick clay zone.
      3. The zone of the silts.
      4. The zone of the clays.
      5. The zone of the shell beds."

For a discussion in greater detail about this survey the reader is referred to Lundqvist 1943, p. 152. In any case it must be admitted that the subdivision is very rough and schematic. A more detailed subdivision therefore was tried and this can be applied to the whole country (Lundqvist 1953). Fifteen different main districts are discerned but many of them must be further subdivided into subdistricts, sometimes to the number of 7 (fig. 29). In these cases it may of course be discussed whether one or other of them would not be better classified as a district. In the following, a short description of the different districts and subdistricts will be given. They are numbered from south to north as illustrated in fig. 29.

1. Southwestern Skåne

(Sydvästra Skåne)

This is a naturally uniform district, whose boundary towards the rest of Skåne passes diagonally from the vicinity of Ängelholm to Simrishamn. The dominating soil is boulder clay (65 % of the land area) that is mostly rather lime-rich, especially the districts situated nearer the coasts. The boulder material is very various on account of the varying rock ground (Ekström). Farthest northwest and down to Landskrona in the south occurs Cretaceous-Lias moraine. The boulder clay along the remainder of the west coast of

G. Lundqvist 1948.

Fig. 30. Glacifluvial sediments and kames in the vicinity of Ravlunda in the eastern part of Skåne. Smoothly rounded forms and low stone "fences" characterize this scenery.
From the moraine district of south Sweden (*3 e*).

Skåne and down past Ystad is dominated by Cretaceous material and is therefore very lime-rich. The continuation to the east, to Simrishamn, is Cretaceous and Cambro-Silurian moraine. The whole of the district mentioned hitherto is occupied by Baltic moraine (comp. fig. 23). The north-east moraine of the district further inland, that is to say from Svedala to Ringsjön, the great lake in the middle of Skåne, is dominated by shales and gneisses and has thus a lower lime percentage.

Concerning this district (i.e. Southwestern Skåne) it should be further mentioned, that sand and glacifluvial deposits occur to such a large extent (70 % of the land area) that it is easy to distinguish a sub district, here called The sand district of the Vombsjö basin, "Vombsjöbäckenets sandområde".

The vicinity of Svedala is, from the morphological point of view, the very interesting "backlandskapet", meaning approximately hummocky landscape. It is deeply undulating, rich in small lakes and small mires, and is best characterized as a kind of ablation moraine.

The Ravlunda area (fig. 30), "Brösarps backar" (the hills of Brösarp) and others resemble Svedala from a morphological point of view but are made up of glacifluvial material.

Regarding the sedimentary clays in Skåne, two special phenomena are noteworthy. The glacial clay is in certain areas found on the hills. It is then called "platålera" which may be translated as "table land clay"; it was described by Westergård in 1906.

His description is as follows: "Within southern Skåne there is, above the highest marine limit in several places, a varved clay which on the moraine heights, and perhaps with a predilection for the highest of them, constitutes remarkably even fields and may therefore suitably be called "platålera". The thickness is commonly some metres but it can reach 7.7 m. But this figure is, however, possibly somewhat too low." From the 'platålera' fields short but deep ravines sometimes plunge down towards the surrounding areas. To the description may be appended a sentence from Munthe (1920): "Especially noteworthy is that only within some boundary areas is the 'platålera' covered by moraine or glacifluvial deposits and consequently has not been much over-ridden by the land ice." Fig. 31 illustrates the distribution of the "platålera" in Skåne. On the geological maps it is marked like other glacial clays, because the division that I have made at the writing-table may be incorrect at some locality. Most remarkable is that the "platålera" is not to be found everywhere in Sweden in supra-aquatic situations. Its deposition milieu must have been very common during the great wastage period. I cannot remember having seen it elsewhere than on a few of the great Fennoscandian end moraines northwest of "Valle härad" (p. 62) on the geological map sheets Lugnås and Lidköping (SE of Lake Vänern).

The second remarkable fact hinted at above is the following. Within certain districts where the glacial clay is varved, the varvity can be very peculiar being of a disputed nature (G. De Geer, Sigurd Hansen). These varves have been denoted "dygnsvarv", that is, approximately translated, day and night varves as distinguished from the annular varves. The name "dygnsvarv" is, however, misleading because these varves probably are not deposited during one day and night but under certain climatic conditions during short periods. Of course it is quite clear that our interpretation of the rate of the ice wastage must be very different if the varves mark such short periods or if they are annular varves. The problems belonging to this category are not yet finally resolved.

2. The limestone isles in the Baltic
(Kalköarna i Östersjön)

The limestone isles of Öland and Gotland in the Baltic have a nature so distinguishable from the mainland conditions that no one can fail to observe it, even during a passing visit. Both of them are well known through the many researches by H. Munthe. Their special nature is principally conditioned by the bed rock, mostly Ordovician limestone on Öland, Silurian limestone on northern Gotland and Silurian shale and sandstone on the southern part of that island. The moraine is developed as boulder clay, but on some areas it can be very stony or boulder-rich (compare fig. 5). This material is largely transported by the land ice from the mainland or from the Archean rock ground of the bottom of the Baltic. Thus on the northern part of Gotland are boulders of porhyry and others which for a long time were interpreted as

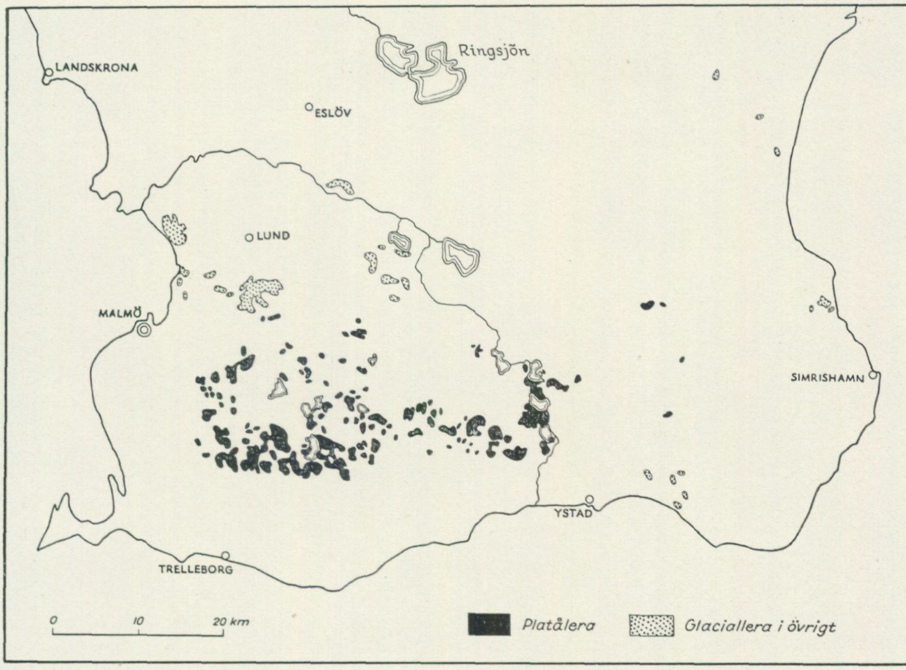
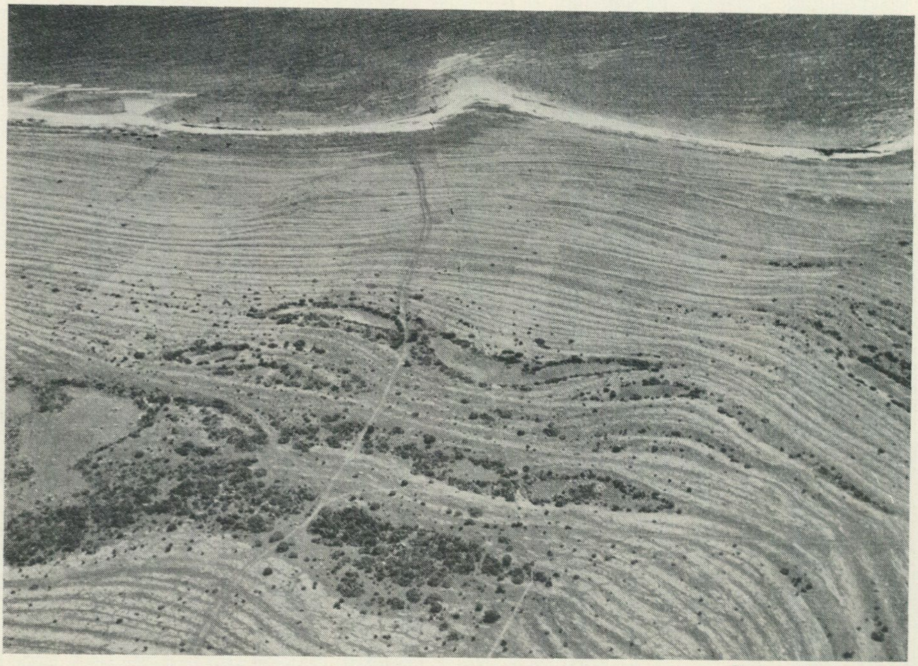


Fig. 31. The occurrence of "platålera" and other glacial clays in Skåne according to the geological maps. The milieu suitable for the deposit of the platålera (approximately equivalent to top clay) must have existed over large parts of the supra-aqueous Skåne. Where such clays are not recorded on the geological maps they may possibly have been overlooked during the mapping.

From the district of southwestern Skåne (1 a).

Dala porphyries. However, by means of the investigations of Hedström, it is established that these must emanate from an area northwest of the island, now on the bottom of the Baltic. The glacifluvial deposits are to a large extent so strongly redeposited, that they are mapped as wave-washed gravel, over an area of about 30 % of the land area. Especially is this valid for the western side of Öland, on the "Västra landborgen" that is initially an esker in part. Here it must be remarked that formerly too much attention was given to the regulation that only material more than 1/2 m thick should be mapped. In these parts of the district redeposition is more extensive than the value mentioned. The mire area is relatively large on Gotland (about 10 %) but the main part of it is nowadays cultivated and as a mire completely transformed. But the mires in their native state are commonly fens, mostly Cladium fens, while raised bogs are very rare (e.g. at Fardume träsk, on the southern part of the isle of Fårön etc.). Their cupola form is very insignificant due to the small precipitation (400—500 mm/year).



G. Lundqvist 1948.

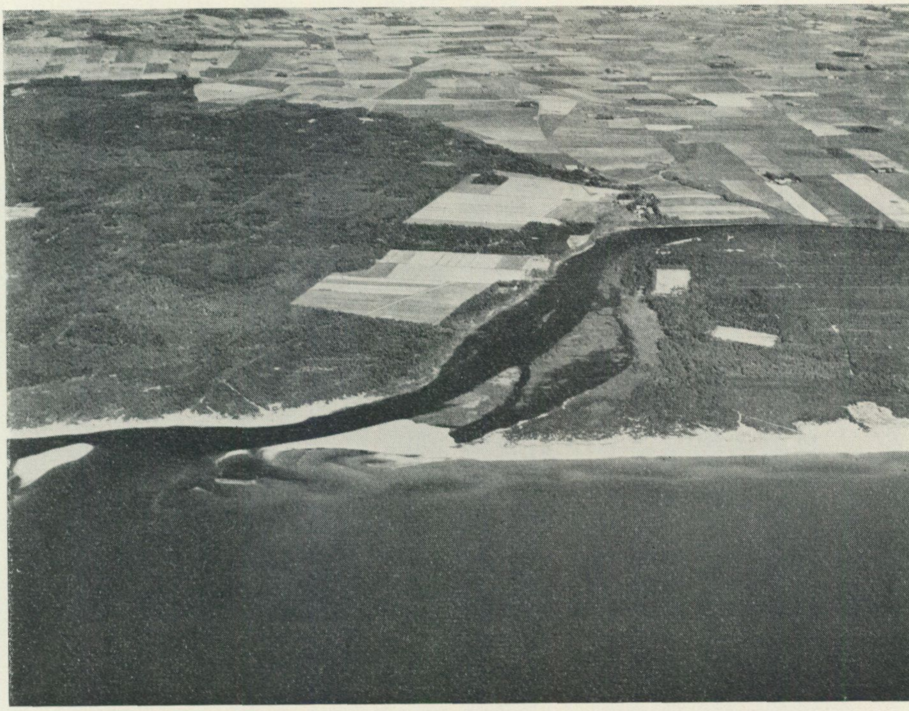
Fig. 32. Part of the shore of Gotland near its southern tip. The whole of this part is covered with banks of shore gravel. Over great areas of Gotland the shore gravel is a very important soil; generally it is more overgrown than here. Such shore gravel fields are very common on Öland too and on many low situated districts near to the recent shore-line, but it is not always that the strand banks are so distinct as here.

From the limestone isles in the Baltic (2).

3. The moraine district of South Sweden
(Sydsveriges moränområde)

The district is remarkably large because it stretches from southwestern Skåne all the way to Visingsö in the Lake Vättern. A first glance at the map shows that this district is rather heterogeneous, though certain features give it unity. The division into not less than 7 subdistricts is thus well-grounded.

3 a. The sand plain of the Halland coast region *(Hallandskustens sandslätt)* begins at Hallandsås in the south and continues about as far as Varberg. The sand dominates completely with its 50 %. A short distance inside the shore line and conformably with it, is found a series of terminal moraines, marginal eskers and deltas of marginal delta type. Therefore one may venture the supposition that the sand has been washed out by the glacial rivers in front of the land ice that finished in the sea. Later this sand and partly the glacifluvial material has been reworked by the breakers, to produce the present final product. The breakers' shaping of the coast fringe appears very obvious especially where the rivers finish up crossing the sand fields, compare, for example, the rivers Lagan (fig. 33), Genevadsån etc. There, the north-flowing coast current has displaced the mouth to the north,



G. Lundqvist 1949.

Fig. 33. The mouth of the River Lagan on the west coast. The mouths of the rivers are often more or less displaced in this manner by the current following the shore line. In this district the current flows north, i. e. going towards the left on the picture.
From the moraine district of South Sweden (3 a).

so that the water-course appears to be abruptly broken off. The moraine (15 %), clay (20 %) and uncovered rock (10 %) form the remainder that is of any significance. The clay is unvarved or to only an extremely subordinate degree varved, being deposited of course in salt water. Therefore a firm geochronology would be very difficult to establish within this district.

3 b. The clay and sand district of the Ängelholm plain *(Ängelholmsslättens ler- och sandområde)* could for the same good reason have been included with "1. Sydvästra Skåne". The sand is 35 % and the clay 40 %. Even in this district it is not possible to realize the geochronology we had hoped to get from the clay (Tullström 1954).

3 c. The sand district of the Kristianstad plain *(Kristianstadsslättens sandområde)* is in a certain manner analogous to the Laholm plain towards which it is directed. But the proportions between the various soils in both of these districts are rather different, the Kristianstad plain having 35 % sand and 10 % clay. It is within this district that ground destruction by the encroachment of eolian sands is said to be of such great dimensions. This is not improbable because eolian sand is rather common here, especially along the coast fringe south of Åhus. 10 % is mire but this value is mostly determined

G. Lundqvist 1945.

Fig. 34. Cultivated ground in Kallgårdsmåla, northern Blekinge. The numerous piles of stones, "hackarrör", characterize the cultivated grounds in the woodland of Blekinge. They illustrate the richness in boulders of the moraine and it is rather clear that these immense boulder mounds cover a large surface and make cultivation less profitable.

From the moraine district of South Sweden (3 e).

by the fen meadows round the well known bird lake Hammarsjön outside Kristianstad. The 25 % moraine is rather lime-rich. Probably the moraine is in part really developed as moraine marl originating in the underlying bed rock, the Cretaceous rock ground.

3 d. The rock and clay district of Blekinge *(Blekinges berg- och lerområde)* belongs to the coast region where the bed rock is often exceptionally well exposed, to about 40 %. The moraine occupies about 35 %, a leading feature of which is its high boulder content or high frequency of large boulders (fig. 34). In the depressions in this district 5 % clay is found providing the most important cultivation soil. Of more general interest for this district is that the forest is dominated by beech *(Fagus silvatica),* whilst in addition there is, by Swedish standards, an unusual abundance of hornbeam *(Carpinus betulus).* Thus the zonation hornbeam—beech—pine forest from the shore line and towards the interior of the district is very distinct. The varying constitution is very well worth a study from the point of view of its history of development.

3 e. The true moraine area of the southeastern part of the district *(Sydöstra delens rena moränområde)* is unusually uniform because there is 70 % of moraine, 15 % mire; all the other constituents amount to 5 % or less. Especially in the frequency of the glacifluvial deposits here and

in the adjacent districts is the difference very sharp. This characteristic relation was observed first by the geological mapping of these parts of the country in the 1870's and 1880's. It is explained by saying that the development of larger glacifluvial deposits requires more broken surface forms than there are in this district (comp. p. 43). This is in reality one of the most extensive plain areas of South Sweden (Magnus Lundqvist 1957). The cause is that it is an old peneplain from the Cretaceous period which continues smoothly from the sub-Cambrian peneplain in the east at Kalmarsund etc. (Asklund 1928).

The glacifluvial deposits in this district are exceptionally small. The material is badly sorted, seldom stratified and mostly of local rock types.

3 f. The sand and gravel district of northwestern Småland *(Sand- och grusområdet)* stretches from Lake Vättern along and around the Lagadalen, the valley of the river Lagan. Hère, immense quantities of sediment accumulated, and one can travel km after km over flat gravel or sand fields, mostly pine heaths. The material at the surface is commonly sand, but the grain size increases downwards in the sections. The surface layers are possibly ice lake sediments deposited in the ancient Lake Storbolmen and still older lakes. Primarily the material, however, is deposited or redeposited by ice rivers. Within certain areas, as for example, north of Lake Bolmen, the sand is in several places eolian; inland dunes too are observed. The area of the Slättö sand, immediately north of Lake Bolmen is surely the best known eolian sand field in these parts. The sand fields north of the lakes in this district have gone dry because the lake basins were tilted to the south on account of the differential upwarp of the land (G. De Geer).

3 g. The moraine and gravel district *(Morän- och grusområdet)* mostly in southern Västergötland is the main part of the district all the way to the Skåne boundary. Of course the moraine dominates, 55 %, thereafter bare rock and mire contribute 15 % each. The glacifluvial deposits form 10 % but this value is divided among the very different parts west and east of the Lagan valley. In the east, these deposits are very prominent. Surely the cause is, as hinted previously, the very pronounced broken surface forms. Certainly the western part has quite a marked surface form too but the hills are smaller and lower within the northern part. Towards the west the valleys become deeper and the glacifluvial deposits increase. In the southwestern part the well known Tönnersjöheden (east of Halmstad) is found; it has been penetratingly investigated by C. Malmström, especially with regard to the development of the mires, forests and heaths. Within this mire and moraine district certain glacifluvial deposits are found too but they are relatively insignificant. Besides, the whole of the district is very uniform on account of the close heath vegetation making it very difficult to distinguish the various soil types, mostly moraine and mire, without removing the heath.

The moraine within the district 3 g has in its northern parts flanking 3 f, a relatively high percentage of lime (comp. fig. 48). Of course the material emanates from the Cambro-Silurian districts in Västergötland (6 a) and Östergötland (6 b).

Fig. 35. Part of the geological map sheet Fjällbacka on the Swedish west coast (Bohuslän). The courses of the fracture valleys are remarkable consisting of NNW coast fractures, and SW—NE fjord fractures. The soils are quite dominated by the clays, while the moraine has a very small development. — Torv = peat; lera = clay; sand = sand; morän = moraine; berg = exposed bedrock and vatten = water, here = Skagerack.

From the rock and clay district of the West coast (4).

4. The rock and clay district of the West Coast

(Västkustens berg- och lerområde)

This district appears to be very uniform. Certainly Bohuslän (between Göteborg and Strömstad) is the most important part of the district but it reaches

G. Lundqvist 1951.

Fig. 36. Edsviken in the vicinity of Grebbestad, Bohuslän. A typical view with bare rock ground and clay in the fracture valleys. The moraine, here marked by the boulders, is unimportant. The sea, Skagerack, and the rocky islets are seen in the background.
From the rock and clay district of the West coast (4).

also into Halland in the south, Västergötland and Dalsland in the east (west of Lake Vänern). The uncovered rock is 55 % and the clay 20 %. The other components, sand and moraine, each form 10 %. The moraine is most commonly found pressed to the rock faces as a relatively insignificant cover (fig. 35 and 36). Mostly it is more or less strongly washed by the breakers in the surface layers. At many places this washing may be so advanced that only immense cobble fields remain. Normally the cobbles are about head size or smaller and lack almost completely the fine-grained matrix.

The leading feature of the district, though it is not visible on the map, is a certain richness in both large and small shell beds. Among the best known are the great deposits at Kapellbackarna and Kuröd in the environs of Uddevalla. They are well known from the days of Linné; later they were investigated by G. De Geer, Antevs, Sandegren and others. At least the first locality mentioned, that at Kapellbackarna, is nowadays preserved. These shell beds (fig. 37) consist of shells and mussels mixed with gravel, sand, etc. in various proportions. Previously the opinion was that the animals had been living on the bed locally and thus were good support for ideas about changes of level (G. De

Geer). Recent opinion, however, is that they have been transported from the place where they lived to the present locality of the shell bed (Odhner, Halden and others). During this transportation they have been influenced by breakers. Generally speaking, a complete shell bed is built up of late-glacial mollusca forms in its bottom layers, and post-glacial types higher up. Naturally the post-glacial types are not found above the post-glacial limit ("PG"). As examples of late-glacial forms may be mentioned *Saxicava arctica, Portlandia (Yoldia) arctica, Mya truncata*. Post-glacial forms include *Mytilus edulis* (common sea mussel), *Tapes decussatus, Pecten islandicus, Mya arenaria,* and others. It is well to remember that certain of the post-glacial forms can be found sparsely in late-glacial layers too. The shell beds in northern Bohuslän have been thoroughly investigated by Hessland (1943).

5. The rock and clay district of the East Coast
(Ostkustens berg- och lerområde)

This district, is, as indicated earlier, a landscape of about the same type as the last mentioned. Strangely enough, the total percentage of bare rock surface is of the same value, 55 %, in both districts, but the surfaces themselves are smaller in the present district. The rock ground is similarly broken up by fracture valleys (comp. Asklund 1923). The moraine area is more extensive, about 20 %, but instead both the sand and clay areas are smaller than in the West Coast district. The fracture pattern is also different, the valleys becoming narrower and more distinct. For this reason the cultivated area is not so large in these parts (comp. the arable land map of Anrick 1921).

6. The Cambro-Silurian districts of South Sweden
(Sydsveriges kambrosilurområden)

These districts, the Cambro-Silurian districts of South Sweden, are subdivided into: a) Västergötland, b) Östergötland and c) Närke (comp. fig. 29). Clearly we are only concerned with the mainland of Sweden (comp. p. 51).

6 a. The Cambro-Silurian district of Västergötland *(Västergötlands kambrosilurområde)* is dominated by moraine, 20 %, and boulder clay, 15 %, totalling 35 % altogether. The glacifluvial deposits form 10 % which is a relatively high value. It is conditioned by the mighty and extended glacifluvial fields (fig. 38) west of the mount Billingen ("Valle härad") and east of the same ("Havstenaterrassen" at Skövde). Both of these are constituents of the great Fennoscandian end moraines. The Valle härad area, investigated by Ahlmann (1916), E. Johansson-Jarvik (1934), and H. Munthe (1905), is largely an esker-net rich in deep small lakes and small mires (fig. 39) on which there are also found the high cyperaceous plant saw grass *(Cladium mariscus)*. But the southwestern part, the "Axvalla hed", is a level delta plain with small pits and a surface niveau about 130 m above sea-level, roughly the same as the marine limit. The material in the eskers is very largely

G. Lundqvist 1951.

Fig. 37. Shell gravel from the illustrious shell bed at Bräcke, east of Uddevalla. Most of the shells are *Saxicava arctica*. The material is often used as hen food, but this particular shell-bed is preserved.

From the rock and clay district of the West coast (4).

constituted of various shales (alum shale and mudstone etc.) explaining why it is so very easily crushed. The "Havstenaterrassen" is of another type. It is mostly a flat delta surface built up towards nearly the level of the Baltic Ice Lake at about 150 m above sea-level. The forms are more gentle and only exceptionally are small lakes found here.

Both of the last mentioned delta areas continue in an east—west direction from the mount Billingen often as rather large end moraines (at Skånings-Åsaka and Sventorp). They correspond to the well known Finnish Salpausselkä line II in the system of great Fennoscandian end moraines.

An interesting phenomenon within this district is the Lake Hornborgasjön, formerly an extraordinary bird lake. It is nowadays mostly drained. At one

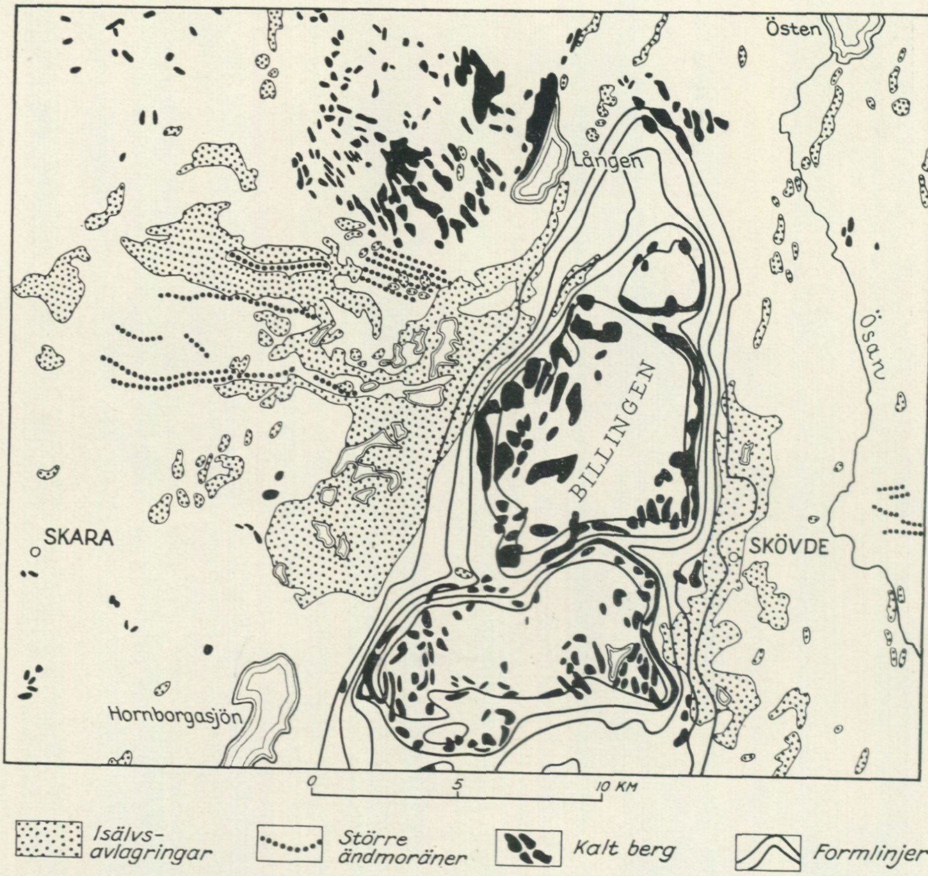
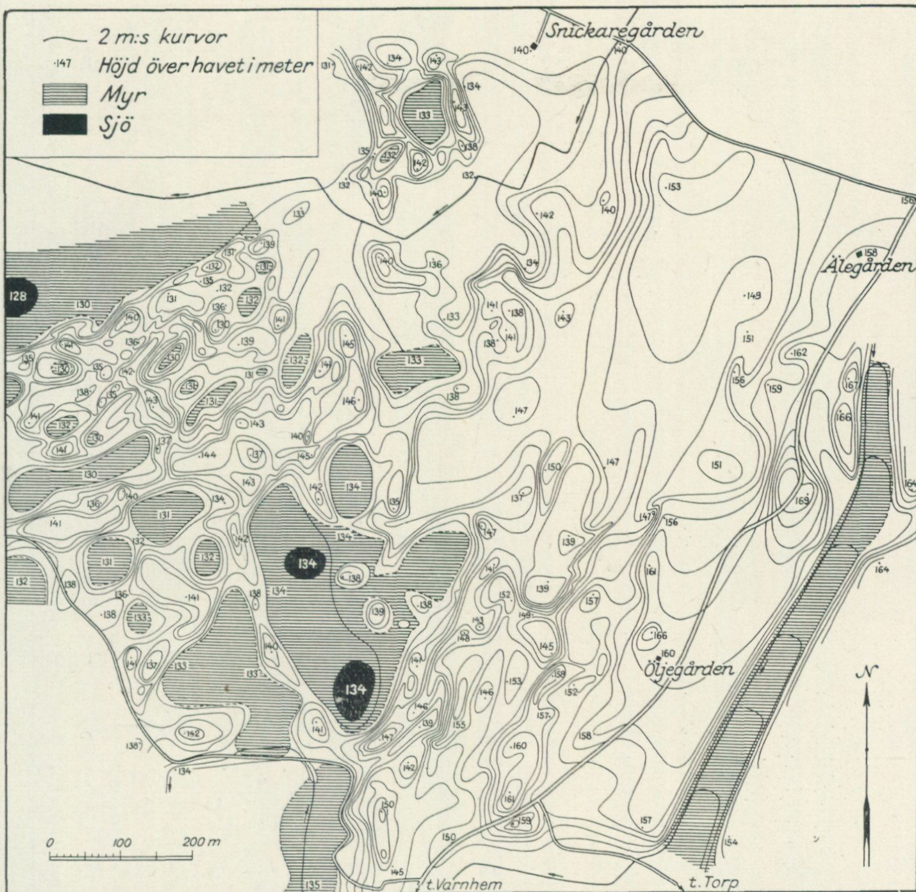


Fig. 38. The vicinity of Mt Billingen in Västergötland. On both sides of the mountain there are considerable glacifluvial deposits, deltas, which are parts of the large Fennoscandian end moraines. On the western side of the mountain, the Valle härad complex, fig. 39, is situated. The contour lines are approximate. Hornborgasjön is the well known bird lake. — Isälvsavlagringar = glacifluvial deposits; större ändmoräner = larger end moraines; kalt berg = bare rock ground; formlinjer = approximative contours.

From the Cambro-Silurian district of South Sweden (6 a).

time it was surrounded by fens and bogs which were investigated by Sandegren (1916) and G. Lundqvist (1928).

6 b. The Cambro-Silurian district of Östergötland *(Östergötlands kambrosilurområde)* is more rich in uncovered bed rock than that in Västergötland. In the latter, only the Billingen diabase is uncovered. Östergötland is full of small rocky hills (15 % of the land area) which stick up through the covering earth layers (fig. 40). Their height above sea-level increases from the great lakes Boren, Roxen and Glan towards the south simultaneously as the rock surface becomes more uncovered. Thereby one gets a strong impression of a peneplane, the sub-Cambrian, emerging from the flat country. This is made up of clay and boulder clay, which together constitute 45 %, while the common moraine is 20 %. Within this district the great Fen-



Enligt E. (Johansson)-Jarvik 1931-1933.

Fig. 39. Part of the Valle härad complex W of Mount Billingen. It consists of eskers, eskernets, kames etc. A comparison with the geological map (map-sheet Skövde, 1 : 50 000) will show that the mires are more extensive than on this picture. This is a glacifluvial part of the great Fennoscandian terminal moraines. Explanation: 2 m:s kurvor = curves for every 2 m; 147 = altitude above sea-level in meters; myr = mire; sjö = pools.

From the Cambro-Silurian district of South Sweden (6 a).

noscandian end moraines continue in two(?) lines. One of them is formed from the deltas of the Mjölby terrace—Malmslätt (west of Linköping) and the other by the delta Djurkällaplatån north of Motala. It is, however, impossible to distinguish a direct and obvious continuation towards the east. It may perhaps be asked whether the large gravel complex at Svärtinge northwest of Norrköping belongs to the mentioned moraine line. In sections one sees, namely, immense moraine floes overthrust from the northwest (comp. fig. 41). It should be further mentioned that southwest of the delta Mjölbyterrassen the great Ljungstorp moraine is found, largely built up as a ridge. This too contains moraine floes and a stratification that indicates overthrust from about

Fig. 40. The western part of the plain of Östergötland. The district is bordered in the north by the fault scarp that continues N of Bråviken. On the plain, clays and boulder clays are predominant (the last according to G. Ekström). In the S and SE there are no moraines. Between the towns of Skänninge and Mjölby the great Mjölby terrace expands. The southern rock district begins in the N as small outcrops that form greater and greater complexes towards the south. Probably this is the sub-Cambrian peneplain that disappears below the Cambro-Silurian in the middle of the picture. — Torv = peat land and mires; lera = clays; sand = sand; isälvsgrus = glacifluvial deposits; moränlera = boulder clay; morän = moraine; kalt berg = bare rock ground.

From the Cambro-Silurian district of South Sweden (6 b); in the north 8 a and in the south 3 g (Cf fig. 29).

G. Lundqvist 1955.

Fig. 41. Section through the Ljungstorp moraine, SW of Mjölby, Östergötland. This ridge forms a part of the great Fennoscandian end moraines (the first Salpausselkä line). It is built up of moraine, fine-grained sediments and glacifluvial sediments, the first two of which are here pushed up on the glacifluvial sediments. M = moraine; S = finegrained sediments; I = glacifluvial sediments.

From the Cambro-Silurian district of South Sweden (6 b).

north. Within one part of this area the ridge also includes kames. Possibly this ridge is a part of the great Fennoscandian end moraine tract.

The district now described has only 5 % mire. This is partly dependent on the fact that these commonly very thin peat layers are cultivated out of existence, their place on the map being marked as clay. A magnificent mire, or more correctly a raised bog, is Dagsmosse with its very interesting mire built up around a spring (spring mire) at Alvastra. This raised bog would from many points of view be very fine if not destroyed by peat-digging. The spring mire is found in the southwestern part and well known because of a pile-work from the passage grave period. The peat complex was investigated by L. von Post (1916), who established a neat correlation between the development of the spring mire and climatic variations. Finally, it may be mentioned, that the absolute age of the pile-work is determined as 2225 ± 130 B. C. using the C 14 method.

In this connection it should be mentioned that Dagsmosse is situated in the neighbourhood of the large and very well known bird lake Tåkern. Remarkable is the fact that despite lying in a lime district it lacks recent lime sediments (marl, marl mud etc.). Instead it has mud-clays, sapropel, in a distinctly reducing milieu. The cause must be that the lime is dissolved after its precipitation, possibly because the lake is not separated from the well-manured clay fields in the neighbourhood.

6 c. The Cambro-Silurian district of Närke *(Närkes kambrosilurområde)* lacks both bare rock ground and boulder clay according to the geological maps which are the basis of the present general map. However, possibly the lack of outcrops and boulder clay is an oversight during the mapping, but no large area is omitted. The common moraine, which is probably lime-rich, is still 30 %, and the boulder clay should be included in that figure. The sand is 10 % and the common clay as much as 40 %. Possibly the last figure may include some boulder clay too. In any case this district embraces the large arable plains of Närke. The mire area is 20 %. Of some interest is the fact that in this district (around Hackvad, Fjugesta and other central parts) the surface form of the moraine is of drumlin type (comp. fig. 7, p. 18). The drumlin area of Närke is, in addition to that of Västerbotten, the most beautifully developed one of its kind in Sweden. Farther eastwards in the vicinity of Sköllersta etc. the drumlins are replaced by small terminal moraines. They belong to the southern part of the terminal moraine zone which continues along the Lake Mälaren basin.

It was mentioned that the district contains a rather large mire area. This is nowadays partly cultivated or quite simply cultivated away, but much is still in existence, particularly the fens. This district contains in addition, a fine bird lake, Tysslingen, west of Örebro.

7. The rock and clay district of the Väner basin
(Vänerbäckenets berg- och lerområde)

This area is situated around the large Lake Vänern. Thus it begins south of Lidköping and continues as far north as Karlstad, north of the lake. In spite of many common features in its different parts the district also presents quite differing aspects, enabling us to make a certain sub-division.

7 a. The clay and sand districts of Västergötland and the Dalbo plain *(Västergötlands och Dalboslättens ler- och sandområden)* are quite dominated by clay with 40 %; the sand is 25 %. Thereafter the bare, washed rock hills should be noted with 15 %. Within this district the clay lies immediately on the bed rock without any intervening moraine. The district contains such different occurrences as the Dalbo plain (west of Lake Vänern) and Mount Kinnekulle (east of Lake Vänern). The first is one of the most absolutely flat plain areas we have in Sweden. Mount Kinnekulle is nearly its opposite in these parts. The composition of the mountain was described by Linné on his journey through Västergötland as far back as 1746. The top is diabase; on the southern slopes the Ordovician mudstone and shale are exposed; the remainder of the surface is moraine of various types. Re-

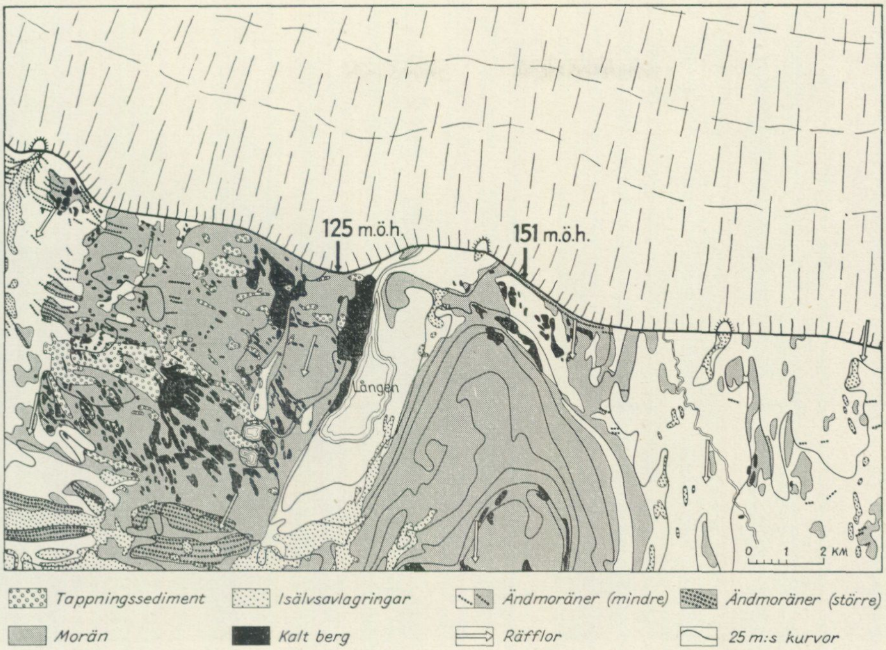


Fig. 42. The drainage district of the Baltic Ice Lake at the northern end of Mount Billingen. The bedrock is washed bare by the draining stream. The drainage sediments are identified by their petrographical composition, which also indicates their original source. Tappningssediment = drainage sediments; isälvsavlagringar = glacifluvial sediments; ändmoräner = terminal moraines (small or big); morän = moraine; kalt berg = outcrops; räfflor = striae; 25 m:s kurvor = contours at 25 m intervals. 151 m. ö. h. = height of the Baltic Ice Lake, 125 m. ö. h. = the sea level; north of them occurs the landice.

From the Cambro-Silurian district of South Sweden (6 a), the western part from the rock and clay district of the Väner basin (7 b).

garding the limestone outcrops it must be mentioned that they show very great similarities with the Stora Alvaret on the isle of Öland (comp. p. 43), but of course the dimensions are here a miniature of the Öland ones. The moraine cover on the south-facing slope, south of the diabase summit, forms high north—south ridges quite like the drumlin form. The cause of this form must be the quite special conditions of deposition: deep down and in the lee of the high diabase summit, Högkullen 306.9 m above sea-level. In connection with the morphology it may be remarked that the sub-Cambrian peneplain with the Cambrian basal conglomerate can be studied at low water-level in Lake Vänern west of Kinnekulle (Högbom and Ahlström 1924). Further, the moraine has an insignificant distribution, namely 10 % of the land area. Of the greatest interest in connection with the moraine are the two very marked points in Lake Vänern, Hjortens udde on the west side and Hinden on the east (Hjorten = the buck, Hinden = the hind). These attracted the attention of the geologist V. Karlsson, during his mapping of the geological map sheet Degeberga 1870. They were then interpreted as end moraines but not until more than 10 years later (1884) did G. De Geer connect them with the large, earlier known

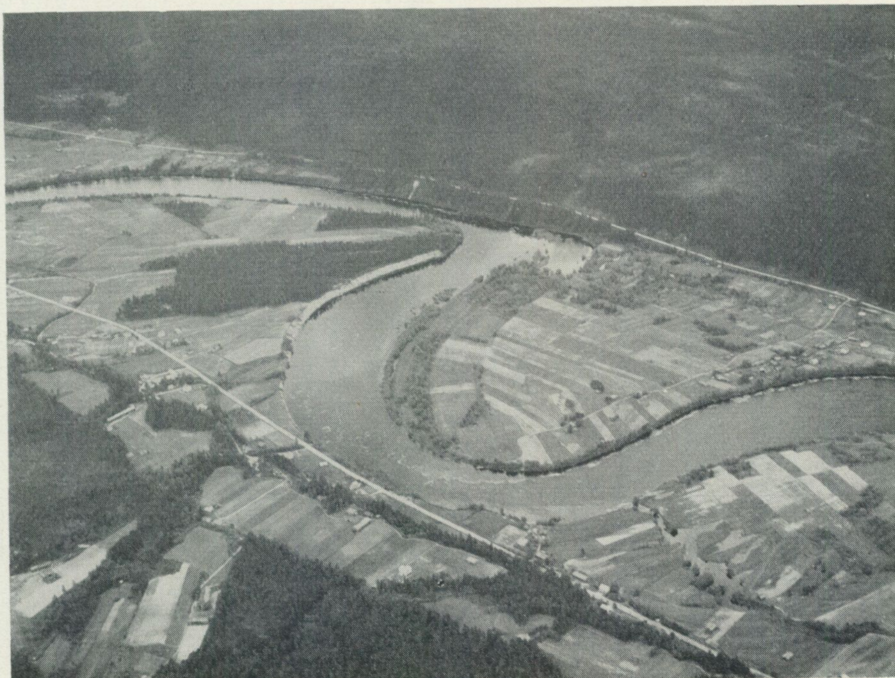
G. Lundqvist 1952.

Fig. 43. The southern part of the island of Hammarön south of Karlstad north of the lake Vänern. The rock ground is traversed by large fractures nearly perpendicular to one another. These fracture valleys are filled up with clay or Väner sediments, which are cultivated; the forest grows on the bare rockground.

From the rock and clay district of the Väner basin (7 c).

end moraine courses "raerna" in Norway and Salpausselkä in Finland. Such was the discovery of the Swedish part of the Fennoscandian end moraines. But it should be remembered that these — as is already clear from the above-described districts — can, in some stretches, be replaced by glacifluvial deposits of about the same external appearance. Thus Hinden is to a large extent covered by sand and the shore boulders towards the point are nearly spherical. Therefore it appears as if even the point Hinden is to a large extent of a glacifluvial nature. Possibly the same is true for the ridge west of Mellerud, that is, the continuation of the course towards Norway. On the geological map sheet it is marked as moraine but the material is well wave-washed gravel and the boulders — mostly very elongated — are well orientated in the direction of the striae, that is, perpendicular to the ridge. It can probably best be interpreted as a marginal cross esker, deposited by a meltwater river along the ice margin. Towards the northwest the course continues via Ödsköldsmoar and Dals Ed to the raerna in Norway.

North of this belt, northwest of Götene (on the plain southeast of the mount Kinnekulle) there is a N—S trending course of small but beautiful terminal moraines. They belong to the smaller type and by their describer, S. Johansson, they are called quite simply annual moraines. He reports that they lie on clay



G. Lundqvist 1949.

Fig. 44. Some meanders in the River Klarälven at Spickebol, N. Ny, Värmland. The river flows from the right to the left in the picture. The headlands consists of river sediments, sand; the forest in the background grows on moraine.

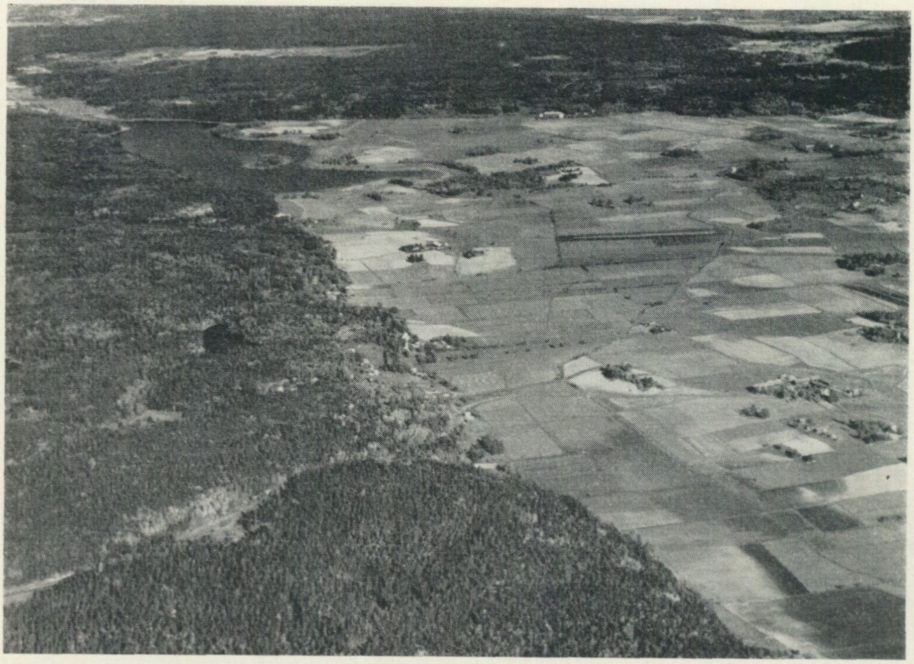
From the rock and clay district of the Väner basin (*7 d*).

as the moraine commonly does at a number of localities on the map sheet (Lidköping). The last remark probably goes too far, but it is certain that clay is often found kneaded into the moraine ridges. These small moraine ridges should prove an ice recession of about 270 m per year.

It is striking that these terminal moraines, like the more easterly situated "Holmestad moraines", are related to a number of parallel courses in the ice movement direction.

Mostly the clay is a marine deposit of varying grain size. Properly speaking there are all sorts of sizes from fine sand, silt and light clay to very heavy clay. The silt occurrences can be traced from the ravine phenomena which are visible on the topographic map on the scale 1: 100 000. The fine-grained sediments, sand and clay are 25 % and 40 % respectively or 65 % of the total land area.

7 b. The moraine and clay district of the Mariestad region *(Mariestadstraktens morän- och lerområde)* has quite a different appearance. About 40 % of it is moraine and 30 % clay. The sand is 15 % and the mires 10 %. Often the moraine is formed as either drumlins or terminal moraines of the smaller type. In this connection must be remarked the moraine area Klyftamon northwest of the mount Billingen, which is very difficult to

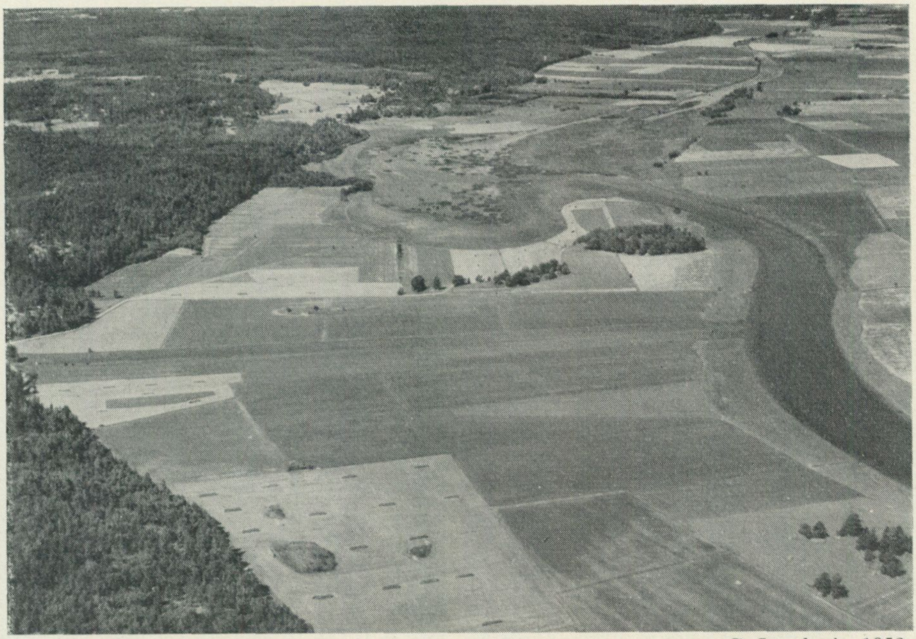


G. Lundqvist 1949.

Fig. 45. The northern part of the Vånga plain W of Lake Glan, Östergötland. The plain is bounded by two faults and is therefore wedge-shaped, i. e. the "Vångakilen" in Swedish. Lake Örn is situated at the northern end of this wedge. The wooded land is bare rockground or moraine, the plain is clay. Possibly Cambro-Silurian deposits are found under the plain.
From the Cambro-Silurian district of South Sweden (*6 b*).

get to. It is very dissected and rich in rocky knobs trending about WNW—ESE. Regarding the moraine it must, however, be mentioned that in the southern part of Klyftamon it is gravelly and rich in rolled boulders. In reality it is not a normally developed moraine but a drainage sediment deposited by the drainage river from the Baltic Ice Lake at the north point of Mount Billingen (fig. 42). The occurrence of terminal moraines was mentioned above. That these are small terminal moraines formed by ice advances of short duration is demonstrated by the clay lumps kneaded into the moraine matrix. Within one part of the district they are connected to an esker, the Holmestadsåsen, and bent up along it. This is caused by the fact that during the wastage an estuary was developed along the esker (G. Frödin 1916). This is one of the most beautiful examples of such a phenomenon yet described from Sweden.

7 c. The rock and sand district of the Värmlandsnäs and Karlstad region *(Värmlandsnäs- och Karlstadstraktens berg- och sandområde)* is quite dominated by uncovered rocks (fig. 43) which form 55 % of the land area. The sand is 20 % and the clay 10 %; the last value, however, appears — when looking at the map — to be too low. But this is not the case. In the sand are included the deposits of the river Klarälven which are really river sediments (fig. 44). With the aid of them it has been possible



G. Lundqvist 1952.

Fig. 46. The faultscarp at Lake Sjömosjön W of Arboga, Västmanland, marks the limit between the woodland and the large clay plain in Västmanland. The faultline zigzags, the angles occurring where fissure valleys intersect.

From the clay and moraine district of the Mälar basin (11); the woodland to the left is the moraine and clay district of Södermanland-Närke (8 a).

to make clear the development history of the River Klarälven and its sediment plain through the ages (Sandegren 1939). During the years the quantities of sediment have dammed up a number of creeks which are now relict lakes or lagoon lakes of the same type as those of the River Dalälven. Moreover the sand includes eolian sand and other sand in immediate connection with the glacifluvial deposits (west of Karlstad, the deltas Sörmon and Törnmon, for example). In a morphological respect part of the sand fields should have been included in the glacifluvial deposits and then the values would have been quite otherwise. The eolian sand is almost to be regarded as small shore dune deposit. The glacial clay is often varved but not regularly through the whole of the stratification — only in zones, stratigraphically speaking (J. Lundqvist 1958). The surface layers are often developed as Väner sediments, that is, earlier deposits of Lake Vänern, "Stor-Vänern". They are often fine sandy and have only an insignificant thickness.

7 d. The moraine and clay district of the lower Värmland *(Nedre Värmlands morän- och lerområde)* is situated around the previous district besides extending up into the valleys Frykensdalen and Klarälvsdalen. It is quite dominated by uncovered rock (25 %) and moraine (35 %). The sand is 10 % and clay 15 %. The two last mentioned are deposited in the valleys and on the plains. The glacifluvial deposits have an

insignificant distribution, less than 5 %. They occur as narrow shelves on the valley slopes or as mouth deltas round the inflows.

Special for the moraine is that it can here have the shape of terminal moraines. This is so for the environs of Nyed (northeast of Karlstad near Molkom) and Kristinehamn (Hörner 1927). Therefore it should be possible to combine this feature with varved clays and get a good picture of the ice recession here, but unfortunately varves are seldom developed. However, it has been possible to get a good idea about it in the region south of Lungsund. The lines of recession, the equicesses, show namely about 160 m per year (Jan Lundqvist 1957). The terminal moraines in the vicinity of Kristinehamn etc. give about the same value.

8. The moraine and clay district of Södermanland-Närke
(Södermanlands-Närkes morän- och lerområde)

This district includes also a region of the northern part of Östergötland. It consists of two rather different parts, which are very clearly seen on the map. They are as follows: 8 a. The western moraine and rock district (Västra morän- och bergområdet) and 8 b. The eastern rock, moraine and clay district (Östra berg-, morän- och lerområdet).

8 a. The western moraine and rock district *(Västra morän- och bergområdet)* is made up of about 45 % moraine and 20 % uncovered rock. The rocky part mostly lies in the southern region, or more correctly, towards the southern boundary of the district. Within its middle region the main part of the sand and clay is found (10 % of each). These sediment plains are bounded by distinctly marked fractures and fault slopes (fig. 45), especially the plains around Tjällmo and Hällestad. Thus morphologically the same phenomena delimit the whole district towards the plain of Östergötland.

North of Lake Hjälmaren the district is of about the same type (fig. 46). Most pronounced from this point of view is the large forest region of Mount Käglan. South of Lake Hjälmaren there are separate small terminal moraines which belong to the course of the basin of Lake Mälaren.

North of the large Lake Vättern are sand and glacifluvial deposits, mostly deltas, which were more closely investigated by Bergsten (1943). Among those examined were the Flädesmon, Gårdsjö and Snavlunda fields. Their even surfaces mark different stages of the Baltic's history. In the above mentioned districts some glacifluvial deposits and large moraine ridges were distinguished which are possibly connected with or equivalent to the Fennoscandian end moraines. No counterpart to them has yet been proved with certainty in the present district. But the gravel fields at Krokek, which on the geological map sheet Stafsjö (on Kolmården) are marked as sand ("mosand"), have such a thickness that they must be interpreted as glacifluvial deposits; the morphology of the field also supports this interpretation. Possibly the field about 5 km north of Kvarsebo (north of the Bråviken bay) is a continuation of the same

G. Lundqvist 1949.

Fig. 47. Lake Finnsjön and behind it Lake Ö. Magsjön in Östergötland. The topographic features of the district are determined entirely by the fractures in the bedrock. The cultivated parts, clayey soil, make up only a small area.
From the moraine and clay district of Södermanland-Närke (*8 a*).

course. It contains among other things moraine floes and Cambrian sandstone boulders.

8 b. The eastern rock, moraine and clay district *(Östra berg-, morän- och lerområdet)* is characterized by just those factors mentioned in the name of the district, each representing 25 % of the land area. Thereafter come sand and mire with 10 % each. Also this district has largely the same general structure as 8 a.: uncovered rock and moraine occur mostly towards the boundaries of the district (fig. 47). Such a distribution gives support to the view that the outside zones are higher and the whole district largely saucer-shaped. This is further emphasized by the fact, that lakes and clay fields are mostly situated towards the central part of the district. The lakes are exceptionally numerous within this district (examples are the lakes Båven and Yngaren).

The glacifluvial deposits are strikingly subordinate within this district. The same is true of both eskers and deltas. This is very remarkable because in this district, too, a continuation of the Fennoscandian end moraines towards the east can be expected. One indication is the large delta between Bergshamra and Stigtomta northwest of Nyköping. A continuation may possibly include the large sand field "Skavsta malm" too.

As already hinted at above a rather distinct continuation of the Fennoscandian end moraines can be expected in both of the Södermanland districts, that is in Kolmården and up towards Nyköping. But one must ask: what is the cause of their apparent absence?. In this connection it is striking, that the critical district is traversed by quite marked rock ridges elongated about west—east, that is, nearly in the same direction as eventual end moraines. Between these rock ridges are deep and narrow valley courses, which are best observed, when driving N—S within the district. If there should be marginal moraines of the large Fennoscandian type they ought to be lying, at least sometimes, on the rock ridges, sometimes traversing the valleys obliquely or lying as insignificant knobs close to the rock faces. There were probably no moraine ridges of greater dimensions deposited on the mountains. It appears namely from other rock districts that such a deposition never occurred, but the cause is unknown. Under such circumstances it does not appear so peculiar that we have not yet found any marked continuation of the Fennoscandian end moraines in these parts.

9. The rock district of Södertörn and the Archipelago of Stockholm
(Södertörns och Stockholms skärgårds bergområde)

This district is in many respects similar to the districts numbers 4 and 5, that is, the West and East Coast districts. The uncovered bed rock is namely 50 %. The moraine is 20 %, but seldom intact being strongly wave-washed or often genuine gravel (wave-washed gravel). Unfortunately the ordinary geological maps do not make it possible to separate the wave-washed gravel fields because they are mostly united with the moraine. The clay area is 20 % but the greater part is concentrated towards the western parts of the district. The farther out towards the sea, the smaller the rock faces become and the clay areas diminish and disappear completely.

The area of the glacifluvial deposits is smaller than 5 %, a value that appears to be a little low. Within the district there are namely numerous both large and interesting fields. That is certainly not surprising because the Fennoscandian end moraines, in which glacifluvial material is a very important component, must pass through these parts. Among more significant glacifluvial deposits is the well-known delta Pålamalm, described by Sten De Geer 1905. It is a rather large delta in the vicinity of Tullinge (southeast of Tumba), southwest of Stockholm. The surface, irrespective of some small kettle-holes, is nearly flat and situated about 82 m above sea-level. One of the kettle-holes with a little pond called Oxögat (= the Ox eye), is now destroyed by gravel-digging and filling up of the pond. At Västerhaninge (southwest of Stockholm) lies a large formation partly with moraine. In the gravel-pit of Oaxen

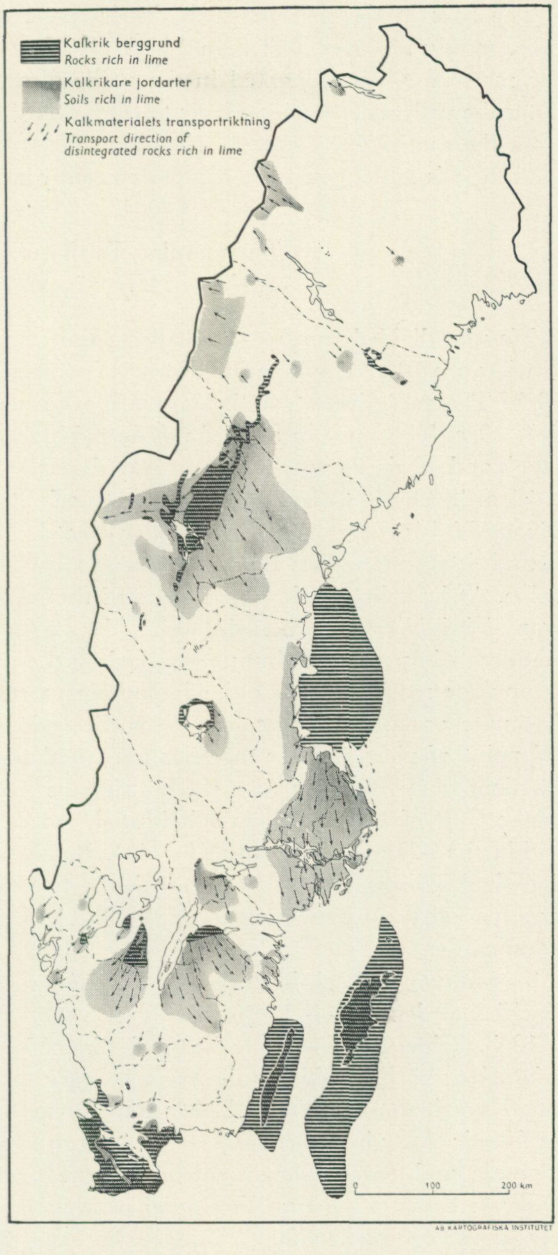


Fig. 48. The distribution of the Cambro-Silurian material in relation to occurrences in the bedrock. The limits of the districts more rich in lime are mainly founded upon the occurrence of sediments rich in lime in mires or lakes. The submarine occurrences are quite hypothetical based partly on bathymetric data, boulders etc. In the Gulf of Bothnia the boulders indicate a distribution "in patches".
According to Atlas över Sverige, map sheets 15—16 (G. Lundqvist).

in Hamra malm near Tullinge are interesting formations like the frost-earth type Brodelboden, a type, that requires tundra climate for its development. But as these areas were not raised above the sea until more favourable climatic conditions had developed, these disturbances must be caused by ice-bergs. A large deposit of interest is the isle Sandhamn which has been supposed to be a component in the Fennoscandian end moraines by many scientists.

The soils in the present earth district have a relative high percentage of lime, mostly however, less than 10 % $CaCO_3$. The surface forms valleys for the most part, are elongated in the strike direction of the gneissic bed rock. Thus the valleys curve successively towards NNE, N, NNW and NW if reckoned from the south. The connection between the structure of the rock and of the landscape is seldom illustrated more elegantly than just here.

10. The moraine district of Uppland
(Upplands moränområde)

May be divided into many smaller parts each with its peculiarities. These districts are 10 a. The moraine district of Roslagen (Roslagens moränområde), 10 b. The rock district of the Uppsala environs (Uppsalatraktens bergområde), 10 c. The mire district of northern Uppland (Norra Upplands myrområde) and 10 d. The moraine and clay district (Morän- och lerområdet).

10 a. The moraine district of Roslagen *(Roslagens moränområde)* is characterized by boulder clay, though according to the geological maps it is not more than 10 % of the land area. But this is certainly a minimum value. At least in certain descriptions of the geological map sheets (esp. Rådmansö) it is clearly mentioned that boulder clay is present — many localities are enumerated as examples but not marked on the map. Without a new and more scrupulous mapping it is quite impossible to state the correct area, but unfortunately such mapping cannot be performed for a long time. From a practical point of view a closer investigation could possibly be of value. The finest fractions of the boulder clay, surely originate from the Cambro-Silurian rocks in the Gulf of Bothnia. This is indicated, too, by the high percentage of lime within the whole of Uppland (fig. 48). But it is also possible that an earlier deposited sedimentary clay is kneaded into the moraine by the land ice during its apparent turning towards the SSW. But this problem also calls for a closer examination.

The uncovered rock is 25 % and the moraine 35 %: the rest — except the glacifluvial deposits — 10 % each.

10 b. The rock district of the Uppsala environs *(Uppsalatraktens bergområde)* appears to be very distinctly marked and bounded. Therefore it must be pointed out, that similar but much smaller areas are to be found locally in the county of Uppland, for example, the Fiby area west of Uppsala and Bergsbrunna southeast of the town. But as already mentioned these areas are of quite another order of size. In any case in the present district the uncovered rock is 50 % and the moraine 30 %. The main part of the remaining 20 % is mire. The moraine often has large boulders or is rich in boulders. For this reason it is very often difficult to traverse. The terminal moraine course of the Mälar basin stretches into this district.

10 c. The mire district of northern Uppland *(Norra Upplands myrområde)* is distinguished by mires 35 % and moraine 45 %, totalling therefore 80 %. The sand is 10 %, the clay 5 %. Boulder clay is not

G. Lundqvist 1949.

Fig. 49. Part of the large ravine complex of Säterdalen near Säter, Dalarna. In the background, forest-clad moraine; in the foreground, a sediment plain formed mostly of silt and very fine sand. The ravines are 30—50 m deep, abruptly incised in the sediments. The development proceeds headwards, i. e. towards the moraine height in the background, where it ceases. After Sv. geol. unders. Ser. Aa Nr 194.

From the clay and moraine district of the Mälar basin (11).

accounted for on the map sheets but there is reason to suppose that this soil is represented, at least locally. The glacifluvial deposits are sparse here: it is principally the Uppsala esker (the Uppsalaåsen) which sweeps through the district with its extension into the Gulf of Bothnia, the tip itself being called Biludden. Its boulder material has been investigated in detail by T. Troedsson. The whole of district 10 c is remarkable from a morphological point of view being so extremely flat. It must be a peneplain and then the most plausible explanation must be that it is the sub-Cambrian one. The area of Hållnäs (north of Lövstabruk) is particularly flat and even.

10 d. The moraine and clay district *(Morän- och lerområdet)* is largely the remainder of Uppland, apart from the previous three special districts. The uncovered rock is 20 % and the moraine 45 %, the last is also the same value as in the district 10 c. Clay and mire are 15 % each. For the most part these values can represent an average for the "normal-Uppland". The present district contains a part of the Uppsala plain, clay and eskers,

among which the Stockholm esker is to be especially remarked. When driving on state highway 13 between Stockholm and Uppsala, large parts of the Stockholm esker are to be seen and numerous large sections therein, all giving the impression that these are immense quantities of glacifluvial gravel. But this esker represents only a small fraction of the whole area. The connected sand fields too are quite insignificant.

11. The clay and moraine district of the Mälar basin
(Mälarbäckenets ler- och moränområde)

In this district, clay (40 %) and the moraine (30 %) are characteristic of the remainder, the sand is 10 % and the glacifluvial deposits 5 %. Here it is very important to note that the fine-grained sediments can certainly be described as clay, but this is only a collective term applicable to the low-lying plains. One type of these sediments is the mud-clay that is found only to about 10 m above sea-level. In the extensive valley tract towards the Lake Siljan, clay is nearly completely replaced by silt. The Tunaslätten (the Tuna plain) is described as the most genuine silt area of Sweden. In principle it appears that the silt is, from a genetic point of view, connected with the river Forndalälven (the ancient Dalälven) or more correctly, the preceding glacial river. On the new geological map sheets Avesta and Hedemora it is possible to follow the silt for some kilometres south of Krylbo, thereafter continue older geological map sheets on which this sediment is not distinguished. Just in this region there appears to be a change to clay. The silt is thickly varved in the great Dalälven depression, most of the varves being of silt, while the winter part of the varve, the clay, is very insignificant. It is quite otherwise down on the sediment plain in the Mälar basin proper. There a very heavy clay is found whose glacial part can be varved but in a most unusual way. Thus the varves can be more than 1 dm thick and very indistinctly laminated (Lehman, 1954).

In connection with this statement about the clay must be added some data about the moraine. It mostly contains large boulders within the district. Where this is not the case, the boulders for some reason or other (cultivation, stone collecting etc.) have disappeared. The moraine areas are mostly elongated in the direction of the ice movement but there are also ridges orientated perpendicular to it, that is, small terminal moraines of the annular type. These are especially beautifully developed within the tract Kolbäck—Västerås—Enköping—Ekolsund (comp. fig. 26). The southerly continuation south of Lake Mälaren is not quite so well developed. From this it can be appreciated that the zone nearly traverses Sweden, and thus probably represents a synchronous deglaciation zone. It is, however, visible only in the area under the highest marine limit.

The glacifluvial deposits are about 5 % of the land area. Mostly they are magnificent formations of the classic type. Among them, the Enköping, Badelunda, Strömsholms and Köpings eskers are to be especially noted. The last of these was the first one described in Sweden — incidentally in an extraordinary

Thomas Lundqvist 1957.

Fig. 50. A frost boil on a road in Indal, Medelpad. These forms are characteristic for districts with fine-grained soils (silt, very fine sand, fine-grained till). During freezing, water accumulates in soil under the road as ice layers. When the soil thaws, the freed water works into the soil through vibrations caused by traffic, and the soil begins to flow. This happens more easily where the solid substratum (moraine or rock) is nearer the surface. Notice the claspknife to the left.

From the coast zone of Norrland (12 b).

manner — by Hampus von Post as early as 1855. The eskers, however, stand out clearly as morphological phenomena in the landscape. Other morphological features concerning the soils are the "nipor" (= approx. earth bluffs) and ravines of the Säterdal type (fig. 49). Both of them are found from the Krylbo area and towards the interior of the landscape. Niporna are steep—vertical bluffs, mostly close by the river. They are developed when one earth boulder after the other falls down, crumbles and becomes transported away by the river. The frozen earth parts, the 'tjäle', is of a certain importance. On account of the steepness of the bluffs vegetation is absent or insignificant. Therefore the dry 'nipor' shine white like Cretaceous rocks, even at a great distance.

The ravines are quite different phenomena. They are mostly deep, branched valley systems excavated 30—50 m in the plains down to the erosion base which is commonly the River Dalälven in this district. The upper limit is the moraine slope (fig. 49) or hard bottom (moraine or bed rock). In some cases the ravines are to be found without such a near connection to a river. But then they open out into a very low part of the plain. The ravine slopes are very steep and thickly forested except on the stretches where landslides are still proceeding. Because of their steepness the ravines cannot be observed until one is standing close to them. At a distance only the tree tops breach the even surface of the plain.

The ravines are formed mainly by the erosion of running water. Earlier it was supposed that subsoil water played the greatest part (A. G. Högbom 1905) but later it was found that surface water is the chief cause (Caldenius 1926). Thus the remedy against the ravine development is that the surface water be drained off in a suitable way. When the development of a ravine has already begun, its continuation can be stopped by filling up the ravine apex, that is, its youngest part, with twigs, stones etc.

The fact that the ravines are developed by the erosion by surface water, suggests that their constitution and development is related to climatic periods with higher precipitation. Through investigations of organic layers (peat etc.) it is proved that landsliding of minerogenous strata — that is ravine development — took place during the periods about 3700, 2300 and 1000 B. C. These are also about the times to which some of the recurrence surfaces in the bogs according to our present knowledge are referred.

The importance of these conclusions becomes apparent when they are compared with the other conditions. Of course one at first will ask: what was the fate of the ravine material? It must lie downstream, and then of course the extensive Husby—Hovran plain northeast of Hedemora catches the eye. It is largely occupied by river sediments, that is, the deposits of the River Dalälven. A scrutiny of the stratification on this plain shows partly a certain abundance of organic matter, mud substance, in the sediments, partly more or less thick layers of purer minerogenous matter. The latter must indicate stronger silt currents which may be supposed to have their origin in the ravines. Age determinations of these strata with help of pollen analysis have shown that such tremendous earth-slides belong to the following times: 2300 and 1000 B. C. and 200 and 400 A. D. These are the most precipitation-rich periods which appear to correspond with both the times for the recurrence surfaces and the ravine developments. A causal relation between all these phenomena is therefore more than likely (G. Lundqvist). What is remarkable is that the time 600 B. C., the time of the recurrence surface III, is not at all prominent in these stratifications. On the other hand it should be remembered that research on these problems is not very extensive.

To the soils of this district belong the land elevation sediments (Ekström), especially those of the Mälaren basin for the most part. They are not distinguished on the map sheets, neither on our present General Staff map or the ordinary geological ones because these soils are mostly thin layers with indefinite limits. They consist of a mixture of the fine material in the moraine and glacial clay as well as the older post glacial clays to some extent. Such land elevation sediments are developed when the breakers influence the hill slopes during the progress of the land elevation. Therefore from a theoretical point of view, large areas of the district should be covered by these sediments but such is not the case. They are found only as narrow strings around the moraine hills.

12. The coast zone of Norrland
(Norrländska kustzonen)

This district includes the strip between the highest coast line (here this conception is better than marine limit) and the present coast line. A glance at the map shows that the strip mentioned can be divided into three naturally delimited districts: 12 a. The moraine district (Moränområdet), 12 b. The rock district (Bergområdet) and 12 c. The moraine and sand district (Morän- och sandområdet).

12 a. The moraine district *(Moränområdet)* is the most southern part extending right up to Medelpad; it is in other words largely the county of Gävleborg excluding certain parts of its interior. The moraine is 25 % and the mire area 35 %. The sand fields are 15 % and clay 10 %. Remarkably high is the value for the glacifluvial deposits: 10 %. In the moraine are included wave-washed moraine and wave-washed gravel, both of which over extensive parts of the district can occupy rather large areas. The wave-washed gravel is found partly up on the heights beneath the highest shore line (HK), partly washed down into the valleys and especially on the water shed of the small valleys and glens. Magnificent fields of wave-washed gravel, which are so intensively worked by the breakers that they have been pure cobble fields, are, for example, the isle Storjungfrun and large parts of the peninsula Hornslandet (comp. fig. 14).

Of further interest in this district is the ice oscillation in the vicinity of Gävle which was so intensively discussed in the 1930's. Conclusions about the latter were based on the occurrence of clay under the esker southwest of Gävle and on the moraine ridges, which were interpreted as terminal moraines (Sandegren 1929 and later). These ridges are elongated NNW—SSE, their western slopes are steep and the eastern ones flat. Now it appears clear that the ridges are radial moraines whose surface form is influenced partly by the Bothnian ice, partly by the breakers from the NE. Of great importance for the discussion too are the glacial striae which prove an ice movement towards the southwest, that is by the Bothnian ice. The marginal form of the Bothnian ice and its character has recently been clarified by Järnefors and Fromm. Their investigation of the ice wastage has proved among other things that the ice has pushed a tongue partly over the peninsula Uppland, partly more towards the southwest into the large depression of the River Dalälven.

The fine-grained sediments are principally clay and silt (fig. 50). Broadly speaking the distribution appears to be clay nearer the coast and silt up the valleys. In the southern part of the district, on the geological map sheet Storvik, the clay is nearly without lime, but on the partly adjacent geological map sheet Gävle it can have up to 14—15 % $CaCO_3$. The origin of the lime ma-

Fig. 51. Part of northern Hälsingland. In the coastal zone the exposed bedrock is more common and the moraine is often wave-washed. On more exposed slopes the wave-washing has resulted in beach gravel. The fine grained sediments are mostly very fine sand or silt. The clay is very rare. Torv = peat; Finmo — lera = very fine sand — clay; Sand — grovmo = sand — fine sand; svallgrus = beachgravel; Rullstensås = esker; isälvsgrus och -sand = glacifluvial gravel and sand; svallad morän = wave-washed moraine; morän = moraine; kalt berg = exposed bedrock; the wavy grey mark water.

From the coast zone of Norrland (12 a).

G. Lundqvist 1950.

Fig. 52. The highest marine limit, MG or HK, on the small mountain Mittiflygget W of Piteå. Along the coast of the Gulf of Bothnia this limit is distinctly formed. At a distance it is seen as a light horizontal line near the tops of the mountains. Above this line the moraine is quite intact and overgrown with forest. Mostly it is fine sandy or sandy. Below the HK, the moraine is strongly wave-washed or replaced by shore-gravel or completely washed away so that the bedrock is uncovered. The latter is here the case.

From the coast zone of Norrland (12 c).

terial is the southern part of the Bothnian Gulf and it is very clearly marked by the limestone boulders both in the clay and the moraine. The varved clay is said to be more and more disturbed and folded towards the east (Sandegren), but this is denied by Fromm, at least for southern Dalarna. In any case it is interpreted as being caused by the movements of the Bothnian ice. But Caldenius is of the opinion that the disturbances in the clay in these environs are not more developed than in other districts, where landslides on rather flat fields have taken place. However, it would be wise to wait with the explanation until the new picture of the ice recession is completely elaborated, because this special problem must be discussed in more detail.

Further north in the county of Gävleborg the clay is thinly varved (2—5 mm) and is found up to about 180 m above sea-level. It has seldom a lime percentage or in any case only a small one. In the vicinity of Ljusdal it may effervesce with acid but the lime percentage is probably not more than 0.5 % (Blomberg 1895). At Hamrånge the value is 4 %, at Ockelbo and Torsåker 2 % and in the south (east of Hedesunda) at Söderfors 36 % (Blomberg). With regard to the lime percentage there is a certain difference in the fine-grained sediments in this district: thick and more lime-rich ones occur in the southern parts, thin and lime-poor ones in the north. The total thickness of the sedimentation is greater in the large and extensive valleys.

In this connection, the east—west variations may be remembered. Towards the coast the clay has a greater lime percentage, which must be dependent on the fact that the lime material originates there or more likely in the Gulf of Bothnia. A. G. Högbom noted in 1906 (in translation from the Swedish): "This glacial clay has an origin other than that further northwards which got its lime material from the west, which is clear also from the appearance of the strata otherwise. They have not, in contrast to whatever else is the rule in Norrland, a pure grey colour since those parts of the varves corresponding to summer and spring deposition are brownish. When this part of the stratum is thicker than the grey stripe representing the autumn deposit, the clay appears brown. The clays in southern Norrland together with those of Uppland and eastern Västmanland have this appearance since they originated in the south Bothnian Silurian area." From this statement of Högbom it will be clear that Gästrikland (from about 61° N latitude to Gysinge), from a sedimentary point of view, is connected to southern Sweden.

One seemingly special soil mentioned by Blomberg, is 'åkerlera' (approx. translated as arable clay). It is described by him as "often sandy clay, grey-blue in colour and commonly rust-spotted; only very occasionally does it show distinct stratification and it breaks up into cube-like pieces on drying. Its thickness is commonly relatively insignificant, as a rule about one metre; in valleys, old river channels and valley plains, which end up in the sea, it can be thicker and the clay is often developed as svartlera (black clay)." From this it is clear that the clay described is a post-glacial one. Blomberg is of the opinion that it is a Litorina clay, but of course it can just as well be an Ancylus clay. In any case this type of clay is met with throughout the whole of the relatively low-lying coast strip and up to about 80 m above sea level. Further inland and higher above sea level, the soil becomes lighter. Thus Blomberg speaks about 'lermelja' (possibly an old word of country people) above the highest limit of the varved clay. It is evidently a silt, which in some degree can be verified by studying the localities mentioned by Blomberg, for example, Färila and Bergsjö.

The glacifluvial deposits are, as already mentioned, 10 % of the land area; the sand 15 %. Under the latter are also included wave-washed sand connected to the moraine as well as sand connected to the glacifluvial deposits (fig. 51). Therefore it must be emphasized that it is frequently very hard to draw a limit between both the last mentioned soils. It is only when good sections are found that it can be decided with more certainty, whether the sand is of glacifluvial or "marine" type. Generally, the distribution is such that the sand connected to the eskers (marked on our general map in orange or green), increases towards the north. In the south there are narrow eskers of about the Mälaren basin type, while towards the north they become broader and broader and can be more correctly termed deltas or valley trains. The most beautiful examples

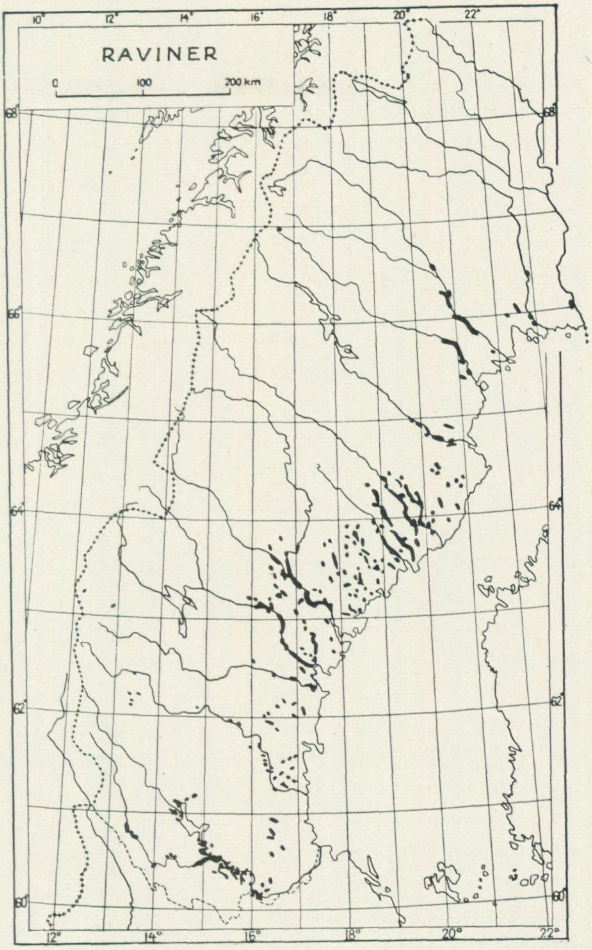


Fig. 53. Ravines in fine-grained sediments in Norrland. These sediments are mostly silt, very fine sand or fine sand. A comparison with the map, fig. 27, indicates better the distribution of the different types. Notice that these ravines are lacking near the shore strip which is partly caused by the fact that a certain fall in elevation is necessary. Comp. fig. 49. According to Sv. geol. unders. Ser. C Nr 457.

of such large fields are to be found in the valley depressions of the rivers Voxnaälven and Ljusnan. It it this difference between such fields and narrow ridges in the south which is of great interest. The conformity of the eskers in the south is probably also of importance. Observe especially the form of the Badelunda and Enköping eskers just north of Lake Mälaren and their continued parallel course towards the north. Of further interest are the courses of the eskers at Gävle and Sandviken. The Gävle esker bends towards the Gulf of Bothnia, while the Enköping esker turns inland. Each is related to the prevailing directions of the striae. As early as 1895 Blomberg gave prominence to the fact that this must show that the land ice had advanced tongue-like into the depression of the River Gävleån. In reality the existence of such a tongue is now proved through the recently completed investigations of Järnefors and Fromm mentioned above. The cause of the conformable windings of the various eskers is probably the pressure of the ice lobe during the movement inwards and over the land (G. Lundqvist) which must have influenced the fracture pattern.

12 b. The rock district *(Bergområdet)* consists of the coast strip from the southern boundary of Medelpad to Bjuröklubb. It is distinguished from the previously mentioned district by its richness in uncovered rock, which is about 20 % of the land area, and the moraine 30 %. The glacifluvial deposits occupy a markedly smaller area, less than 5 %, but the sand is about 20 %. It is, however, not only the rock area but also the morphology of the rock knobs which makes this district so distinctive. This is especially accentuated within the stretch Härnösand—Örnsköldsvik where the rocks are high and well rounded. As an example of this may be mentioned the environs of Nordingrå, where hills 250—300 m above sea level are found immediately on the coast line. The height therefore appears even more striking. This phenomenon was first observed by Olaus Magnus in his great work "Historia de gentibus septentrionalibus" (1555) and made the subject of special comment. Thus it is here we find the highest part of HK, the highest shore line (fig. 52), namely on the Rosstjärnsberget, 295 m above sea level in the vicinity of Skuleberget. This mountain was during many years considered as the locality for the real HK.

In this rocky landscape, the valley courses are deeply entrenched and only filled up to a small extent with sediments, mostly silt and sand. The latter is commonly of the wave-washed type. The glacifluvial sand is also of more subordinate importance which is quite natural since eskers, as already mentioned, have a very insignificant area. A remarkable feature is that the eskers stop, or more correctly begin, a distance from the recent shore. This also occurs in the Västerbotten section of the district, where it has been previously commented upon by Granlund (1943). He explained it by saying that the land ice was flowing within this zone so that tunnels could not develop.

Regarding the morphology of the moraine, the drumlin ridges are noteworthy for this district; they are especially characteristic for the environs of Nordmaling (A. G. Högbom 1905). The drumlins appear as swarms, up to 1 km or more long and some hundred metres broad. They traverse the region in a marked N—S direction which is also the direction of ice movement. On maps the landscape becomes striped in a characteristic manner, a feature well known from Finnish maps.

Further north, drumlins are replaced by terminal moraines which are described in connection with the next district.

The fine-grained sediment is mostly silt. It is best and most beautifully seen in the many high "nipor" (vertical cliffs), which in addition to the ravines are characteristic for the district. Both require, as mentioned, soil with a certain flowing power together with a relatively great height difference between the sediment surface and the adjacent river. At first with such a height difference, typical cliff forms are obtained, and the occurrence of nipor is, so to speak, a product of the soil type and the normal morphology of the region.

In the nipor the stratification of the silt is best seen. It is often varved as in varved clay, but the thickness of the varves can range from one to many decimetres, sometimes even more. The clay stratum, or in any case the most fine-grained stratum corresponding to the winter stratum, is not more than a few millimetres. Often the thickness of the total sediment pack amounts to more than 50 m.

It was mentioned that the size of the grains is in some degree critical for determining the distribution of the ravines. Therefore it is possible to illustrate with the help of a ravine map (fig. 53) the zone within the coast line occupied by silt, including the very fine sand.

Outside the silt zone come still finer grained sediments, namely clays of various types (comp. fig. 27). As far as is now known they are about the same as those in the previous district, that is, Ancylus and Litorina clays.

12 c. The moraine and sand district *(Morän- och sandområdet)* is the remainder of the coast zone up to the Finnish boundary. Towards the north it becomes more narrow, while in the south a wedge extends inside the preceding district to near the boundary with Ångermanland. The moraine and the sand are here each about 25 % of the land area. The mires are 30 %, while the other components make up 10 % or less.

It is of interest to note that moraine is often developed as terminal moraines (fig. 54). This is certainly the case in the most northern part of the preceding district, but not to anything like the extent of the present district. Exceptions are its most southern and northeastern parts. The terminal moraine district is most broad about the latitude of Luleå, and extends up towards Svartlå north of Boden. The ridges are largely elongated about SW—NE. Their size is about the same as the annual terminal moraines of southern Sweden but their extension is commonly longer. They have been more closely studied by Hoppe, who is of the opinion, that they are built up in front of land ice at its calving. G. De Geer considered that such small terminal moraines were thrown up by the advance of the ice during the winter, a kind of bulldozing effect: certainly calving could occur but only in exceptional cases.

Among the details about the moraine the following is of some interest. When the open pit of Boliden mine (WNW of Skellefteå) was excavated a beautiful long section was exposed which was interpreted as moraine. From a closer examination it appeared to be built of two moraine beds and was therefore spoken of as "the double moraine at Boliden". Later it was found that the upper bed has a peculiar structure. It consists mostly of sand, stones and small boulders, the two latter being rather well rounded or globular. But in addition the stratification presents a very special arrangement: boulders and stones are smallest in the uppermost levels but downwards the size increases gradually so that the largest are found near the bottom. Such a size distribution in a vertical sense is characteristic for coarser material gently agitated in a matrix. The stratification, therefore, is interpreted as a sediment washed to and fro in a little basin or lagoon which was present here just when the area was level with the shore line (G. Lundqvist).

Another feature of the structure of the moraine is a type of stratification

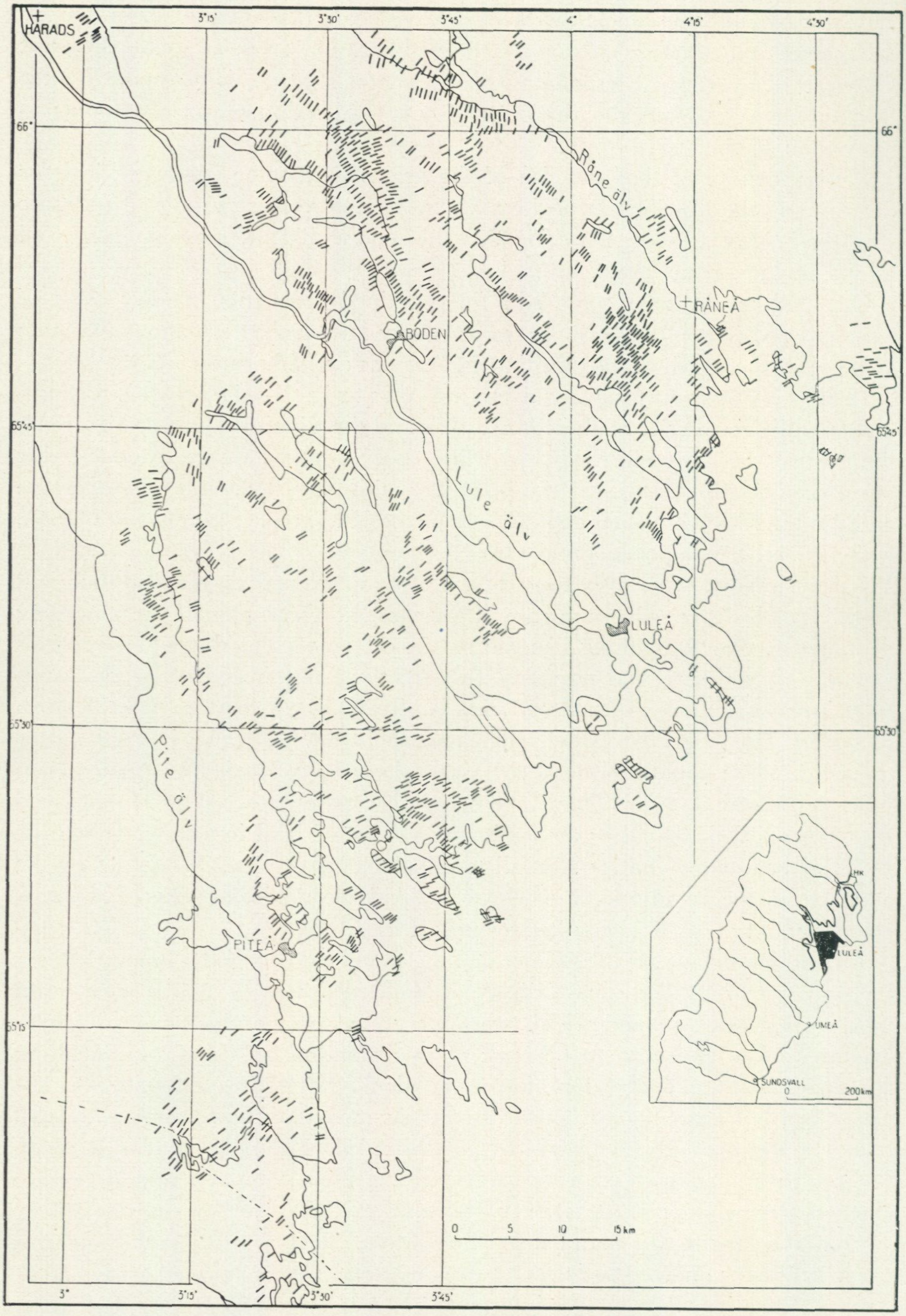


Fig. 54. Terminal moraines in Norrbotten according to Hoppe 1948. On the small map to the right the highest marine limit (HK) is marked with a heavy black line. According to the map the terminal moraines are to be found below the HK and mainly in the bottoms of the valleys. *From the coast zone of Norrland (12 c).*

F. Rengmark 1933.

Fig. 55. Kalixpinnmo (Kalix till) at Nederkalix, Norrbotten. It is built up of sand or fine sand, or possibly sometimes more morainic beds. These sediments are more or less folded or overthrown and the stratification commonly still visible. The boulder content is mostly very insignificant. Sometimes the moraine character is better developed.

From the coast zone of Norrland (12 c).

known as "Kalixpinnmo" (Beskow 1935, G. Lundqvist 1943, Hoppe 1948). It is most peculiar and best known from the coast strip where the terminal moraines cease towards the northeast, that is to say, in the environs of Råneå and Nederkalix. The "Kalixpinnmo" (fig. 55) is made up of sediments, commonly sand and fine sand ("mo"), in folded and crumpled packs of strata. The insignificant content of boulders is also striking.

The glacifluvial deposits have only an inconsiderable area. A remarkable feature of the gravel deposits within this district is that it is often very difficult to distinguish between the glacifluvial gravel and the often immense accumulations of wave-washed gravel. The latter lie close to the heights and can be 15—20 m thick. This determination is quite certain when a shell bed is found low down in the stratification. A criterion, if the expression is permitted, of wave-washed gravel of these larger dimensions is that it is found irregularly and not in distinct courses like eskers. Examples of such deposits are to be found on the eastern side of the River Luleälven between Luleå and Boden. On the western side is the glacifluvial course whose most widely known deposit is the delta Kallaxheden. This has been in use for two decades as an aerodrome. The material is mostly sand but shingle beds are found too, though they are seldom visible on the surface. Towards the shore-line of the Gulf of Bothnia, the material is almost eolian sand. In connection with this it may be remarked that from the air very interesting sandbanks transverse to the shore are seen beneath the water level and near the shore line. They are directed about perpendicular to the shore and appear to be the resultant of the river current and the shore current from the Gulf of Bothnia.

Sand and clay are together 35 %. The first is mostly limited to the valley courses and connected with the glacifluvial deposits. But in addition a considerable part of the sand fields is made up of wave-washed sand from the moraine slopes. The clay is largely of the post-glacial type: besides, there are more coarse types as for example, silt. Heavy clay is met with in the lower and more southerly regions. On the other hand, the silt is found farther to the north, even north of Pajala in the valley depression of the River Muonioälven, about 130 km north of the Polar Circle. Even from the main road it catches the eye by the way it flows out into the ditches and fills them up.

Among the clays there is one special type that is only met with on lower levels near the recent coast line. It is the mud clay (gyttjelera), mostly found in the vicinity of Luleå and other localities. It is rich in organic matter and limonite, mostly precipitated in the fissures and clothing its walls. The newly ploughed fields are brown and at a distance similar to sand fields. When this soil dries it crumbles to small pieces and is therefore called "grynlera" (grain clay). In these regions alum soil is found.

It is remarkable that varved clay is very seldom found in this district. Typical varved clay or silt similar to that found more towards the south in the Norrland coast region, is only found farthest up the floors of the old fjords below the highest shore line (Fromm). Also noticeable regarding the fine grained sediments both of this district and in the previously mentioned one towards the coast strip, is that the most fine grained strata are found in the middle of the stratification. This principle of construction is connected with the development of the river deltas: at first it was displaced inwards from the coast in connection with the ice recession, and then outwards towards the coast in connection with the land elevation. The most fine grained sediment is mostly clay. Unfortunately, the report of Svenonius that varved clay is common in Norrbotten, is false. In fact the district is very poor in varved clay which is much to be regretted, because the chances of elucidating the geochronology of the ice recession within the district are quite small.

In this connection, Fromm has called attention to an important relationship. In the sediments along the rivers Pite and Lule älvar is found a fine sand stratum about one decimetre thick in the boundary between the post-glacial and glacial clay. Fromm interprets this as representing a flood or catastrophic outflow from ice-lake drainages in the high mountains. It is important to note that such varves are lacking in the sediments in the rivers Torne and Kalix älvar, therefore no ice-lakes of any importance can have existed. This has been pointed out by Holdar for Lake Torneträsk.

Of special interest in these regions are the sulphidic clays of Norrbotten (investigated by Hannerz, Fromm, Wiklander and others). These clays are the youngest in the stratification, but the older parts have also been previously studied. The latter are made up of a black striped medium grained clay; the sulphide coloured stripes are on average a few mm thick. Between these black stripes the colour is light gray—reddish. Lowermost it is possible to distinguish an indistinct varveity with a small number of varves and best developed in the valleys of the rivers Piteälv and Luleälv. In the lower part the diatoms indicate salt bottom currents (Yoldia time); higher up, in the black striped clay, occurs an Ancylus flora.

Over the last mentioned Ancylus clay follows a homogeneous light clay marking the beginning of the Litorina period. Upon this lies a finely stratified or finely varved light clay with fine stripes of sulphide colour. But in addition, the clay appears to have a real lamination, with about 1 mm thick laminae, which show up as slices when the clay dries out. This must, according to Fromm, be a biologically conditioned varveity and must be similar to the lamination described by Granlund (1931) from the Kungshamnsmossen, a little raised bog in the vicinity of Uppsala. Fromm considers that the fine varved clay described by him from Norrbotten corresponds to the Litorina maximum.

Uppermost comes 1—5 m thick black or dark grey-blue, homogeneous light clay. The sulphur content is high, considerably more than 1 %, and the content of organic carbon about 2 %. On drying, this clay becomes rust-spotted and readily falls into small pieces. Where the ground is swampy and the sulphur content well preserved, this clay, on draining and later oxidation, forms alum soil.

13. The moraine and mire district of the interior of Norrland
(Inlandets morän- och myrområde)

This district is very extensive in a north—south direction, but in spite of this it is rather uniform with regard to its soils. From the environs of Karesuando, about 230 km north of the Polar Circle, it stretches down through the whole of Norrland into Dalsland west of Lakes Vänern and Vättern (fig. 29). Of course it is only the map picture which is so uniform; with regard to other phenomena such as those dependent on climate, the differentiation is quite great. Within this large district the moraine is commonly 45—55 %. There are many subdistricts: 13 a. The moraine and mire district (Morän- och myrområdet), 13 b. The Cambro-Silurian district of the Siljan region (Siljanstraktens kambrosilurområde), 13 c. The Cambro-Silurian district of Jämtland (Jämtlands kambrosilurområde), 13 d. The rock district of Revsund (Revsunds bergområde) and 13 e. The south-western Värmland—Dalsland district (Sydvästra Värmland—Dalslandsområdet).

13. a. The moraine and mire district *(Morän- och myrområdet)* is the main part of this large district. The moraine area is 45 % and the mires 35 %, uncovered rock is 10 %, also quite a low value. The remainder

G. Lundqvist 1957.

Fig. 56. Falkvålstjärnarna in the mountains NE of Ljungdalen, Härjedalen. Ablation moraine rich in small lakes. The direction of the ice movement was diagonal, approximately from the upper left corner. The anastomosing forms of the ridges do not in any way give the impression of having been influenced by an active ice front.

From the district of the high mountains (15).

constitute 5 % or less. Of course the 45 % of moraine is not at all uniform throughout the whole district. But one feature that pervades a large part of it is ablation moraine, the dead-ice moraine. This is nearly always a characteristic feature of the flat areas of the interior of Norrland. Mostly the ridges run in all directions; in the depressions between them lie lakes or mires in various stages of development. In some districts the ridges are rich in large boulders, in others they are poor in boulders. The forms can be gently rounded or rugged and sharp. The height of the ridges varies from a few metres to 10—20 m. These moraine forms were earlier interpreted as terminal moraines, but their irregularity, and especially their location up to and even on the last ice shed proves that this cannot be correct (fig. 56 and 57). Examples of areas with this moraine form are met with at Lainio ("the Lainio bow" as it is called in the older literature) in the north, Nautanen (near Gällivare), northwest of Murjek (under the Polar Circle), Giltjaur (the vicinity of Sorsele), east of Holmfors (the environs of Malå), Öjaren (lake NW of Strömsund), the Rogen district (north of 62° N latitude), north-east of Malung (at Västerdalälven), at the Lake Örsjön in northern Värmland and many other localities.

G. Lundqvist 1957.

Fig. 57. Ablation moraine SE of Lillholmssjö at Lake Gysen about 50 km N of Östersund, Jämtland. The flat level is covered with mires. The varying directions and morphology of the ridges show that they were not pushed together by an ice front. These land forms are characteristic for the interior of Norrland.

From the moraine and mire district of the interior of Norrland (13 c).

Within certain parts of the district the ablation moraine is replaced by a form whose ridges are orientated along the direction of the ice movement (J. Lundqvist 1958). In certain cases these ridges are clearly drumlins (Nordmaling SW of Umeå in Västerbotten, Töcksmark in Värmland), in others they are quite as clearly radial moraines (the vicinity of Äppelbo in Dalarna). In Norrbotten the type is not yet decided upon but the drumlin-like morphology is here more distinctly developed than almost anywhere else. In many localities it gives the landscape the same striped appearance that we know so well from Finnish maps. This phenomenon is caused by the presence of mires which are quite well seen on the general map within the district Vitträsk—Murjek—Hakkas (the last SE of Gällivare) below the Polar Circle. This is in spite of the fact that a very great number of mires have been omitted altogether or united with each other.

Terminal moraines — the third morphological type of moraine — are met with at many localities within this very elongated district, for example near Karlsborg (west of Lake Vättern), Kristinehamn, Filipstad etc. The most exclusive terminal moraine field is found in the bay Åråsviken (at Lake Vänern) and thereabouts, e.g. Gullspång (fig. 8). Other moraines of this type occur in parts of Västerbotten and Norrbotten and are connected to those mentioned above (fig. 54). But in the interior, i.e. the supra-aquatic district, no terminal moraines in the normal sense are found.

The stratification of the moraine is rarely differentiated and this is the case here too. However, the occurrence of Kalixpinnmo was mentioned under the district 12 c and areas with this continue into the present one, that is to say north of Råneå and Nederkalix. It may also be mentioned that morainic strata in other parts of Sweden show Kalixpinnmo, which is in no respect different from that of its original area. Thus it is found, for example, in Dalarna (Särna) and in Värmland.

In connection with the discussion of the stratification of the moraine it must be remembered that the moraine in certain regions can be gravelly up to the surface. There are only a few observations showing the stratification within these regions, therefore we do not know if it is only a superficial phenomenon. It is also common that these regions lie near the ice shed or west of it. However, one gets the impression, that the surface is washed over and the material redeposited. Therefore it is possibly better to interpret it as sediment instead of moraine. But in such a case it is peculiar that the material shows vague traces of pressure. Examples of such regions are found north-west of Kiruna, in Härjedalen and northernmost Dalarna.

The glacifluvial deposits form about 5 % of the land area. Of course over such a large surface area many different types must be present within the relatively limited record. Thus there are many types like the large delta Svedmon south-west of Hjo at Lake Vättern, genuine eskers and deltas north-east of Lake Siljan, even as far as the large gravel and sandfields south of Karesuando far north of the Polar Circle. They are found within practically the whole of the district, but of course there are large gaps locally as in south-western Värmland and the westernmost part of the Norrland region towards the boundary to district 14. The moraine district of the piedmont belt (Förfjällens moränområde). A striking feature in the appearance of the glacifluvial deposits is that they are very intimately connected with the surface forms of the country. They follow the valley-courses — the rivers. Where the forms are deeper they are more frequent, lie closer and become larger. One of the more remarkable courses is the Malung esker which appears to begin at Karlskoga (NE of Lake Vänern); it passes Hällefors and continues up along the River Västerdalälven. It certainly follows a marked fracture valley. However, it is not impossible that it is a continuation of a course, which begins with the delta Svedmon west of Lake Vättern. On both sides of this long course are similar, but only relative short eskers. Past Ludvika there is one, the Malingsbo esker, which begins with the well known delta Riddarhyttefältet (Nelson 1910). That,

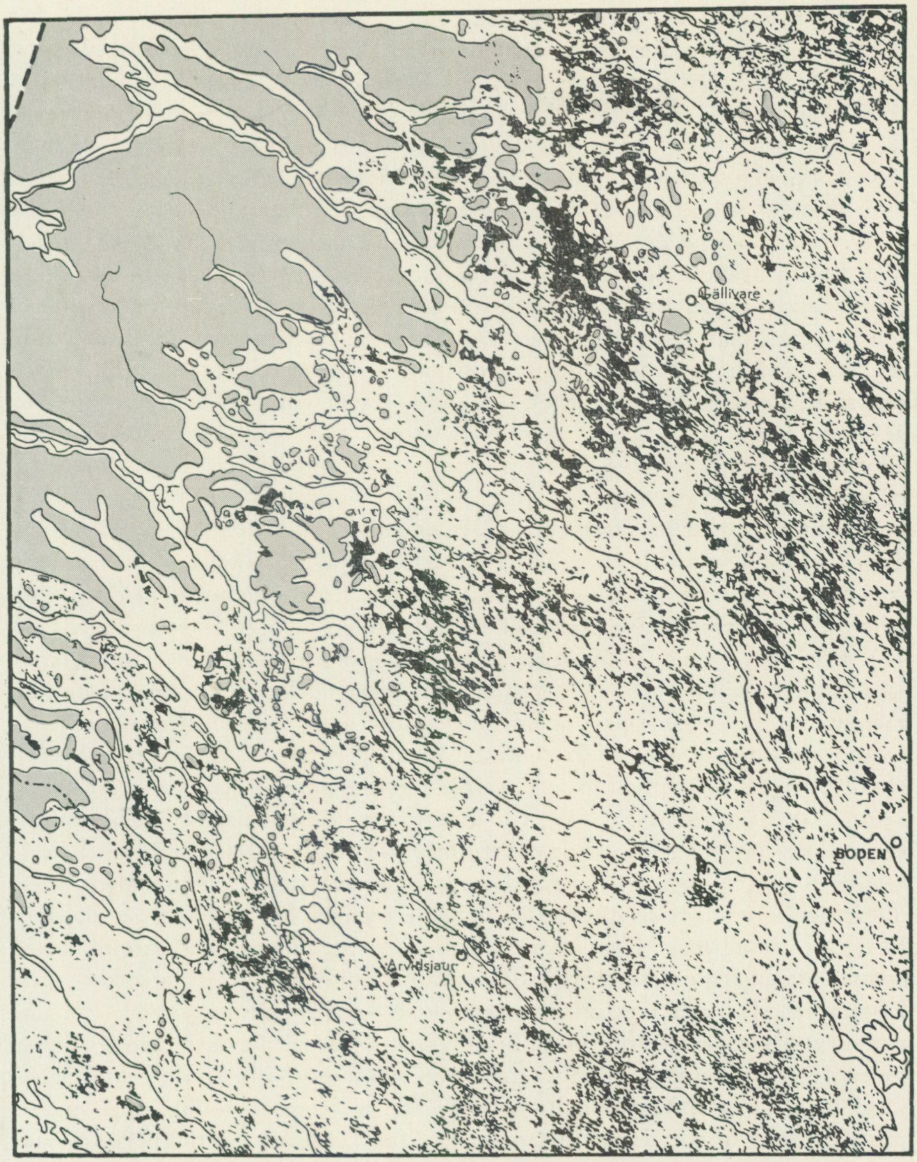


Fig. 58. The distribution of the mires (black) in the district Arvidsjaur—Boden—Gällivare—The Norwegian border (in the NW). The high mountains are grey (screened). The accumulation in the high flat districts between the rivers is interesting and this mire zone can be followed from southwestern Sweden nearly along the whole of the country to beyond Lake Torneträsk in the north.

From the moraine and mire district of the interior of Norrland (13 c). In the NW, the district of the high mountains (15).

in its turn, may possibly be composed of a secondary esker to the Norrköping esker and of the Köping esker. In (towards) Dalarna comes the Älvdal esker, which also begins with a large delta, the Mora delta. A direct continuation of this esker is the Idre esker which extends into the mountains. The Rättvik esker begins with a delta in the district 13 b and follows the River Oreälven upwards as the Ore esker. This course is developed as alternating gravel deltas with shingles, sand fields or eskers. A long and well marked esker is the Järbo esker. It appears to be divided into two: the Lo esker and the Voxna esker. The last mentioned does not lie just in line but its dimensions are larger. In reality it is a rather broad field of sand and gravel in the valley depression of the River Voxnan. The Sveg esker is of the same type and possibly situated on its continuation; it can be followed up past Hede (north of 62° N latitude). On some stretches the whole of this esker—delta complex is interrupted by either moraine hills or hills shaped like them and very similar to moraine. Therefore it is not possible during a rapid survey to draw the correct boundary of the glacifluvial deposit.

Towards the north, practically all river valleys including the smaller ones are occupied by glacifluvial deposits of various types. But what is most striking is that they stop so suddenly towards the west; this is better seen on a map where these deposits have been isolated (comp. Atlas över Sverige maps 17—18). It is most distinct in the region around the upper part of the long, narrow lakes Malgomaj, Vojmsjön, Storuman and Storvindeln. The cause cannot be merely that the western part of this long district is relatively unknown.

Another striking feature is that the distinct NW—SE direction ceases at about 67 1/2° N latitude. North of this there appears to be two main directions, NW—SE and NE—SW. Conditions are thus similar to those of the central part of Jämtland, though there they are less marked. Possibly the cause of this is that the ice on the flat land is more markedly split up along these directions. The glacifluvial deposits in these regions, however, are so different from those in adjacent areas, that quite special wastage conditions are indicated compared with those towards the south. Examples are Kalixälv esker—Jukkasjärvi esker, Lainio esker, Råstoeno esker—Åggojokk esker etc. (for the names and a clear picture of their distribution see 'Atlas över Sverige', map sheets 17—18). In connection with these mention should be made of the Särkijärvi field and the Muonionalusta field. The dimensions of the latter exceed those of most of the deltas in Norrland. Many of these northern fields have reworked surface layers or a superficial layer of eolian sand. Possibly this is dependent on the fact that they are largely covered by ice-lake sediments of a grain size susceptible to wind action. Their eolian nature is nowadays often seen on bared surfaces of sand.

The clay occupies a very insignificant area within this district. In reality it is found almost only in the extreme SW, east of the Lake Vänern and in southeastern Dalarna and adjacent parts of Västmanland. North of this "clay district", as has been repeatedly pointed out, silt and of course clay extend as tongues up valley depressions from the eastern districts. As already mentioned

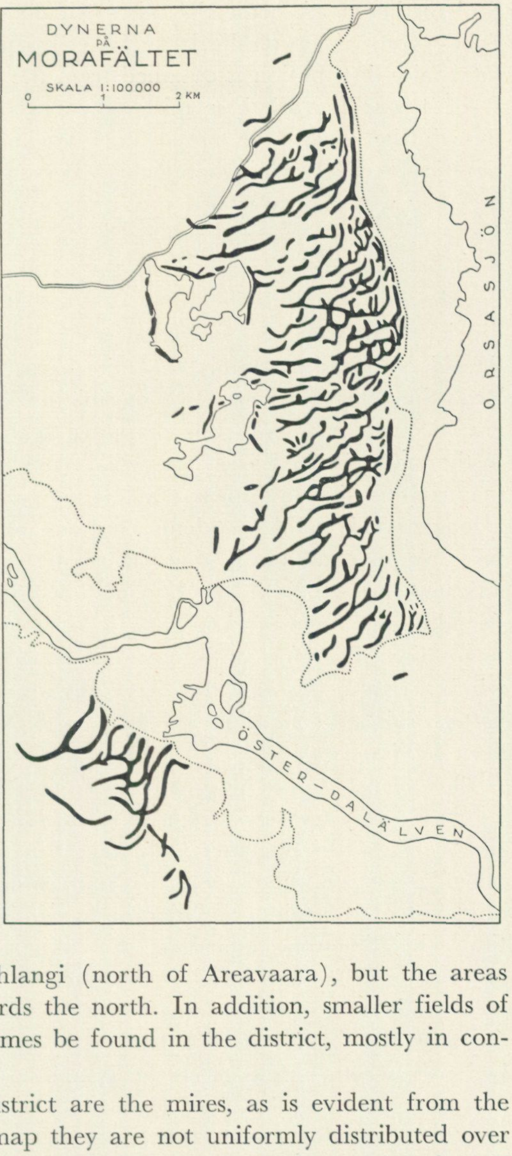


Fig. 59. The dune field W of Lake Orsasjön, N of Lake Siljan in Dalarna. The ridges are black; the dotted line is the Bonäslinjen, a supposed shore line of L. von Post, which has been much discussed in Swedish Pleistocene literature. A more correct interpretation is given by Halden. After Sv. geol. unders. Ser. C. Nr 457.

From the moraine and mire district of the interior of Norrland (13 b).

silt occurs north of Pajala to Kihlangi (north of Areavaara), but the areas become smaller and smaller towards the north. In addition, smaller fields of fine grained sediments can sometimes be found in the district, mostly in connection with the great lakes.

Of great importance in this district are the mires, as is evident from the district name. According to the map they are not uniformly distributed over the surface. Most remarkable is their marked accumulation in a series of small regions near the western boundary of the main district. The largest of these mire areas is met with in northwestern Dalarna where the mire area is 40—60 %, and locally up to more than 70 % of the land area. From here a long series of smaller mire regions is visible towards Lake Storsjön in Jämtland. A large mire field outside the main district proper may be mentioned because it is well in line with these mires. It is the area situated SW of Strömsund. After that follow the mire areas around Vilhelmina, SW of Lake Storavan, SW of Jokkmokk, and northwards the large mire complexes of Muddus and Sjaunja.

Still further north come the mires Ripakaisenvuoma (north of Vittangi) and Sekkuvuoma (east of the large Lake Torneträsk). A very good survey of the total mire distribution is obtained from the 'Atlas över Sverige', map sheets 42—43. Regarding all these mire-rich areas (fig. 58) it can be said that great though the areas are, the average thickness of the peat layer is quite insignificant, roughly less than 2 m. A pervading feature, too, is that these mires are very wet, mostly ribbed mires, often with sharply limited 'strings' (comp. fig. 20).

Of course one may ask what the cause of this lengthwise zonation of the distribution of the large mires can be. It is especially striking because the district to the west, nr 14 (comp. fig. 29), appears at a first glance to be almost devoid of mires. Certainly the mire area there cannot be more than 10 %. Regarding this difference two possibilities can be considered: either the topographic map is at fault, the mapping to the west being inferior, or the mires in the more elevated areas are replaced by dry heaths. The first alternative we may reject as it is not likely that mapping of an extended zone performed over a long period, should suddenly be worse along a nearly straight line. A more probable explanation is that the eastern part of the high mountains and adjacent districts lie in the rain shadow of the moisture-laden Atlantic winds. In addition, the mire-poor zone is situated on the large lower slopes of the mountains. Therefore it is quite plausible to assume that when the easterly winds arrive in this area they have already lost most of their moisture. Finally, better drainage conditions also help to explain why development of mires has been inhibited.

13 b. The Cambro-Silurian district of the Siljan region *(Siljanstraktens kambrosiluromrâde)* is nearly completely included in the "ring", which together with Lake Siljan encloses the so-called "Siljanskupolen". The area of the district is quite insignificant; uncovered rock is almost non-existent. Certainly the moraine cover is cut away occasionally in connection with limestone quarrying, but this is not a natural occurrence. The moraine is 25 %, and in addition there is 5 % of boulder clay. But this is very local and connected exclusively with shale occurrences in the Boda valley (between Ore and Rättvik). Here it is certainly difficult to determine if it is bed rock weathered to pieces or a shale crushed down by the ice. These occurrences have certainly no regional importance. Glacifluvial deposits and sand are 20 % each. Probably the latter is, from a genetic point of view mainly glacifluvial. Here the glacifluvial deposits are for the most part large deltas with very heterogeneous material, varying from sand to about 1/2-metre large rolled boulders. The surface forms vary greatly from nearly flat fields to rounded, hilly kames south of Lake Oresjön, or fields dominated more or less by esker ridges, north of Skattungsbyn. The latter is a large delta and of interest because of the formation of eskers directed SW and SE, proving that the delta is of a complex nature: thus it is deposited by glacial rivers flowing towards the SW and SE.

In connection with the glacifluvial deltas there is, as already mentioned,

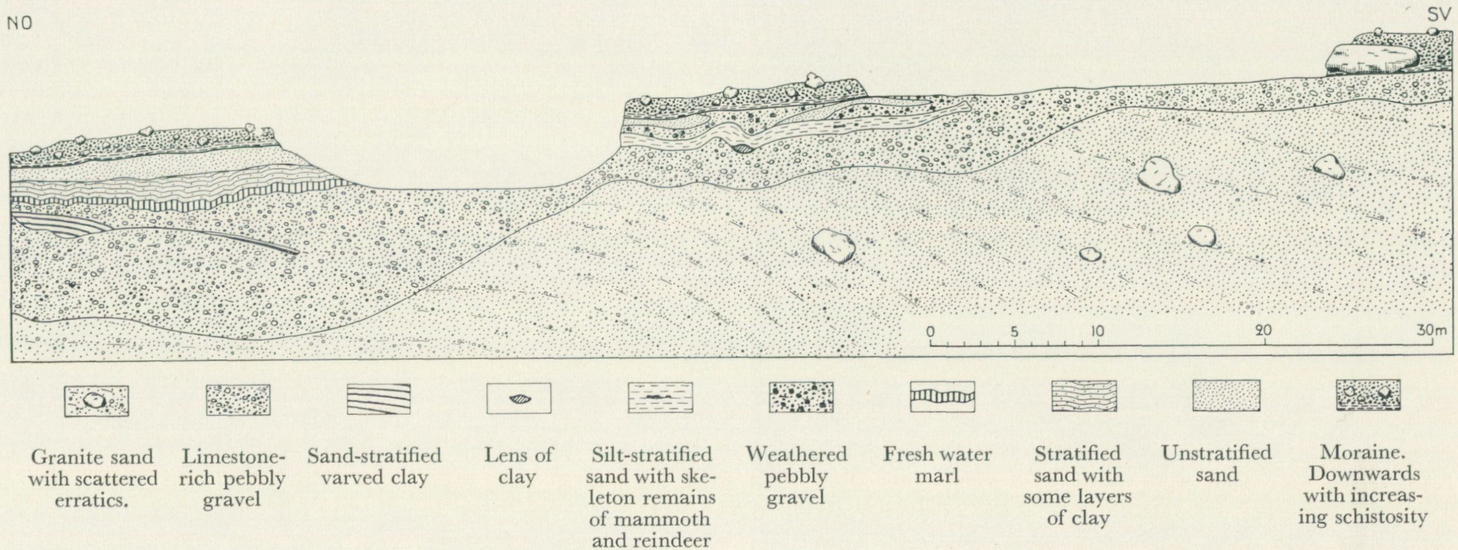


Fig. 60. Section through the glacifluvial deposit at Pilgrimstad (according to Kulling 1945). The stratigraphy is characteristic of certain parts of Middle Jämtland: one upper moraine with material from the west (or north) and a lower one with Pre-Cambrian material from the east. Between the limestone-rich gravel and the upper moraine lie the mammoth-containing sediments, which are $>$ 38,000 years according to dating with the C 14 method.

From the moraine and mire district of the interior of Norrland (13 d).

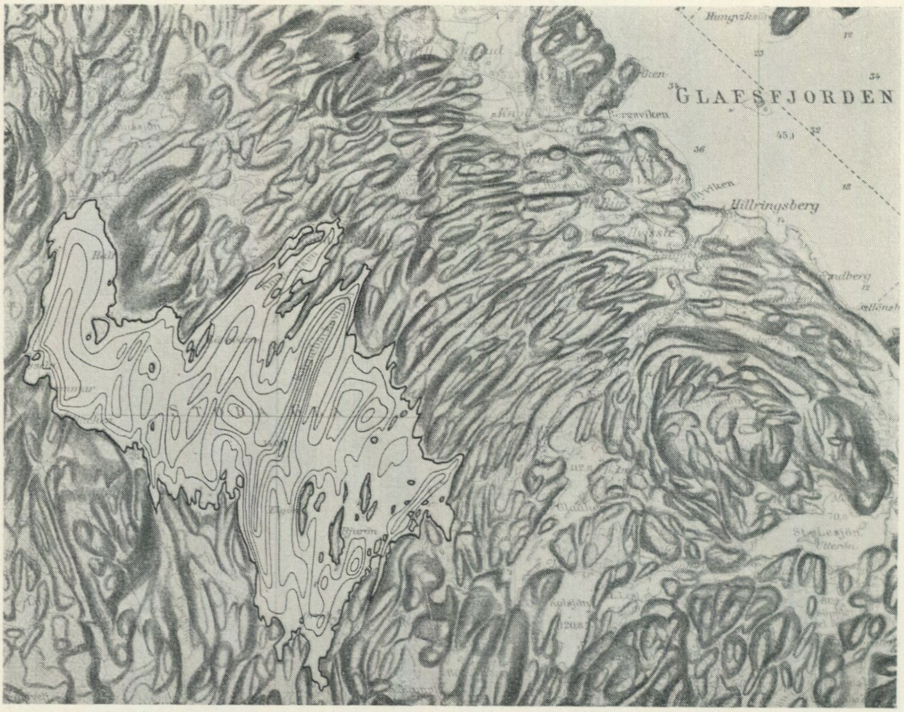


Fig. 61. The terrain forms in the vicinity of St. Gla—Glafsfjorden S of Arvika NW of Lake Vänern; the morphology from the manuscript to the Morphological map of Sweden by Magnus Lundqvist. The characteristic forms depend on the strike of the bed-rock in the marginal area of the Gillbergaskålen, a well-known petrographical area, a synclinal, described by N. H. Magnusson. The same forms continue on the bottom of the Lake St. Gla (depth contours at 5 and 10 m intervals according to E. Teiling 1916).

From the moraine and mire district of the interior of Norrland (13 e).

sand that is primarily associated with it. Later, it is locally redeposited by the wind as eolian sand. Smaller similar fields are found, for example, NE of Orsa. The most magnificent, indeed one of the finest dune fields in Sweden, is the Mora field situated west of Lake Orsasjön (fig. 59). It has been many times described and discussed in the literature (I. Högbom 1923, Enquist 1932, G. Lundqvist 1943 and others).

13 c. The Cambro-Silurian district of Jämtland *(Jämtlands kambrosilurområde)* has, on the maps 15—16 in "Atlas över Sverige" quite other boundaries than those shown on the present general map. The reason for this is that it has recently been thoroughly revised during summary travels by G. Lundqvist and Jan Lundqvist (1956) who in doing so found that the area marked as almost completely boulder clay, 55 % of the land area, on the older map, has no such appearance. This value according to the new mapping is about 20 %. After a further two summers' work Jan Lundqvist has still further corrected the picture in detail. The constitution of the boulder clay is very various as is clear from the summary on p. 14. Of course sub-

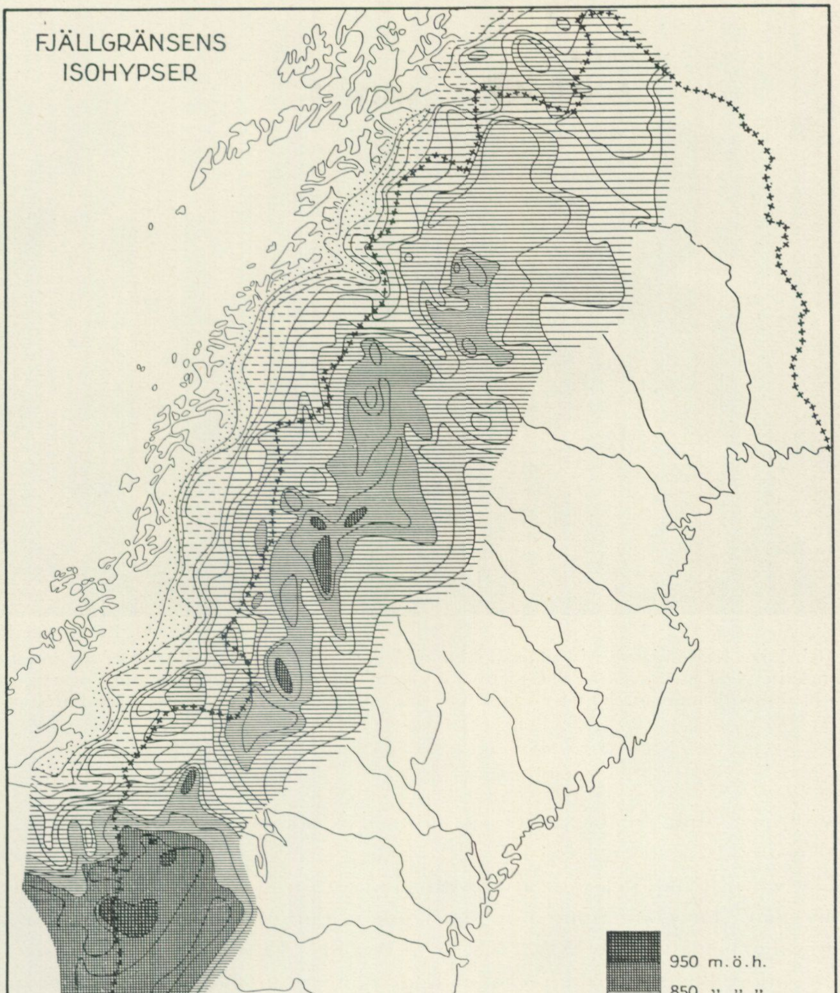


Fig. 62. The isohypses of the timber line in the high mountains according to the maps of the General Staff. The altitude of the limit increases towards the higher parts of the mountains ("massupphöjningen") but decreases to the north. In spite of the very various altitudes of the timber line for different aspects of the same mountain, this map gives a good idea of the main principle.

After Sv. geol. unders. Ser. C. Nr 457.

G. Lundqvist 1950

Fig. 63. Lake Kajtumjaure with Tjikkopakte and the high mountain district of the mountain Kebnekaise N of St. Sjöfallet. The picture is characteristic for these mountains: scarps, often overthrusts, with immense boulder heaps. On this side of the lake is fine delta land around the Tjikkojokk.

From the district of the high mountains (15).

division according to the principles outlined is not possible on a map on this small scale.

The glacifluvial deposits are, within this district, of rather insignificant dimensions. They are limited to short eskers but the directions of these are interesting being mainly SW—NE or NW—SE. These are the directions of the ice movements and the crevasses and fractures in the land ice which were perpendicular to them. Often the ridges are rather marked but of insignificant height. As examples can be mentioned the little esker along the road NE of Mörsil and the esker between Sikås (NW of Hammerdal) and Yxskaftkälen (SW of Strömsund).

Glacifluvial deposits of the large type, valley trains, deltas and such like are very rare but one example is found in the great valley of the River Hårkan north of Lit. This glacifluvial area is made up of even fields, rounded hills and eskers, and the material varies from boulders to sand. Locally these deposits are broken through by moraine hills; particularly is this the case towards the north, where the field dies out in a rather diffuse way.

The mires form 35 % of the land area. They are spread over the whole of the district, but a special concentration is met with in the triangle Hammerdal—Strömsund—Flykälen (W of Strömsund). Immense, highly elevated mires, often with bog areas, are a very characteristic feature of the landscape.

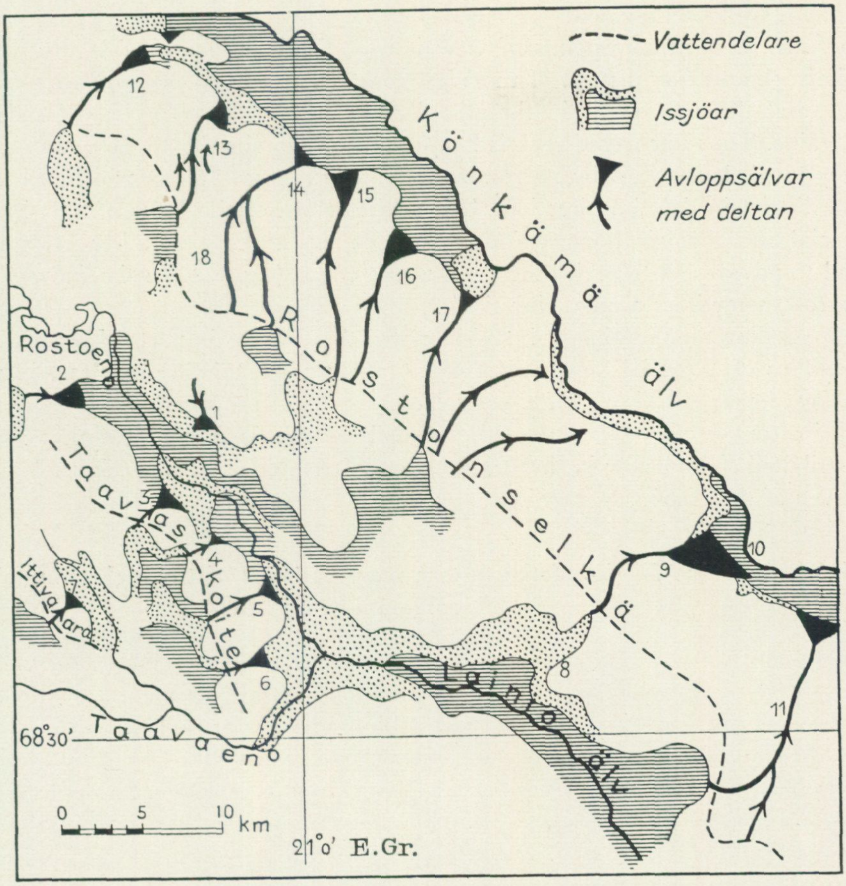


Fig. 64. Schematic picture of the marginal hydrography of the ice sheet in northernmost Sweden according to Tanner 1914. — Vattendelare = watershed; issjöar = ice lakes; avloppsälvar med deltan = outlets with deltas.
After Sv. geol. unders. Ser. C. Nr 457.
From the district of the high mountains (15).

13 d. The rock district of Revsund *(Revsunds bergområde)* is situated SE of the previous district. On both the map and in the field it is well defined. Travelling in these regions it is very easy to observe when one arrives in this district owing to the abundance of steep sided hills or knobs of smoothed rock. Thus uncovered rock forms 20 % of the land area and moraine 45 %. Of the remainder only the mires are of any importance forming 25 %. The moraine can often contain large boulders but locally these may be sparse. Sometimes it can be quite rich in clay which is the case in the valleys. To the glacifluvial deposits belongs the gravel field at Pilgrimstad (fig. 60) in which a famous mammoth find was once made (Kulling 1945). This field, which was built up of interglacial layers too, is nowadays largely dug away.

13 e. The south-western Värmland—Dalsland district *(Sydvästra Värmland—Dalslandsområdet)* is the little district NW of Lake

Vänern from the boundary to Norway through Töcksmark and Årjäng down to Åmål. From many points of view it is a direct continuation of district 4, The rock and clay district of the West coast (Västkustens berg- och lerområde), but differs from it in that the largest part of the clay is replaced by moraine. Thus uncovered rock is 25 % and the moraine 55 %. The district is very much broken up by narrow and limited fracture valleys which traverse the district in definite directions. The region south of the Lake St. Gla has a special morphological expression. The rock exposures are rather elongated and trend parallel to each other in a gentle curve (fig. 61). In the furrows lie narrow, sometimes arable, clay fields.

Regarding the moraine it should be noted that in certain parts of the district drumlins of a special type are formed (Jan Lundqvist 1958). At least in the surface layers the clay is of a post-glacial type and not varved. But even the glacial clay is very rarely varved: normally this is found only in thin zones distributed sporadically in the stratification (J. Lundqvist). A geochronological survey of the district is therefore very difficult to realize.

14. The moraine district of the eastern marginal zone of the high mountains
(Förfjällens moränområde)

This district is a relative narrow strip between 13. The moraine and mire district of the interior land (Inlandets morän- och myrområde) and 15. The district of the high mountains (Kalfjällsområdet). The appearance is very uniform according to the present general map, as are the area values: the moraine is 65 % and the mires 25 %. The moraine is often rich in boulders or has large boulders. Its forms are rather often hummocky and of the ablation type. Large fields of this type are found, for example, north of the northern part of Lake Flåsjön, west of the northern part of Lake Vojmsjön, north of Lake Storuman and north of Lake St. Lulevatten. Smaller fields are found nearly everywhere within the more level areas of the district. Regarding the constitution of the moraine, it is noticeable that locally it can be rather rich in Cambro-Silurian material or other more special rocks. Such is the case near Alanäs; near the northern part of Lake Flåsjön occurs a black, clayey shale moraine. Another example is the district west of Kiruna where the moraine is very rich in porphyry material (Geijer 1922).

Glacifluvial deposits are rather rare within this district and, as already mentioned in connection with the foregoing, the limit is very sharp. In the eastern district (nr 13) eskers etc. are quite common, but they cease very abruptly nearly along a line parallel with the high mountain ridge.

15. The district of the high mountains
(Kalfjällsområdet)

This district is in many respects different from the previous one. This is partly dependent on the fact that the different regions are either connected with each other or of a uniform type. But unfortunately it is also in regard to maps that a very serious discrepancy arises as it has not been possible to get certain important data directly from the old topographic map sheets. As already mentioned the mires and the uncovered rock are obtained from this map. Above the timber line, whose altitude varies very much but to some degree regularly (fig. 62), the topographers have unfortunately changed their technique: neither uncovered rock nor mire are distinguished there except in exceptional cases. Especially as regards the bed rock is this lack very unfortunate because certain regions are quite uncovered, while in other regions it is impossible to discover the smallest rock surface. However, from the air it is found that the uncovered bed rock is very rare in certain regions of Sweden, but nearer the boundary with Norway the land surface changes appearance in a quite remarkable manner: here the mountains are characterized to a large extent by uncovered bed rock. This is best seen during rain when the rock surface is seen to shine brightly from a long way off. It is especially the case in such districts where the rock is made up of mica-schists. The differences are very clear in Jämtland and Lappland, where such schist surfaces shine locally. Other rocks such as greenstones of different types, especially amphibolites, which characterize our highest mountain districts, can be very strongly weathered and broken up by the frost. These areas of bed rock are then pure boulder fields. But it is not only the amphibolite outcrops that have such an appearance; some sedimentary rocks, like sandstones and quartzites can be similarly much frost shattered. Examples of such mountain districts are found in Dalarna (Fulufjället, Städjan etc.), Vemdal, the Klövsjö mountains and others. Leading features in the northern mountain district are the overthrust precipices (fig. 63).

As already mentioned the other forgotten factor is the mires. It is inevitable that there are mires above the timber line, locally to a rather great extent. As examples may be mentioned the mountains in Dalarna, in the region of Kebnekaise in northernmost Lappland etc. But a complete and accurate treatment of their distribution in the mountains is lacking because of the reasons indicated above. In this connection it may be remembered that L. von Post was of the opinion that mires could not be found above the timber line on account of earth flow (comp. Troll). This is so but only with reservations. Furthermore it must be here mentioned, that according to information given me orally by Troll, von Post is responsible for the incorrect altitude reports within Sweden on the map fig. 1 in Troll 1947.

Among phenomena of interest in the mountain district are the glacifluvial deposits. Commonly they occur as eskers which can be rather persistent and beautifully delineated in the landscape. As an example may be mentioned the Härjång esker NE of the Helagsfjället, clearly visible on the topographic map. A similar one is found in the Remdalen valley north of the northernmost point of Jämtland. In certain stretches the latter is surrounded by silt or very fine sand, which are relics of the ice-lake that once upon a time occupied this depression (A. Högbom 1925). Another important esker is the Kummajokk esker just south of the Treriksröset the common boundary cairn of Sweden,

G. Lundqvist 1949.
Fig. 65. Stone rings on the plateau below Mount Jakobshöjden at Grövelsjön N of 62° N latitude in northern Dalarna. The forms are not so regular as those within the high alpine part of the Swedish mountains. The picture was taken from a 5 m high ladder.
After Geografiska Annaler 1949.
From the southern part of the district of the high mountains (15).

Norway and Finland (Treriksröset). This esker, too, is partly surrounded by fine grained sediments. It is also of interest, because it consists of two parallel eskers, which is rather common in northern Finland (according to the literature, e.g. Tanner 1914) though rare in Sweden.

Besides such larger and more normal eskers there are probably a very great number of smaller ones. They are often found within the small hummocky ablation fields, which are so common on the large and even valley plains. One example is the mountain heath in the neighbourhood of the Helags and Sylfjällen mountains. Of the same type but to a certain degree well displayed, is the esker complex that is found in the Dörrsjöarna lakes at Mt Hundshögen in the Jämtland mountains (Mannerfelt 1945).

Quite special eskers are the small "slukåsarna" (translated approximately as engorged eskers according to Mannerfelt). These are found in flat depressions on the mountain slopes and are orientated perpendicular to the contours. Mostly they are not more than some 100 metres long and a few metres high. The finest area is on Mt Fjätervåla in northern Dalarna, mapped by Manner-

G. Lundqvist 1950.

Fig. 66. Boulder trenches on the mountain Tuolle SE of Kebnekaise. These boulder trenches extend along the slopes perpendicular to the contours on certain mountains. At a distance the slopes consist of dark and light stripes; therefore we called them zebra mountains as a field name. *From the northern part of the district of the high mountains (15).*

felt (1945). See also the pictures in G. Lundqvist 1951. Furthermore they are met with at many other localities in Dalarna and in Lappland (J. Frödin, 1915, called them "submarginala dejektionskäglor", or submarginal dejection cones).

All these areas are situated above the timber line. Under this limit engorged eskers are known from northernmost Värmland (Jan Lundqvist 1958).

Also worth mentioning are certain eskers situated upon the water shed on both sides of the border with Norway. They are of special interest marking as they do the drainage rivers from previous ice lakes (A. Gavelin 1910).

The fine grained sediments which are found locally (fig. 64), also give information about these ice lakes. We have already mentioned the fields in the Remdalen valley and along the Kummajokk esker. Certainly, such areas with fine grained sediments, mostly silt or very fine sand, are to be found at numerous localities within the mountains, but it is difficult to discover such small occurrences. One example is the varved clay, which is described by Axel Erdmann (1868) from the northern shore of the Lake Saggat just west of Årrenjarka (east of Kvikkjokk). He states that it is of a significant extent (the original description is quoted by G. Lundqvist 1943, p. 93), but despite this the occurrence is not easy to find. However, the material that is now left after "clay digging" is not clay, but can be described for practical purposes as very fine sand with clay or silt laminae. In the sediment, organic matter is also commonly found, at least in that part of the stratification which it was possible for me to study.

Most distinctive for the district of the high mountains is the frost earth, that is, a synthesis of all the soils which are destroyed by the frost. It is mostly the moraine that has suffered such treatment. Commonly it is possible to see by the surface forms if these processes have occurred. However, the surface is often quite flat and smooth, but it is nevertheless possible to get some idea as to whether anything has happened by studying the boulder directions. Normally at least, the longer boulders lie with their axes in the direction of the ice movement. If that is not the case one may suspect that earth flow has taken place: when the ground is inclined and the boulders orientated perpendicular to the height curves one can be quite sure it has occurred. A beautiful example where the slope is nearly unnoticeable is known from Mt Hundshögen in Jämtland.

The more general and obvious forms are shown in fig. 22 where the surface forms are arranged with regard to the most important factors which influence the development, namely, the boulder content, the vegetation and the slope of the ground. There are besides many forms, whose development is quite unknown. Some of the main types of these small forms include earth hummocks, earth fissures and stone rings (fig. 65), the last two being often summarized under the Swedish designation 'rutmark', meaning approximately stone nets. Also noteworthy are the turf-banked terraces and stone-streams. The dimensions of these forms can vary from less than 1 m to about 100 m. But besides the above mentioned types is one, provisionally called boulder fractures (blocksprickor); these are large fractures filled up with stones and boulders and traversing obliquely the mountain slopes. Whether they are common or not we do not know and the same applies to a form which could be provisionally called boulder trenches (blockdiken). These can cover the whole of a mountain slope and are arranged perpendicular to the contours. On account of them the ground becomes striped in dark and light (fig. 66) shades in a very characteristic manner. From the air they can be seen at a great distance. I know such cases from Ultevis and the region of Kebnekaise.

All the frost earth forms with stones or boulders are characterized by the fact that the largest stones or boulders lie closest to the surface. Their size diminishes more or less towards the bottom. The cause of this is that the material is elevated by frost heaving, that is to say, the freezing of the water content in the earth; on thawing, the smallest boulders etc. fall down first and thus support the larger ones above. This profile with more coarse material at the surface and successively smaller sizes down towards the bottom, is also developed at localities where it appears very improbable that any water could remain. Such readily accessible profiles are found in boulder depressions (blocksänkor) that is, the special frost earth type which is found deep in the forest land. They are found even far down in Småland (G. Lundqvist 1952).

Of course it would be of interest to know if the frost ground forms have a regional distribution. Unfortunately, we cannot yet give the answer to such a question because the data is too fallible. A slight tendency, however, appears to be for the earth fissures, at least those found up to now, to occur only in those parts of the high mountains, Kebnekaise, Sarek, N. Storfjället, Ammarfjället, Helags etc. which have the most mountainous features. Also it appears as if the previously mentioned boulder trenches have a limited distribution. I can, for example, only recall having seen them from the marginal, smoothly rounded mountain slopes at the foot of the mountains Sarek and Kebnekaise.

Concluding remarks

Possibly the preceding account in some parts may be considered to be rather meagre and this is indeed so; but it could have been extended to an almost unlimited extent. I have, however, preferred to lay the chief emphasis on the illustrations for in this way a better idea of the map picture is obtained. Possibly it would have been better to have had more small maps of the type shown in figures 26, 35, 40 and 51, that is, maps of detailed phenomena which are not readily shown on the general map. Certainly the photographic material is quite extensive in relation to the text, but yet it is still not adequate enough to illustrate the various types found in the different districts.

The map is now as complete as the available data permits. My hope is that the map in the future may be completed in two important respects, namely as regards the sub-division of the moraine and the fine grained sediments. Remarkably enough we shall know in a few years these types of phenomena better in Norrland and northern Svealand than in even relatively newly mapped regions in southern Sweden. My hope too is that the high mountains may be better known. This concerns the primary sub-division into primary soils, frost earth and uncovered rock ground. The last factor must be quite simple to get from aerial photographs. Also a separation of the two above mentioned main groups of soils can be made with the same photographic material. Broadly speaking, it is a fact that the small hummocky areas are built up of coarse soils through which precipitation easily passes. Therefore only an insignificant amount of frost action affects them; they are also of a primary type. The mountain slopes have nearly always more or less flowed and been redeposited to some extent. In every case it is always necessary, at all stages of the work to have fully clear the scale of the map.

The data of the map

Probably it may be of some interest to know something of the material of the map. Firstly it can be said that it is mostly based on other maps in very various scales. But also included in the picture are statements from the literature and unpublished records of different kinds and reliability. Of course an extensive amount of material was collected during my own travels.

Southern Sweden, up to a line between, broadly speaking, Gävle—Grängesberg—Filipstad—Säffle—Strömstad, was previously mapped and the maps published by the Geological Survey of Sweden in the scales 1: 50 000, 1: 100 000 and 1: 200 000. These maps were all generalized by K. E. Sahlström and published by the Geological Survey in the scale 1: 400 000 (1947—49). For the remainder of Sweden the following county maps were available: for Kopparbergs län (1: 250 000) by G. Lundqvist 1951, and the county of Västerbotten below the cultivation limit (1: 300 000) by E. Granlund 1943, and Värmland (1: 200 000) by Jan Lundqvist 1958. Norrbotten was mapped under the direction of E. Fromm for reproduction in the scale 1: 200 000 (not yet published). Of the remaining parts of Norrland only more or less schematic maps were available from which scarcely more than the eskers could be reproduced.

The previous material from Norrland was combined, including literature statements, in a map in the scale 1: 2 million by G. Lundqvist (1942 and 1943). Through methodical collection of new material this map of Norrland was successively completed.

When a map of the soils was required for the extensive work "Atlas över Sverige" under the editorship of Dr Magnus Lundqvist all the above-mentioned maps were used and combined to form map sheets 15—16, the soils (Jordarterna). This map, with accompanying text (by G. Lundqvist 1953), was a necessary prerequisite for the present general map because all the Atlas originals could be used, thanks to the courtesy of the editors.

Of course the Atlas map was completed for the present one and this required in particular new mapping in the counties of Gävleborg (G. Lundqvist), Jämtland (Jan Lundqvist) and Västernorrland (E. Fromm).

Furthermore it must be mentioned that in Norrland, where the mapping must be more summary in nature compared with the county mapping, the topographic map (with slope hachuring and curves for rock ground) has been of fundamental importance. From this map the uncovered rock, mires and the mountain boundary are derived.

From the preceding summary it is clear that the degree of precision must be very variable on different parts of the map. Where the map material has been available in a greater scale it is quite satisfactory but one must then bear in mind that the originals were primarily drawn for a reproduction in the scale 1: 2 million, whilst the present map is in the scale 1: 1 million. Because of this the map is more generalized than is really necessary. On account of the cost it was not possible to revise the original, that is, the Atlas material. Therefore it was necessary to choose between having a map generalized in this way and intended for a map on a smaller scale or no map at all. The result is the first map of the Quaternary deposits of Sweden in the scale 1: 1 million.

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