INTERNATIONAL GEOLOGICAL CONGRESS
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RECESSION OF THE LAND ICE IN SOUTHWESTERN SWEDEN

GUIDE TO THE EXCURSION NO A 20

By

C. CALDENIUS, B. JÄRNEFORS, E. MOHRÉN
AND H. TULLSTRÖM

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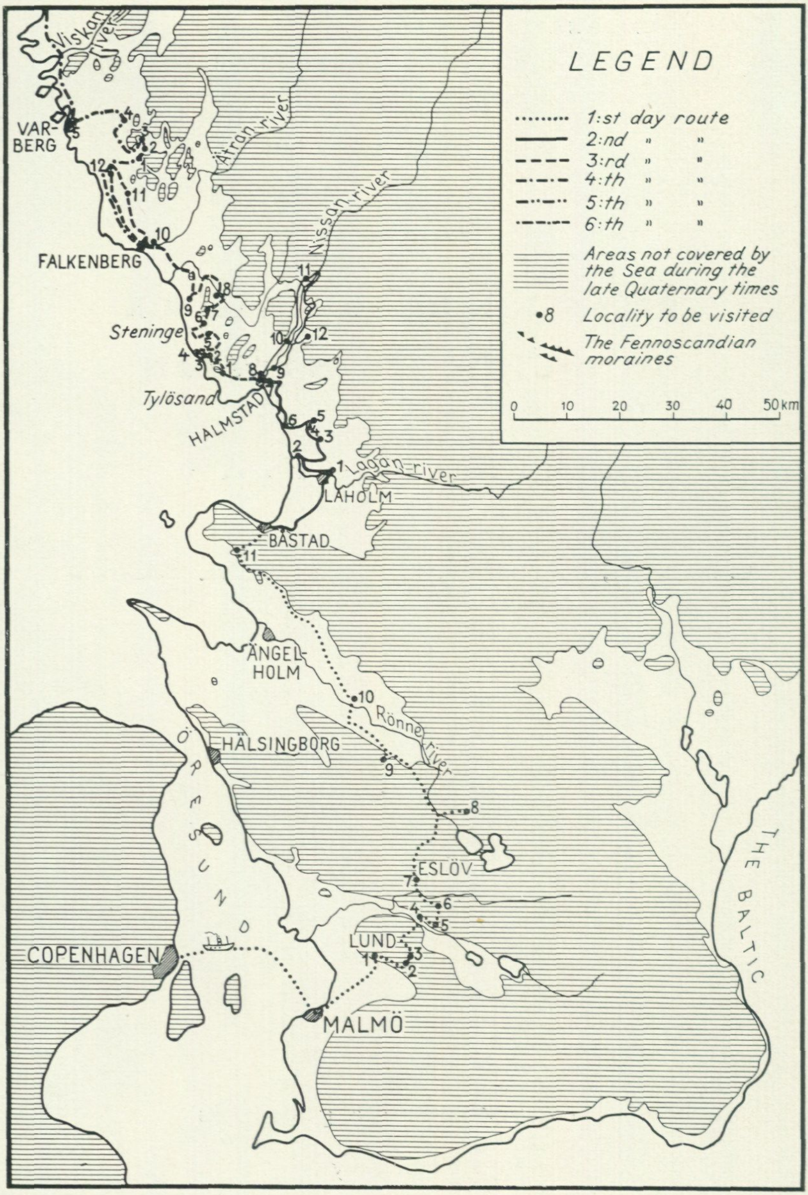

Fig. 1. Excursion route and positions of localities to be visited. 1:st—3:rd day.

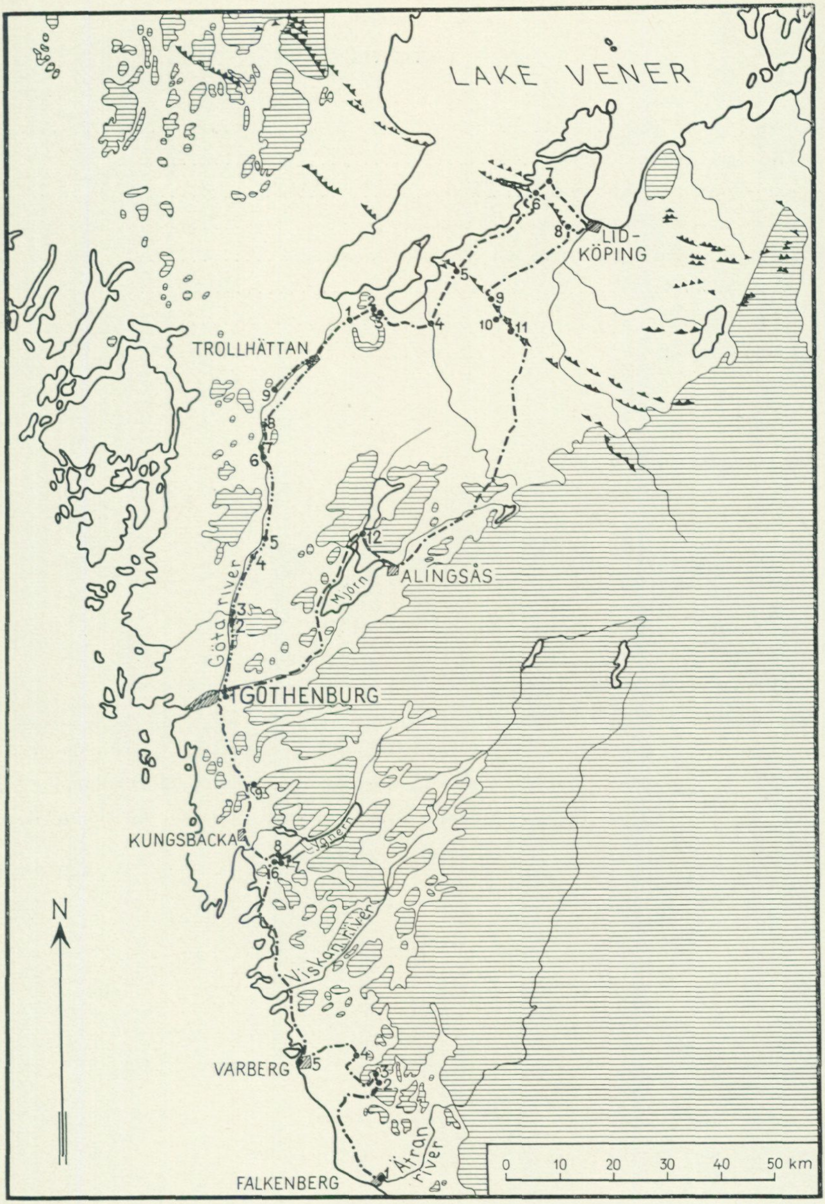

Fig. 2. Excursion route. 4:th—6:th day.

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Route map, see fig. 1—2.

Key map: See inside of back cover

Excursion No. A 20: August 8th—August 14th

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Introduction

By H. Tullström

The object of the excursion

is to study Quaternary geology from Scania to the Fennoscandian terminal moraines along the Swedish west coast, Göta River, and Lake Vener. The principal subject is the "Recession of the Land Ice". In addition moraine stratigraphy, sediments of Glacial origin, Postglacial marine and eolian sediments will be studied. One day is reserved for studying landslides in the valley of the Göta River. Several marks of the Quaternary change of level can be seen along the route, and raised beaches of different ages will be shown.

Late-Quaternary History of Southwestern Sweden

As indicated by glacial striae, erratics and the directions of eskers and drumlins, the motion of the Ice during the latest glaciation, with the exception of parts of Scania, the southernmost province in Sweden, was approximately from N to S within the middle parts of S Sweden with a gradual deviation towards SW in the western districts and towards SE in the eastern districts.

In the area to be visited the boulders and other rock-fragments in the drift consist principally of gneisses from the Middle and Early Archean rocks of Southwestern Sweden. The till is practically without clay, contains a large percentage of gravel, and is very stony and rich in boulders.

Ice Streams and Deglaciation in Scania

In Scania, however, this "NE-Ice", which is the principal ice, also crossed sedimentary rocks, and thus the drift partly consists of material from them. The moraines in north-eastern Scania are Cretaceous-Archean tills. Some other types are developed as Sandstone till and Shale-Archean till. All these tills are generally very stony and gravelly. They were formed when the ice stream was able to overflow the Scanian mountains ridges which are oriented NW to SE, *(11),* cfr. fig. 4.

During the deglaciation, however, the ice sheet rapidly thinned and stagnated over the northern parts of Scania while the ice within the Baltic depression took the character of a more separate stream. A conspicuous lobe was formed in which the ice briefly traversed the southern parts of Scania from SE to NW and even in the western parts of the same province in a direction from SW to NE where, earlier, the NE-Ice had flowed towards SW *(31; 33; 46; 47)*.

Drift from this Young Baltic Ice covers (usually with a marked limit) *i. a.* the southern and southwestern parts of Scania and the Danish island of Seeland.

The recession of the Ice from Scania was probably very complicated with small oscillations of the ice border of the Baltic Ice and separations of dead ice in depressions of more or less important size. The recession in Scania was, moreover, primarily subaerial.

Between Lund and Malmö there is in the Cretaceous limestones a pre-Glacial rift valley the stratigraphic succession of which gives the key to the Quaternary development of Scania. This depression originally was thought to be a pre-Glacial erosion valley like the Cromer River Valley in eastern England by its explorer N. O. Holst *(17)*. Dr Holst called the supposed river "Alnarpsfloden" (the Alnarp River). He concluded this from the fossil content of the sediments of the valley. These are nowhere outcropping but only known from well drillings. The general stratigraphical succession of the valley is the following (fig. 3).

1. Youngest Baltic till (also called SW-moraine); a till, rich in small boulders of Danian limestone and its grey flint, white chalk of the Maestrichtian and its black flint, Cambro-Silurian shales and Cambrian sandstones of SE Scania and Ordovician-Silurian limestones from the Baltic islands of Öland and Gotland or from the bottom of the Baltic. Besides these sedimentary rock boulders, there are also Archean crystalline rocks. Some of these are very easily recognizable and serve as indicator boulders of the stream directions of the land ice. The colour of this youngest till is light blue (weathered: brownish yellow).

2. Second till or NE-moraine. Sometimes it is separated from the covering bed by a thin layer of sand or gravel. In the area here in question this second till is very hard and compact, relatively rich in boulders, stones, and gravel, but even the clay content is considerable. Among the boulders the Archean rocks of southwestern Sweden predominate. The colour is bluish grey (weathered

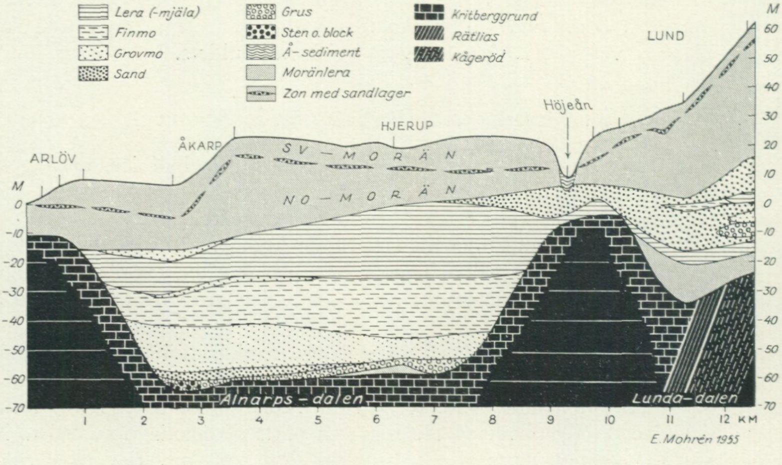

Fig. 3. Section through the Quaternary sediments of the Alnarp valley. After Magnusson—Lundqvist—Granlund 1957.

Lera = clay (glacial)
Finmo = silt
Grovmo = fine sand
Sand = medium sand

Grus = gravel
Sten o. block = pebbles and boulders
Å-sediment = rivulet deposits
Moränlera = boulder clay
Zon med sandlager = zone with sand layers

Krita = Cretaceous
Rätlias = Rhaetic-Liassic
Kågeröd = Triassic

and dry: whitish grey) because of the content of silty material from Silurian shales.

3. Glacial clay with rare boulders of NE-origin.
4. Silt and fine sand.
5. Medium sand.
6. Gravel, stones and boulders: mainly Danian limestones and flint, Archean rocks, Baltic Ordovician—Silurian limestones.
7. Oldest Baltic till rarely occurring.
8. Youngest Danian limestones.

Strata 4—6 are fossiliferous, but fauna as well as flora are of a complex origin. Species indicating a warm-temperate climate, *e. g. Brasenia purpurea* and *Dulichium spataceum,* are to be found together with arctic species as *Salix polaris, S. reticulata* and arctic mosses. The warm species are to be regarded as redeposited from Interglacial — Tertiary deposits in the southern part of the Baltic. This opinion is confirmed by finds of amber and lignitic wood of *Sequoia* species. Some drillings have been gas-bearing (methane) and real peat has also been found in such a position that it may be regarded as older than the oldest till bed (stratum 7). Unfortunately these finds are made under such circumstances that no reliable samples of the peat have been collected which could be scrutinized as to their primary fossil content. We therefore do not know whether the oldest till (the Old-Baltic moraine) belongs to the latest glaciation or an older one.

Historically, the succession of the strata of the Alnarp valley combined with the directions of the glacial striae, is to be explained as follows. — An ice stream along the Baltic brought with its till earlier sediments, Archean granites and porphyries, Algonquian sandstones, and Cambro-Silurian limestones from the bottom of the Baltic indicating the ice movement. Thus it is not surprising either to find pieces of the Oligocene amber in Scania transported from its source in East Prussia or Tertiary and Interglacial wood and peat. The high-glacial fossils may have lived just before the advancing ice front and been mixed into the lodgement till. The Old Baltic ice stream can be traced across Scania coming from an E—SE direction and reaching the NW corner of this province. At its recession the ice probably was followed by a transgression of the sea. Parts of the till was eroded, and further boulder material was rolled forwards on the bottom of the Alnarp depression by meltwater (stratum 6). The farther the ice retired towards the East, the finer the deposited material became, until at last a heavy glacial clay concluded this sedimentation cycle. The clay is probably marine, as further to the Northwest sediments are found containing fragments of arctic marine shells *(Saxicava i. a.)*. The Alnarp valley succession may be regarded as a parallel to the Danish North-Jutland Skaerumhede series, but possibly not synchronous with it.

Whether the ice cover wholly disappeared after the deposition of the Alnarp sediments is not clear. Thus we do not know whether the sediments should be called Interglacial or Interstadial. The latter opinion seems to be most acceptable, as no organic sediments are yet found in situ. — The Old Baltic moraine even occurs at some places in relatively high altitudes but always in a protected position in regard to later ice movements (generally on the lee side of rock hills or ridges). The age is revealed by the stratigraphic position and by the content of Ordovician-Silurian limestones and other Baltic boulders and everywhere a high lime content.

The succession of sorted sediments in the Alnarp valley was broken by the advance of the NE-ice crossing the valley. Somewhere the marginal glaciofluvial sediments of the NE-ice are found, known by their high stone per cent and grey colours. This ice stream came from the NE to this region. But, as is pointed out, the ice movement of this principal stream in the southeastern Sweden came from the NW. Thus the name NE-ice and NE-moraine is only adequate in SW Sweden. The boulder content of this NE-till emanates mainly from Småland (the province northeast of Scania) and northern Scania and consist mainly of gneisses and granites. Basalts (central Scania), granate-amphibolites (SW Småland), mottled flint and lime grit (NE Scania) serve as indicator boulders. On the plains of SW Scania, indeed, it is specially characterized by the Upper Silurian shale (with *Monograptus colonus*). This blue marly shale occurs as a 20—25 km broad belt along the NW—SE diagonal of Scania. Other rock boulders to be mentioned are Cambrian sandstones and alum shales, Liassic clay ironstone and Rhaetic-Liassic lignitic coals. Because of the clay shale content and in spite of the richness in boulders, this till is well arable and rich where it constitutes the soil surface. The thickness of the NE-moraine of the SW Scanian plains generally is 10 metres and seldom exceeds 30 metres.

The youngest ice stream over W Scania advanced from the southern Baltic. From the Öresund depression the ice, on its right flank, advanced from the SW over Scania, whence the name SW-ice and SW-moraine. This ice ploughed up young, non-consolidated sediments, rich in clays and limestones, mainly of Mesozoic or Tertiary age. Above all Cretaceous limestones, brittle black, or dull grey flintstones of the same age characterize this drift. Because of the clay and lime content and the low frequency of large boulders, this till is a very rich agricultural soil, possibly the first one to be cultivated in Fennoscandia. The cairns and other cave tumuli from the Younger Stone Age and the Bronze Age bear witness to this. Now it is the most prominent alimentary producing region of Sweden.

Ice Streams and Deglaciation at the Swedish West Coast

From indicators (Norwegian rocks) and striae we know that during the last glaciation an early ice stream existed with a direction towards SSE. The old striae are, however, very seldom preserved due to destruction by weathering. Later on, the ice stream changed direction towards SW, and the youngest striae are directed towards WSW. It is evident from the distribution of the valleys and basins of western Sweden that the glacial erosion was most effective in these directions, even if the quarrying also depends on the more or less well-jointed rock and the directions of planes of weakness.

The youngest, nearly westerly direction of the ice movement may have been determined by the relatively great depth outside the coast, which at the beginning of the retreat of the ice-border facilitated the formation of calves from the submerged portions of the ice sheet.

The recession of the ice was more rapid within the southern and southeastern districts of Sweden than in the western ones as proved by terminal moraine lines converging from southern Sweden towards the Oslofiord. This may have been dependent on the more continental and dry climate in the lower South Swedish regions than that of the western, more humid, mountainous districts.

Just inside the west coast there are numerous terminal moraine lines often parallel to each other, many of which will be pointed out during the excursion. These accumulations often look like mighty end moraines, but in sections they are seen to be different. On the ice-contact side there commonly are found variable kinds of till, often with sand or clay layers worked into it. Outside this zone there is a zone of glacio-fluvial coarse gravel which becomes finer further out. As a result of intermittent pressure the stratification became folded.

The westernmost of these terminal moraines are straight, elongated, ridgelike hills. Further eastward they are curved, formed by ice lobes protruding into the valleys. Some of the lobes stagnated and separated from the still active glaciers which could form new lobes accumulating new drift higher up in the valleys. The separated ice became a dead ice and prevented the sedimentation of glacial drift in the bottoms of the valleys, causing great depressions.

As a result of a general rise in temperature the deglaciation continued rapidly from southern Sweden to the Fennoscandian terminal moraines corresponding to the Alleröd epoch at about 9 000 years B. C. in Denmark and Scania. The deglaciation north of the Fennoscandian moraines is of small but unknown amplitude.

Soon, however, a change of the climatic conditions caused the deglaciation to cease and it was replaced by renewed expansion. According to G. De Geer *(14)* the period of reactivation lasted for 800 years, and during that time the Fennoscandian moraines were built up. The excursion will follow the recession of the ice to these moraines.

Changes of Level

The extra load on the crust of the earth, caused by the masses of the Pleistocene inland ice, brought about a pressure on the ice-covered regions, and, since the ice has melted away, these parts of the geoid have striven, in accordance with the laws of isostasy, to recover their normal surface position. The isostatic elevation of the land, however, must be correlated with the eustatic movements of the surface of the sea when interpreting the course of changes of level in Sweden since the Ice Age *(38; 39; 40)*. The intensity of the land upheavel was greatest immediately after the removal of the ice load (about 10 m per century) and has gradually abated until the present time. On the other hand, the elevation of the sealevel should have proceeded fairly slowly at the beginning of the melting period and thereafter increased in intensity as the rapidity of melting increased. Accordingly a regression of the sea began immediately after the last glaciation everywhere in Sweden, and in areas with strong intensity in the elevation of the land this regression has continued down to the present time without being interrupted by any transgressional period. In the marginal parts of the elevation area repeated interruptions occur which have shown to have been caused by eustatic movements of the sea surface. The most important one was the great Postglacial transgression which reached its maximum about 5 000 years B. C. The return from transgression to continued regression is caused by the fact that the rise in the sea surface stopped, and the elevation of land became the only factor affecting the shore line.

The present uplift is about 1 m per century in northern Sweden at 64 degrees latitude, about 0.3 m at the southern shore of Lake Vener, and along a line diagonally in NW—SE through Scania there is no present uplift at all.

The highest level which the sea has attained since the last glaciation is sometimes visible in cut terraces, cliffs or banks of shore gravel. Above this highest Marine Limit (Swedish: MG or HK) the till is quite intact, but below it the till is strongly wave-washed or replaced by shore-gravel or completely washed away so that the bed rock is uncovered.

The Marine Limit has about the following levels: at Båstad 58 m, Halmstad 63, Varberg 70, Gothenburg 95, Lake Vener (Kinnekulle) 125 m above present sea level, cfr figs. 1, 2, and 9.

Within the most marginal parts of the elevation area the regression during Finiglacial time continued to a level below the present sea level. Borings at Halmstad have shown a Lateglacial (probably Finiglacial) clay with mud cracks in its upper part a depth of 12 m below sea level *(8)*. It is overlain by clay (muddy in its lower part, in the upper part interbedded by loamy and sandy layers) deposited during a transgression which has taken place in early Postglacial time.

This great Postglacial transgression has also been called the Tapes-transgression after *Tapes decussatus,* a lamellibranch, preferring higher temperature than we now have in our waters.

It may be noticed that the Postglacial transgression limit in Seeland and southernmost Scania partly reached above the Lateglacial shore levels consequently forming the Marine Limit in these districts.

The Postglacial transgression limit (PG) is found at the following levels: at Hälsingborg 10 m, Halmstad 13 m, Gothenburg 25 m, Uddevalla 37 m above present sea level.

At some localities there are shore lines at very high levels. In Halland series of *nunatak* lakes or local marginal lakes have been formed above the Marine Limit. Sloping drainage channels, eroded at the ice margins, occur and some of them ended at the level of a *nunatak* lake and the lowermost ones discharged into the sea at the Marine Limit.

It should be observed that the Marine Limit is not an isochronous shore line (as the PG limit), and in fact its level sometimes differs rather considerably over short distances owing to the time when land was uncovered by the ice sheet.

Field Guide

FIRST DAY — AUGUST 8

By E. MOHRÉN and H. TULLSTRÖM

Route: Copenhagen—Malmö by boat; Malmö—Båstad by bus

The excursion starts in Copenhagen, Havnegade, landingplace for the boats to Malmö. Customs inspection. In Malmö the excursion by bus begins.

The route first goes in a northeasterly direction to the centre of the province of Scania, crossing the geologic boundary between Dano-Scania and Fennoscandia. Following the Rönne river valley we drive to the northwestern corner of Scania and cross the Hallandsås ridge before we reach the small town of Båstad.

Arriving in Malmö you are standing on the threshold of the Fennoscandian Archean shield. During the first 18 km along the motor road Malmö—Lund you indeed still are going on the youngest stage of the Cretaceous, the Danian (fig. 4). As in the Danish island of Seeland, it here consists of white limestones with flint which generally are uniformly grey. They crop out at Limhamn (W of Malmö) and are exploited at the cement factory, the white smoke of which is to be seen far over the SW-Scanian plains. At the first stop, Lund, 18 km NE

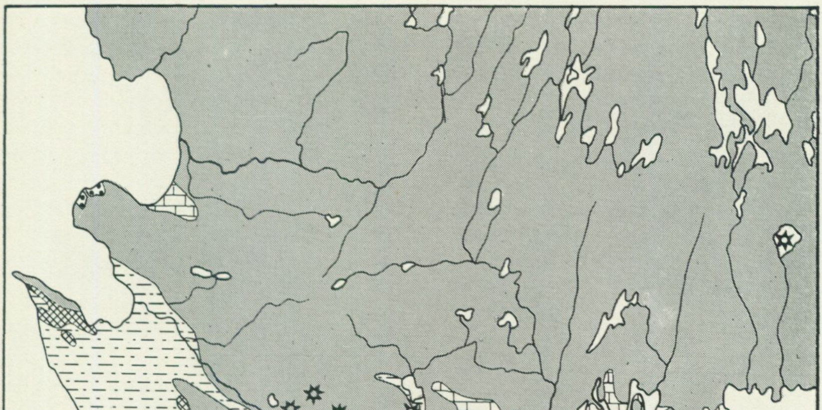

Fig. 4. Map of the pre-Quaternary rocks of Scania.

of Malmö, the rock floor in the southernmost parts of the town are still built of the Danian limestones at a moderate depth, 10—20 m below the soil surface.

Between these two towns a graben lies in a NW—SE direction according to the general tectonic structure of Scania (see fig. 3). In Scania, from Öresund in the W to the coast of the Baltic in SE, the floor of this graben is situated at 60—63 m below present sea level and consists of the youngest Danian limestones.[1] This is the Alnarp valley.

The Quaternary deposits are described in detail on page 6.

The area between Malmö and Lund is covered by the youngest Baltic boulder clay (SW-moraine) as is the whole western part of Scania from the shore of Öresund in the west to the slopes of the highland in the East. The eastern border of the SW-moraine is plotted on agrogeological maps which will be demonstrated at the third stop to-day.

After the deglaciation the even plain between Malmö and Lund became a bay of the Sea, reaching up to a level of about 35—40 m above present sea level. The water may have been rather fresh and filled with mud thus preventing marine creatures to live. No shells have been found. Foraminifera are met with but the discrimination between primary Glacial species and secondarily redeposited Interglacial, Tertiary and Cretaceous species is not an easy task. In the heavy clay of the bay (at Lomma) skeletons of the polar cod *(Gadus saida)* have been found.

At the retreat of the sea wave action washed the surface of the boulder clay making it sandier to a depth of 30—40 cm, in places with a concentration of flintstones on the transition between the sandy top soil and the heavy boulder clay below it.

FIRST STOP — LUND

Lund, the oldest town of Scania, probably founded in the 10th century. The present cathedral which is built of Höör sandstone (Rhaetic-Liassic) from a quarry 30 km NE of the town, was founded in the eleventh century but had predecessers of wood. The University of Lund was inaugurated in 1668 in connection with the Swedish conquest of Scania from Denmark. The now used university-building was erected 1878—82. The purpose of the stop in Lund is only for personal business (bank, post, shopping).

We leave Lund in an easterly direction. The road runs along the foot of the Romeleåsen horst on the fault and flexure zone with the upthrown Archean-Silurian to the left and the downthrown Cretaceous to the right. Within the zone the Triassic—Lower Cretaceous strata are disturbed and more or less upraised. The vertical displacement between the town of Malmö and the next stop, for instance is about 1 500—2 000 m. The main road runs parallel to and just above the highest Marine Limit. The exact position of this limit is difficult to demonstrate here, but it will be demonstrated at a later occasion. Indeed, you can see that the land is more even to the right than to the left, and this is

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[1] According to F. Brotzen (*6*) this depression is no graben or rift valley but a syncline.

not only because of the higher position of the bedrock but also a result of wave action.

SECOND STOP — ARENDALA

From the highway at a level of 35 m we are at Arendala 60 m above present sea level and at the outermost border of the SW-moraine, just where the SW-ice lost its last offensive power *(12)*.

The SW-moraine, which is a heavy, marly boulder clay, covers the NE-moraine which is a gravelly, sandy till (nearly without clay) containing a considerable amount of Cambrian sandstone and Archean gneisses (97 % of the stones) descending from the outcropping rocks of the Romele ridge.

It may be observed that the SW-moraine border forms a smoothly rounded embankment, which may be regarded as a marginal moraine.

There is often a water bearing sandlayer between the two moraine beds in this region. The thickness of the SW-moraine in these peripheral parts is important — on the average 10 to 15 metres — but only 2 to 5 m in the plain some kilometres to the SW *(10; 33; 46)*.

In a few places the NE-moraine appears through "windows" in the SW-moraine.

THIRD STOP — HARDEBERGA

At the church of Hardeberga we pass the water shed of the Romele ridge. The large amount of boulders of Cambrian sandstone at our second stop was brought to that place by the NE-ice from this locality. The sandstone quarry is about 25 m deep. The banks are nearly horizontal, but along vertical fractures doleritic magmas (dark) have been intruded. Some of the blocks have sunk stairwisely. The youngest parts of the sandstone in the North are consequently to be found at a lower level than the older strata in the South. A drilling from the bottom of the quarry has revealed a minimal total thickness of the sandstone of 125 m. The general dip is 10° towards WNW.

The sandstone surface is uncovered at the quarry and we hope to be able to find striae. On earlier occasions striae have been observed with the directions N 42°, 43°, 47°, 52° E together with N 77°, 80° and 85° E *(46)*. As far as it has been possible to determine their relative age, the striae from N 42—52° E seem to be older than those from about N 80° E.

Sand blown surfaces of outcropping sandstone and of larger boulders have been observed here. Generally the strongest polishing faces towards an easterly direction. Sometimes real dreikanters are found. The boulders seem to have been polished after their deposition by the NE-ice, some time after its recession. Whether the SW-ice had also retired at that time is not discernible but does not seem probable.

Driving northeastwards we first pass a valley the bottom of which here lies at + 50 m being once an outflow channel of the melt waters of the SW-ice further westwards. Gravel deposits E of the road bridge over the brook seem to be complex: an older (NE-ice) glacio-fluvial esker has been levelled by the melt water from the SW-ice and in its more superficial parts mixed with pebbles of flint. The gravel deposit lies at 50—55 m above present sea level and is — partly — to be looked upon as a delta.

The next 4 km of our represent a NE-moraine plain at + 70—+ 80 m. The till consists mainly of material of the bedrock: soft Ordovician—Silurian shales. Its clay content is about 15—25 per cent. Archean pebbles and Cambrian sandstones are nevertheless predominant. Pieces of the shale constitute 15 per cent (diam. > 2 cm). Pebbles of a dull brown sprinkled flint from NE Scania are not seldom. As a comparison with the stony soils at Hardeberga, we can see at Linnebjär a trench in a NE-boulder clay of this local type nearly without boulders and stones.

E of Odarslöv we meet with till of the SW-ice once more. When ploughed the difference between the two soils is clearly visible being different in boulder content and colour: the older one is grey, the younger one is yellowish brown.

The western part of the Kävlinge River valley was once filled with SW-ice, damming in the East an ice lake to 50—60 metres above present sea level. After its maximum the ice probably melted as a dead ice, and at this stage it was divided in blocks by radial fissures along which the melt water found its way to the Sea at 45 m above the present sea level. The lake water caused an important erosion down to and below the Sea level cutting through the SW-moraine (10—15 m), its underlying sorted sediments, and even at some places the upper part of the NE-moraine. The last 200 metres of our way from the plain level at + 40 m down to the valley bottom of the Kävlinge River at + 16 m is a half-artificial trench in the SW-boulder clay. An intermorainic fine sand has here been observed at + 25 metres.

FOURTH STOP — RÖDABÄCK

A little brook, Rödabäck, just as the greater Kävlinge River, once formed the outlet of an ice dammed lake and cut its way through the morainic deposits. In a section both moraine beds can be seen, one over the other. The SW-moraine is only 2 metres thick and here separated from the basement by a thin layer of fine sand. In the younger till the colour, the absence of greater boulders, the lime content, and the composition of the boulder association may be observed in comparison to corresponding conditions in the older one.

Driving eastwards on sandy and fine sandy sediments to Flyinge village at + 20 metres, we turn northwards and go up the valley slopes to a level of + 35 metres on heavy glacial clays.

FIFTH STOP — FLYINGE

The clay-pit belongs to the brick yard at Flyinge. Earlier a clay pit 600 m E of the actual one was open. There the following succession was observed:

1. Stony sand (top soil)	0 —0.5 m
2. Medium sand	0.5—3.5 »
3. Fine sand with current bedding	3.5—4.5 »
4. Heavy, glacial clay — light clay with distinct varves	4.5—6.5 »
5. Fine sand with clay laminae	6.5—6.7 »
6. Medium sand	6.7—7.2 » +

The fine sand (layer 3) is supposed to be a deposit in front of the advancing SW-ice and the above medium sand (2) a deposit at the maximum of the same ice. Even the glacial clay (4) ought to have been deposited at the time when the SW-ice advanced, as we find small pebbles of black flint of the Maestrichtian in it. In the heavy clay even lumps or lenses of folded fine sand are seen. This may be of an older stage and transported by icebergs in a frozen state. In the eastern part of the pit the same general succession was to be seen but with strong disturbances of the upper part. The fine sand (3) and the glacial clay (4) were both folded in an irregular manner. Different interpretations of this phenomenon have been proposed: ice pressure from the W (by the SW-ice), from the NE, from the SE (by a glacier tongue — the Vomb glacier — which was supposed to fill all the Vomb depression *(46)*, and, finally, slides.

In the actual clay-pit we find the same stratification principally.

1. Medium sand with some stones and pebbles which may be considered as regression sediments.
2. Fine sand and heavy clay kneeded into each other by an ice pushing its till forward into the already deposited series.
3. Fine sand at least 1.5 metres thick.

The glacial clay amounts to + 45 metres. And still higher (at + 60 to + 62 metres) a richness of stones and pebbles in the fields of the slope indicates, according to Mohrén, the highest shore of the Vomb ice lake. At the maximum of the SW-ice this lake for some time may have discharged its waters across the main road n:o 4 where now stony fields bear witness of its washing action. Just north of the foot of the slope the stone cover continues into sand, the latter being covered by heavy glacial clay.

Driving further we pass into the area of another ice lake, the Skeglinge ice lake. The outflow water from this lake seems to have been at its northern beach until fissures in the dead ice permitted the waters to find their way along the + 50 metres contour line through the ice towards the West. A successor of the ice lake was a shallow lake which was artificially drained 100 years ago.

SIXTH STOP — SKARHULT

The Renaissance castle Skarhult was, according to the inscription over the gate, completed in 1562 by the Dane S. S. Rosensparre. Having belonged to the family de la Gardie, it was later owned by the Kings Karl XIV Johan and Oscar I of Sweden who sold it. It has a private art gallery, an imposing library and castle archive.

At the railway SE of the castle there is a dolerite dike trough Silurian shales with *Monograptus colonus,* and in the Brå River limestone bands have been found with a rich fauna. A third ice lake has existed round the castle and the river, reaching + 55 to + 60 metres above present sea level. Flint pebbles have been found at least one kilometre towards the East, indicating a water transport of icebergs from the SW-ice and a water flow to the lake Ringsjön in Central Scania, until the ice was broken in the West and a deep erosion valley was formed.

Once more we cross the SW-moraine between Skarhult and a point 2 kilometres SE Eslöv.

SEVENTH STOP — ESLÖV

The SW-ice climbed up against the NE-moraine hills W of the town of Eslöv. The melt water was caught in depressions N of the town. The depressions were already to some part filled with NE-ice gravel and the hydrographic conditions seem to have been somewhat ambiguous. Sandy-gravelly sediments with flint can be followed to nearly 65 metres above present sea level. Thus we can conclude that waters of ice lakes have reached this level. South of the town the water followed the ice border towards the SE to the ice-lake E Skarhult. An immense washing of the NE-moraine surface as can be seen from the lowest parts of "Eslövs fälad", an area still not cultivated on account of the numerous boulders. Its higher parts may represent the natural appearance of the NE moraine surface before the cultivation.

The above mentioned depression N of Eslöv is now occupied by a swamp which is divided in two parts by a glacio-fluvial esker — the Bosarp-esker — belonging to the NE-ice. The esker winds like a Loch Ness monster through the swamp. This ancient ice lake was drained to the NE to lake Ringsjön for some time.

Having crossed the Saxå valley, we also cross the Bosarp esker but as it is not typical as to its composition, we are going on via Bosarp to the Rönneå River, outflow of the lake Ringsjön.

At the highest point of the road (+ 112.8) at Hjortsås (Hasslehill) we cross a dolerite dike which can be followed from the eruption centre at Konga, about 20 kilometres to the NW.

In the distance the central heights of Scania, the Linderödsåsen horst, appears behind the Lake Ringsjön depression. This depression seems to have been the great catchment-basin for glacial melt-water during the maximum stage of the SW-ice. It is separated in three parts by thresholds one of which is the Bosarp esker. The two southeastern parts are lakes with a maximal depth of the easternmost lake of 20 metres and the westernmost of only 4 metres. The northwestern part is now filled up by two separate bogs. During the Baltic Ancylus epoch (5000—7000 BC) it still was a shallow lake with several dwelling places on the shores.

EIGHTH STOP — MUNKARP

Munkarp. Having passed the Rönneå River we meet with the Archean gneisses and with a typical glacio-fluvial esker of this region. As the road was in building last year several good sections are visible. The morphology, the interior stratification, and the boulder composition will be taken up.

Driving back again we return to the Silurian region W of the Rönneå River and follow this river on its western side towards the northwest. The terrain on both sides of the road is characterized by smoothly rounded hills. Further to the East the details of the horizon line are more vivid and varied. The slopes of the gneissic hills are steeper. The most prominent summits belong to basaltic eruption pipes of Tertiary (Eocene) age. One of the largest is Jällaberg 3 kilometres to the right when passing Röstånga. Another one, probably the smallest one, is Rallaté, a small hill of only about 5 metres height, about 2 kilometres before the next stop.

Röstånga, at the end of the Söderåsen horst, is one of the classic areas of Swedish and international Cambro-Silurian investigations.

NINTH STOP — SKÄRALID

The horsts of Scania have been mentioned before. One of the most prominent fault-lines is that of the NE-side of Söderåsen. As a distinct ridge wall it emerges over the hilly plain to the NE and can in this respect be followed from Åstorp in the NW to Röstånga in the SE (30 kilometres). It is less prominent further to the SE but still visible to Lake Ringsjön. By borings and other geological observations it can be followed to the southeastern promontory of Scania into the Baltic. These greatest tectonic movements of Scania are of a post-Silurian and pre-Rhaetic age. Generally they are referred to a Hercynian age. The strike of the tectonic faults is NW—SE. In this connection doleritic magmas were intruded constituting solitary dikes or swarms of dikes, such as we earlier have seen (second stop and between seventh and eighth stops). Later (Saxonian) movements occurred along lines in WNW—ESE direction. These can be studied in the Rhaetic-Liassic coalfields of NW Scania. Here they have been found to be partly syn-sedimentary, partly younger. The joint valleys thus may have been carved before the Quaternary age. The mouth of the joint valley of Skäralid lies at a level of + 50. The upper point of the valley is + 150. The question is why this and other similar valleys have not been filled with glacial drift. They have been exposed to all ice moving from the NE. The interpretation may be that the valleys at an early stage of every glaciation were filled by ice and snow of local glaciers and when the land-ice later moved from N—NE it slipped over the horst ridge depositing but very little débris.

Already 2 kilometres after Skäralid the landscape opens and the forest disappears. We are on a plain consisting of gravel and sand — resting on a Rhaetic-Liassic bed rock — with the highest levels at + 50 to + 52 metres. This is an outwash delta of the NE-ice built up to or fairly near to the Marine Limit. The eskers NE of the Söderåsen horst show a deviation to the right, indicating a declining power in forcing the heights and a linking of the drainage towards NW parallel with the horst. Immense masses of glacio-fluvial drift seem to have been deposited in this bay of the Sea. Drillings have shown gravel thicknesses of 20 metres.

According to the opinion of the present authors the main part of sedimentation took place during a recession stage of the NE-ice and according to Mohrén before the SW-ice maximum.

Very soon the NE-ice became dead. Landforms similar to kame fields with kettle holes occur. At Sjögården in Bonnarp to the left of our route a kettle-hole lake is to be seen. Other kettle holes are filled with mud and peat.

At the time for the SW-ice maximum the Sea probably had retired to a lower position. After passing Bonnarp two plains often can be observed, one outwash plain at about 55 metres above present sea level (the Marine Limit) and another at 35—40 metres above sea level corresponding to this later stage.

At the road cross before turning to Klippan we can see on the left side another joint valley, Klöva Hallar, at Söderåsen similar to that at Skäralid.

Tenth stop — Klippan

The stratification in the Rönneå valley can be studied in a section at the tile works at Klippan. In 1949 the following record was made. Surface 36 m above present sea level *(45)*,

1.	Top soil	0 — 0.2 m
2.	Rust-coloured sand without distinct bedding	0.2— 1.1 »
3.	Cross-bedded sand, fine sand and fine gravel	1.1— 3.5 »
4.	Brown varved clay and silt with thin beds of sand or fine sand, without $CaCO_3$	3.5— 7.5 »
5.	Grey to bluish grey, heavy glacial clay, with a $CaCO_3$ content of 15 %	7.5—16.1 »
6.	Fine sand	16.1—16.2 »
7.	Till	16.2 + »

Since 1949 the picture is somewhat altered but now you may see, if the weather is favourable, varved bedding in layer 5. Some varves are over 0.5 m thick. This layer was earlier regarded as more or less homogeneous. Strata 2—4 are the already mentioned regression sediments, but sediments from drainage of ice-lakes may be included.

For lack of time we must pass several localities worth seeing and go 40 km to Grevie. Several glacio-fluvial eskers and outwash deltas will be passed. Only the top of the eskers are to be seen as they are buried in deep glacial clay which covers the main part of the plains on the left side of the road.

The first 20 km from Klippan we drive below the Marine Limit (55—58 m above present sea level) then we follow it very near and the last 7 km we are above it. The outwash deltas are built up very near this limit, at Tåstarp for instance to 56 m above present sea level.

Eleventh stop — Grevie

The horst Hallandsåsen is traversed by the Sinarp valley which is of the same type as that of Skäralid. The Sinarp valley, however, has served as drainage channel for those large volumes of melt water who deposited the eskers oriented in NE—SW at Grevie. The highest parts of the eskers are 65 m in SW and rise to 90 m against NE for a distance of about 1 km. The watershed in the valley lies at 105 m above present sea level.

Thus the eskers are subaerial and probably deposited in open channels in the ice when the land-ice became dead on the southern side of the Hallandsås ridge.

The gravel is mixed with pebbles from those Cretaceous limestones which are outcropping on the northern side of the Sinarp valley.

The ride to the small town of Båstad goes along this valley. If the weather permits a beautiful perspective opens out over the plains in southern Halland, a province which will be visited during the next three days.

SECOND DAY — AUGUST 9

By C. Caldenius and H. Tullström

Route: Båstad—Halmstad

Starting from the hotel at 9.00 a. m. we go eastward along the steep slopes of the Hallandsås. On the left a now waterfilled limestone-quarry can be seen just at the province boundary between Scania and Halland. The Cretaceous limestone, consisting of shell fragments, contains boulders of the crystalline bedrock showing that the Hallandsås already existed when the Cretaceous was deposited.

Between Båstad and Laholm we follow the highway over a vast cultivated plain, with deep Quaternary deposits.

Turning to the left at the church of Ö. Karup (11th century) and thereafter following the main road northward, we pass a plain between the Laholm-bay on the left side and the gradually raising land on the right.

From borings we know that the Quaternary beds are over 60 metres thick.

Near the small river Stensån the following Quaternary strata have been found.

0— 3 m	Clay containing shells of *Limnea* and *Planorbis*
3—13 m	Clay containing shells of *Cardium* and *Mytilus*
13—15 m	Postglacial sand, free of lime
15—52 m	Glacial clay with *Portlandia arctica*
52—56 m	Clay and sand with lime

The Quaternary beds become thinner towards the north. Nevertheless, 1.5 km south of the railway station in the little town of Laholm there are 47 metres Quaternary deposits consisting of

0 — 5.8 m	Postglacial sand
5.8—32.8 m	Glacial clay
32.8—39.8 m	Sand
39.8—47.0 m	Gravel
47 m +	Bedrock of grey gneiss

In this area borings often have saliferous ground water in the sand and gravel deposits just above the bedrock.

The town of Laholm is situated where the highway crosses the river Lagan. It grew about 1100 A. D. under the cover of the castle Lagaholm, the remains of which are to be seen when we pass the river. The castle was built on a rock in the river, which was navigable and rich in salmon. There was also a good harbour at Laholm but by action of eolian-sand near the mouth of the river all shipping is now made impossible, and a hydroelectric powerstation has brought most of the salmon-fishing to an end.

On the way northwards the soil cover is thinner and exposed bed rock more commonly visible, which is also to be seen from the combined rock and soil maps *(26; 27)*.

FIRST STOP — L. TJÄRBY LAKE

L. Tjärby lake is a kettle or a basin in stratified drift, created by the ablation of dead ice once buried in the drift. This vast glacifluvial deposit was accumulated in front of and along the ice border during a halt in its recession. As will be shown, while the excursion continues, such pausings are characteristic features for the ice retreat in southwestern Sweden.

Grave-hills from the Bronze Age are very common in this area, and several of them can be seen close to the highway.

From Tjärby we turn in the direction of the coast passing over a low, slightly undulating ground of marine sand deposited as a rather thin veneer, and generally reposing on Gotiglacial clay and silt.

SECOND STOP — SPANNARP

At Spannarp situated close to the last bend of the river Lagan before it empties into the sea, we find good examples of the last landscape-moulding geological processes in Halland viz. from seawaves- and wind-actions. They are represented here by raised beaches from the great Postglacial transgression, reaching about 8 metres above present sea level, and well developed dunes. The well rounded pebbles in the beaches have been derived from a glacio-fluvial deposit which crops out in the river bluff and probably is a joint in a chain of marginal iceborder deposits.

Driving inland again we note on the left side the dunes near the southern limit of the great field of eolian sand inside the Postglacial transgression beach, and when turning to the left at the church Tjärby, we see on the right hand side a vast glacial delta plain about 60 metres above sea level, close to the Marine Limit and belonging to a somewhat later stage in the land ice retreat than the delta at Tjärby lake.

THIRD STOP — GENEVAD

The tile works at Genevad. An excursion in western Sweden does not offer good opportunities to study the well known glacial varved clays. In the salt seawater particles of different sizes kept together in greater and greater aggregates by settling to the bottom and gave rise to a deposit in which only sand and other coarser particles form well sorted layers, while the minor ones are mixed together in one and the same layer. As the seawater during the ice recession grew saltier on account of the open connection with the North Sea the varve structure abates towards north.

In the clay pit at Genevad, however, the varves are still rather well developed, accumulated as their material has been in a seawater, where the big meltwater outflow from the Baltic had a great influence on the composition of the seawater.

FOURTH STOP — ELDSBERGA

From Genevad we continue to the church of Eldsberga, where we will be confronted with one of the greatest glacio-fluvial deposits on the Swedish westcoast. It is a repeated combination of radial eskers and marginal deltas, the latter ones developed along stationary ice borders. The orginal glacial deposit has been eroded by marine wave action and partly reaccumulated at its sides. Several deeply wave cut terraces, especially on the front facing the sea, show the great extent of the abrasion. An idea of the reaccumulation work carried out by the waves can be got even from the outcrops in the gravel pit at the railway station where the contacts between the glacial and the wave-washed deposits can be seen.

The church is one of the best preserved of Romanesque architecture in Halland. The tower rebuilt 1892.

FIFTH STOP — HAGA

Following the road to the NE on the glacio-fluvial plateau we find at Haga, 2 km NNE of the church of Eldsberga, a locality where we can get a certain idea of this complex accumulation. Its surface lies there 20—30 metres higher than the surroundings. The plateau itself is twice as broad as in general, and from its southeastern flank a branch projects as a marginal delta and is connected with a feeding esker.

After returning the same way to the church of Eldsberga, we pass to the northwestern side of the Eldsberga esker with several gravelpits on the left side.

The highway will be followed 300 metres southeast, thereafter we go 1.5 km south-westward. After turning to the right the road follows a marked Postglacial shoreline about 10 metres above sea-level, the same level as the raised beach at the second stop to-day. On the left the area is covered with wind-blown sand.

SIXTH STOP — LAXVIK

Close to the small sea-side resort Laxvik a stepped series of raised beaches are well developed from the present sea level up to about 16 metres. They have the form of gravel bars lying close to one another. For the most part they belong to the period of the Postglacial transgressions and the time thereafter, but due to the exposed situation their crests reach higher levels than those of the contemporaneous wave cut terraces. Among the pebbles Cretaceous flint, chalk and Cambrian sandstone may be mentioned, all probably derived from Gotiglacial clay, into which they have fallen from icebergs, probably coming mainly from the south. A large field of low grave-mounds from the Iron Age occupies the beach gravel ground.

From Laxvik we will drive via the village Snöstorp to Halmstad, county town in Halland, at the mouth of the river Nissan.

SEVENTH STOP — NYHEM

We visit an excavation for a foundation in a new suburb, Nyhem, southeast of the town, where an outcrop of well humified *Phragmites* peat can be observed at a level of about 8 metres below eolian sand and resting upon a marine shell bearing sand. This supra marine layer dates from the regression of the shoreline from the Postglacial marine limit. Unfortunally pollen-grains are very rare, making a pollen record impossible.

Entering the town on the highway we pass through more modern quarters before we cross the Nissan river on a rather new bridge just in front of the old Hotel Svea-Gillet. From the bridge we can see the castle built in 1615 in Dutch Renaissance style by the Danish King Christian IV and at present residence of the governor and the county-board.

In order to reach the next locality of geological interest we travel through the town on the street, Karl XI:s väg, which follows the outside of the old fortifications, which were reinforced at the beginning of the 17th century but demolished already during next century. Remnants of them, however, can be observed at several places, and many old buildings such as half-timbered ones, date from the Danish time.

Eighth stop — Galgberget

Halmstad is situated at the foot of the big hill Galgberget, (the Gallows' hill), and we ascend with the bus noting that it is a great glacio-fluvial delta, accumulated in form of a horseshoe with the feeding esker mainly from NE or

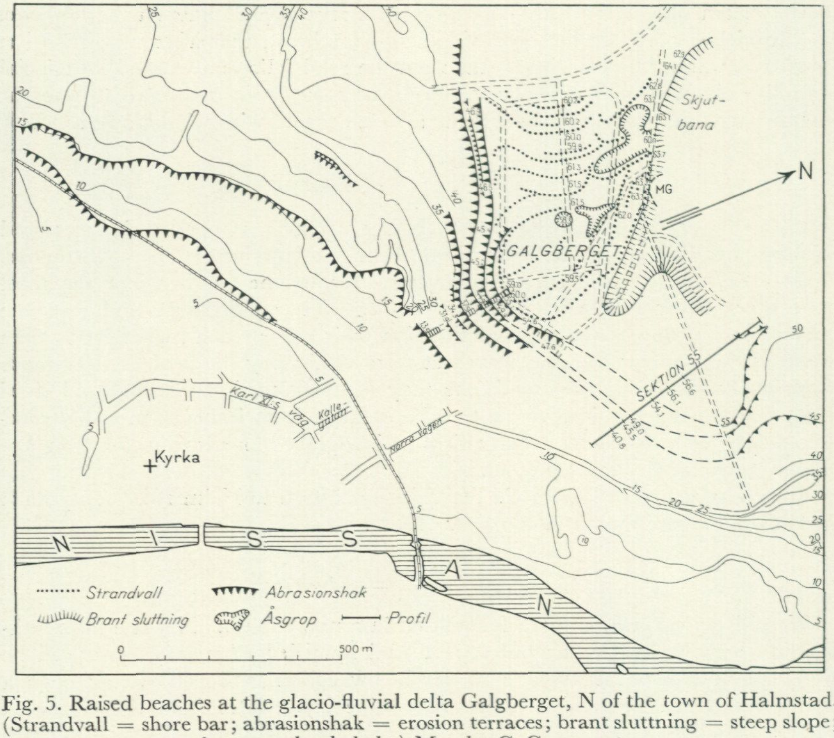

Fig. 5. Raised beaches at the glacio-fluvial delta Galgberget, N of the town of Halmstad. (Strandvall = shore bar; abrasionshak = erosion terraces; brant sluttning = steep slope; åsgrop = kettle hole.) Map by C. Caldenius.
För spridning godkänd i Rikets allmänna kartverk den 20 maj 1960.

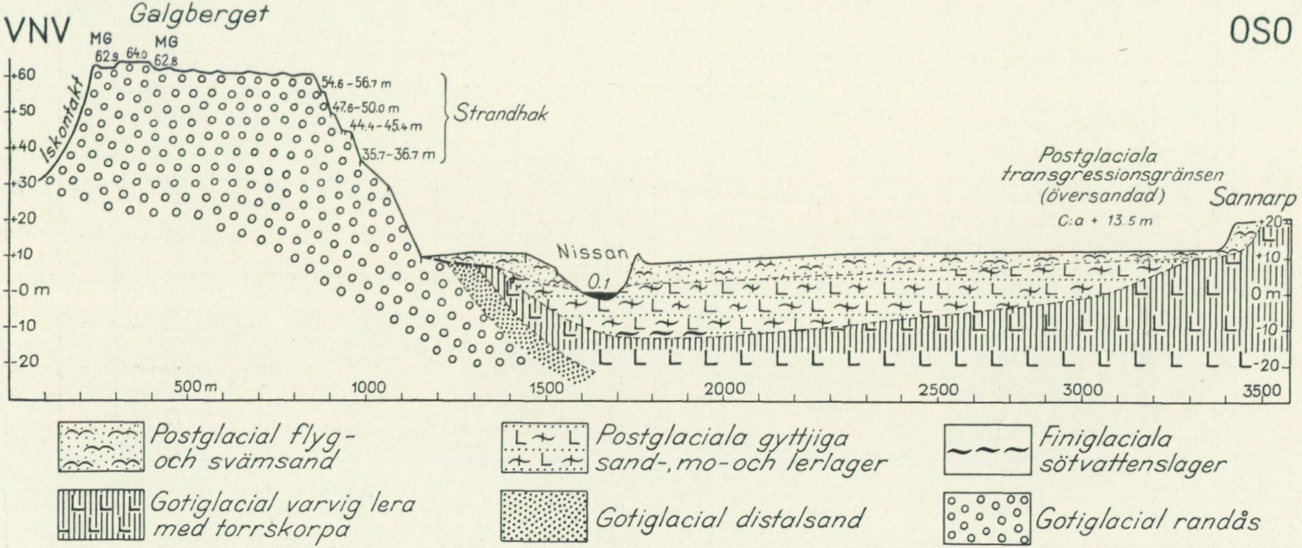

Fig. 6. Section across the Nisssan valley from the Galgberget glacio-fluvial delta (left) towards ESE. (Postglacial flyg- and svämsand = Postglacial eolian and river sand; postglaciala gyttjiga sand-, mo- och lerlager = Postglacial marine sediments; finiglaciala sötvattenslager = Finiglacial fresh water mud; Gotiglacial varvig lera med torrskorpa = Gotiglacial varved clay with dry crust; Gotiglacial distalsand = Gotiglacial sand; Gotiglacial randås = Gotiglacial delta-gravel.) By C. Caldenius.

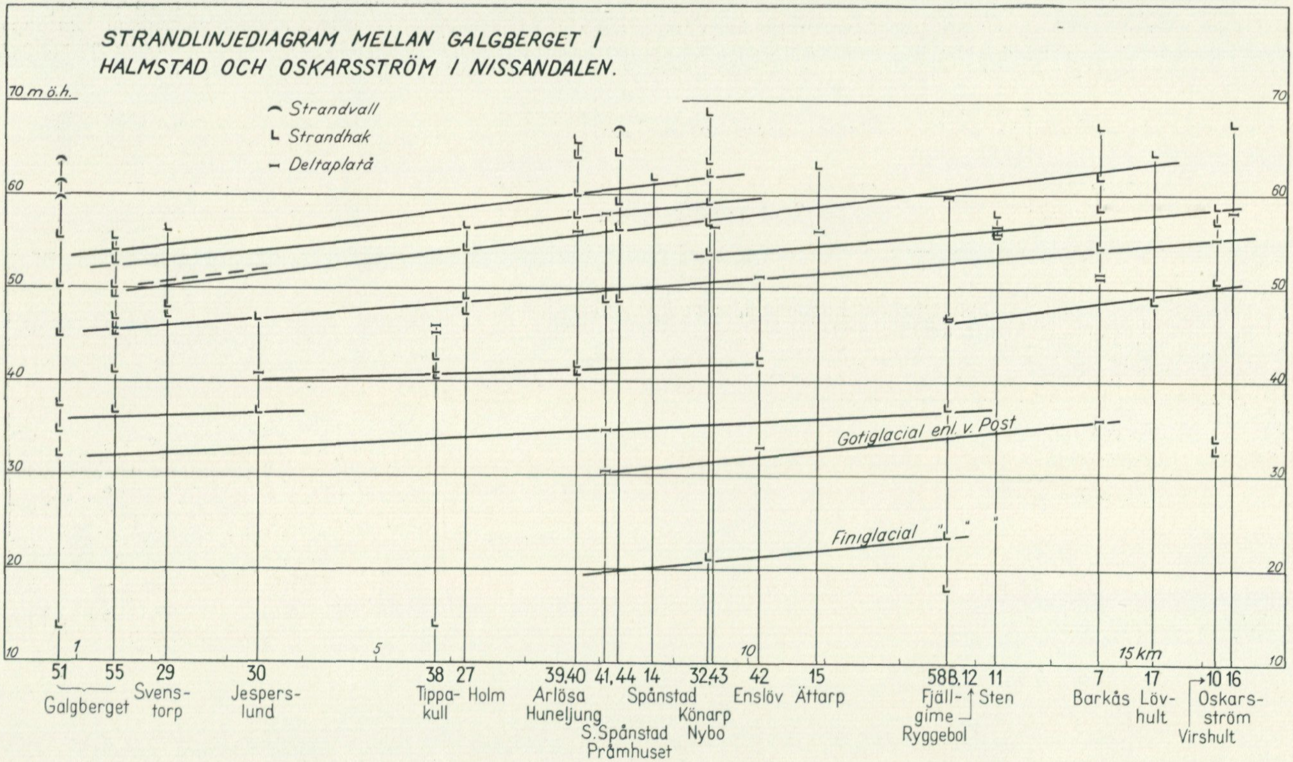

Fig. 7. Diagram of raised beaches between Galgberget (Halmstad) and Oskarsström in the Nissan valley (strandvall = shore bar; strandhak = marine cut terrace; deltaplatå = delta plain). By C. Caldenius.

from the valley of the Nissan river. The plateau is furrowed by shorebars with their crests at 60 metres above present sea level and with the Marine Limit at 63 metres close to its proximal slope. The distal slope in a very open exposition towards the sea shows a fine series of marine cut terraces, the lowest one at 13.5 metres above sea level being the limit of the Postglacial transgression. Every terrace has its highest level just at the most projecting corner of the plateau and slopes in both directions from it (fig. 5).

NINTH STOP — SLOTTSMÖLLAN

Decending from the delta plateau and taking the road along the Nissan river we stop at the border of the 15 metres deep clay pit belonging to the brick yard at Slottsmöllan.

The clay is a Gotiglacial varved clay, but there are great difficulties in distinguishing exactly the limits of the single varves. Measurements of the varves have been performed at several profiles in the clay pit but their results do not show any good concordance, probably due to slight displacements in the huge clay mass. The surface layer is a wave washed gravel from the Galgberget delta. Thin and small shells of *Portlandia arctica* and *Saxicava arctica* occur at the lowest levels in the clay, and there is reason to assume that the great amount of meltwater here discharging into the sea made the seawater rather fresh *(4)*. The consistency of the clay is very heavy throughout. In a boring in Halmstad the surface of the Gotiglacial clay has been observed at a level of — 12 metres under a thin layer of fresh water mud, which was covered by marine sand and gravel accumulations from the Postglacial transgression *(8)*. The clay is densely consolidated, at least down to a level of — 16 metres, showing that the shoreline had a still lower position after its regression at the end of the Gotiglacial period and before the Postglacial transgression set in (fig. 6).

During the continuation of our excursion this day we travel further inland in order to get a look on the meltwater deposits and the ice-recession in the highland part of the Nissan river valley. We reach the mouth of the valley at Himmelkulla (Hill of Heaven) at the foot of the big glacio-fluvial delta, that once blocked the valley entrance. At Åled we drive up on the delta plateau, the Älvasjö-terrace, 57 metres above sea level and note the occurence of several marked E-W gravel ridges, kettle holes, Bronze Age graves and raised stones (fig. 9).

TENTH STOP — SPÅNSTAD

We advance to the proximal side of the delta at Spånstad and descend to a cutting where Gotiglacial varved clay is lying as a veneer on the delta-gravel and conformably with the slope. The vast depression between this glacio-fluvial delta and the next one further into the valley must have arisen during the ice recession period. Subsequently, remaining dead ice probably prevented filling the valley completely with glacial sediments.

Our excursion route in the Nissan valley follows an old medieval riding path leading from the west coast to the interior of the land and modernized for present day traffic. Remnants of the Gotiglacial sediment plane exist as terraces left by

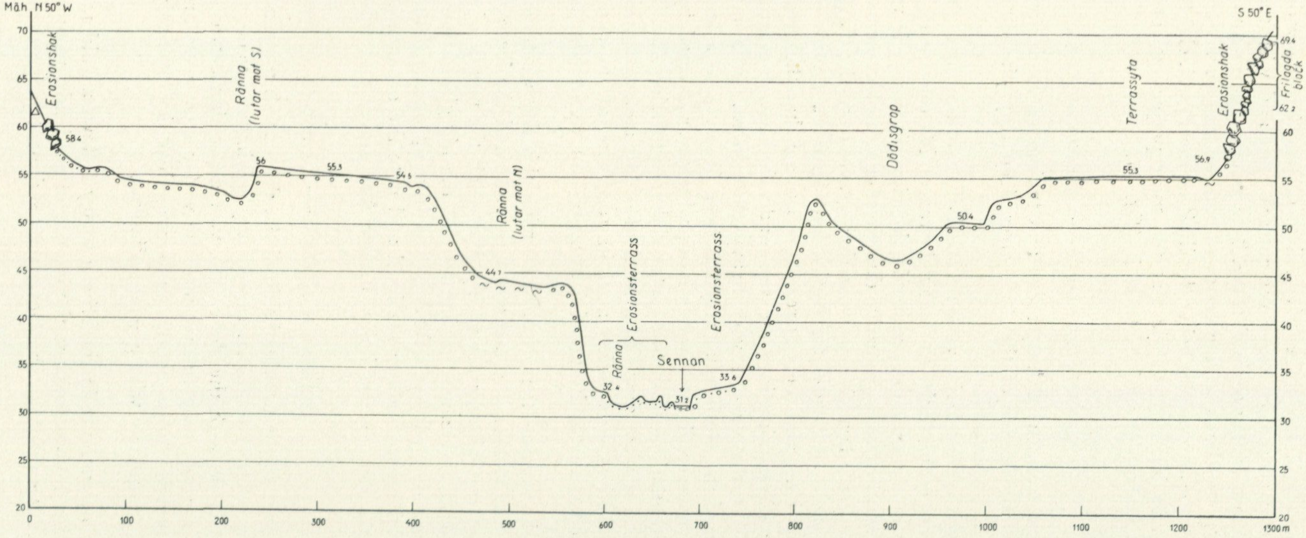

Fig. 8. Glacio-fluvial deltas on both sides of Sennan river at Virshult. Erosion channels along the valley sides and cut terraces along the river valley. By C. Caldenius.

Erosionshak = The break in slope between cliff and terrace; Erosionsterrass = Marine cut terrace; Dödisgrop = Kettle hole; Ränna = Erosion channel; Terrassyta = Glacio-fluvial deltaplain

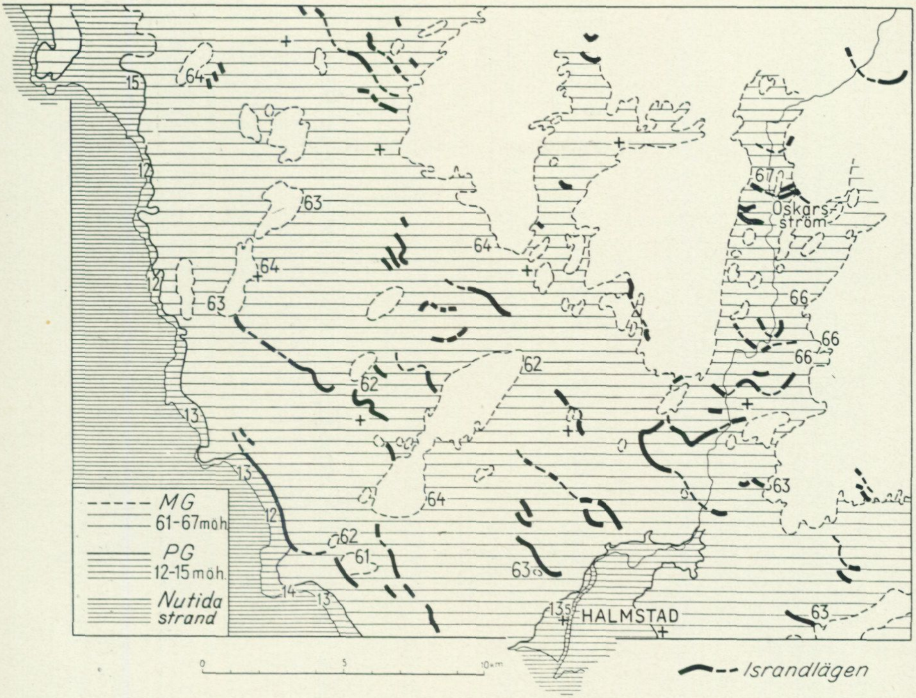

Fig. 9. Terminal moraines (israndlägen) within the geological map sheet Halmstad. Map by C. CALDENIUS.
(MG = Marine Limit; PG = Postglacial transgression limit; nutida strand = recent shore)
För spridning godkänd i Rikets allm. kartverk den 20 maj 1960.

the later erosion, and they sometimes lie on levels closely below the Marine Limit. Thus the Gotiglacial narrow fjord reached this limit 67—70 metres above present sea level. Lateral glacio-fluvial erosion has cut a series of drainage channels in the moraine on the valley slopes down to the contemporaneous shore, which has often caused difficulty in determining the Marine Limit (fig. 7).

At Oskarsström, a country-town with textile- and paperpulp-industries, we pass one of the innermost glacio-fluvial delta thresholds in the Nissan valley.

ELEVENTH STOP — SPENSHULT

The Gotiglacial shoreline has been traced about 5 km further inland but thereafter high eskers and glacifluvial erosion are predominant as we will see at Spenshult, near the turning point of our excursion in the Nissan valley.

By returning to Halmstad we first drive along the opposite side of the Nissan river valley to Oskarström, thereafter eastwards to the Sennan river, whose valley we follow to the South. At Åled we cross the Nissan river and follow the highway to Halmstad.

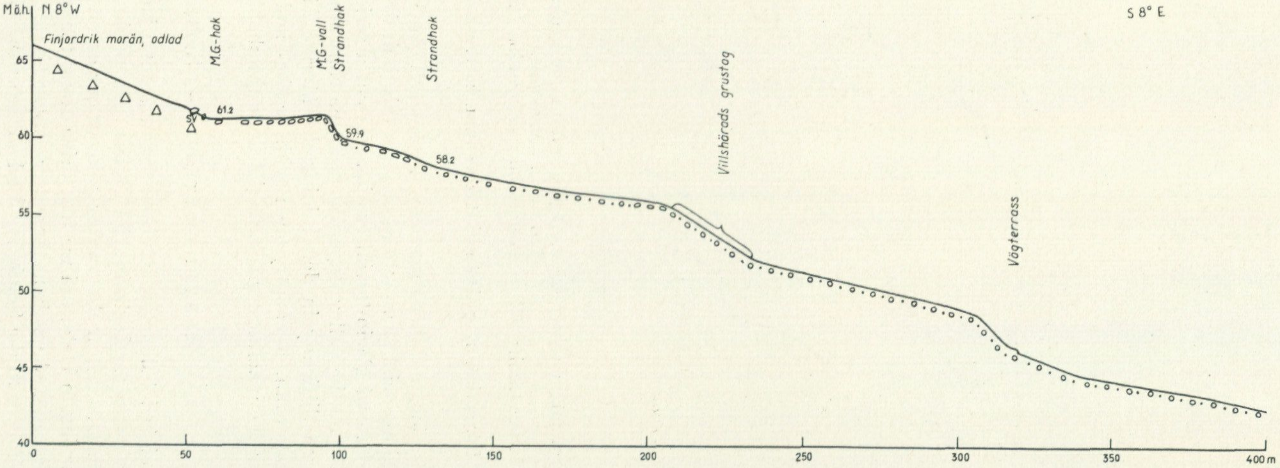

Fig. 10. Gotiglacial marine shore-terraces, south of Onsjö. (Finjordsrik morän, odlad = silty till, cultvated, M.G.-hak = highest marine shore line). By C. Caldenius.

By studying the map on the way we find glacio-fluvial deltas corresponding to other deltas on the right side of the rivers (cfr fig. 8).

TWELFTH STOP — ÄTTARP

Lack of time permits us to ascend only one of them, the Ättarp terrace, which is equivalent to the Spånstad-terrace. The Ättarp delta was mainly accumulated by meltwater running along the valley side, where eskers and drainage channels occur.

At Sennan there are two clay pits, Gotiglacial clay with well defined diatactic varves. No marine shells have been found here. We have, however, no time to stop at them.

Those who are interested in different types of old farmhouses have a chance to see two log-cabins with thatched roofs when passing Ludvigstorp and Norre Katt park in Halmstad.

THIRD DAY — AUGUST 10

By C. CALDENIUS

Route: Halmstad—Falkenberg

North of the Nissan river valley the landscape morphology changes in so far as that high mountain-ridges divide the low coastal plain into broad NE—SW valleys. They extend down to the actual shore-line and their existence has been of importance for the glacial development during the initial as well as the concluding phases of the glaciation.

Change of level will be demonstrated at several localities, and the effects of the immense wind action on the west coast of Halland will also be shown.

In the morning we leave Halmstad in a westerly direction. At Söndrum, 4 km W of the town centre, the road runs up on the remnants of a terminal moraine which will be followed about 2 km.

FIRST STOP — ONSJÖ

From the main road the bus at Onsjö turns north on a by-way across a gentle undulating gravel slope, where on the lower levels marine cut terraces and on the higher ones up to 61 m above present sealevel shore bars of Gotiglacial age are to be seen. In the well exposed localities the gravel has been washed out by the waves from the till covering the mountain — highest point + 83 m — and the boundary for the wave action is sharply marked on the ground. This is the Marine Limit (cfr. fig. 10).

SECOND STOP — MARSKOG

The Haverdal area is under protection and extends over a 350 hectares wind blown sand area along the coast. The flat sand beach is bordered by very high sand dunes (according to Swedish standards) one of which reaches 37 metres above present sealevel at Marskog. The level of the surroundings at the foot of the dune is about 11 metres.

At the present time the drift-sand is bound by *i. a.* lyme-grass and pines, but not long ago the wind blown sand was a grave danger for the plain country along the coast of Southern Halland.

A good outlook over the dunefield is afforded from the top of the dune just mentioned.

THIRD STOP — DUNGEN

At Dungen we leave the bus for a short walk on a small path into the woody belt inland from the dunes along the coast. After a while we meet with more open ground with scattered pines, where flat worn pebbles have replaced the eolian sand in the surroundings. Several well developed shore bars can be distinguished up to a level of about 13 m, the marine Postglacial transgression limit. The pebbles are mixed with coarse gravel and form a 200—300 m broad and more than 3 km long belt extended in the same direction as the Gotiglacial terminal moraines. Thus it is most probable that they indicate the existence of such a glacial deposit, which has been deeply eroded by the action of the Postglacial sea.

FOURTH STOP — SKALLEN

Skallen (The Skull) is the name of a mountain protruding into the sea and partly covered with thick till, which from the top to the foot of the hill exhibits all those kinds of reworking that later marine agencies have caused. We approach the hill on its southeastern slope and the road bends between marine cut terraces, indicating different stages of the shoreline from the Gotiglacial period to the present time. In good weather a splendid view is afforded along the coast where modern summer-cottages in bright colours contrast with the old farmhouses often still with their thatched roofs.

A large stone quarry in the steep western slope of the hill recalls the time when Swedish gneiss was exported as paving stones to the European continent and elsewhere.

From Skallen we will drive in a wide curve inland. At the village of Harplinge our road turns to the NW and follows a well marked terminal moraine-ridge, which crosses the broad Harplinge valley and is visible at its surface with the exception of about 700 m at its deepest part between Skintaby and Skäpparp, where sand soil reveals the existence of the moraine-ridge at a deeper level.

FIFTH STOP — SKINTABY

Looking from Skintaby towards the coast we note that the ground there lies higher and the geological map indicates the existence of a rock threshold in that region. Such topographic features of the rockground are still more conspicuous in the neighbouring valleys north of the Harplinge valley. They are completely closed by rock barriers at their ends at the coast. The cause is probably overdeepening by the land-ice during the early stages of the glaciation.

From Särdal at the southern end of the high Steninge mountain-ridge the bus continues NW to Steninge strand. At Nytäppet the road crosses the Postglacial transgression beaches with their lagoon-bogs and, turning NE, ascends on the wide wave washed gravel slope to about the Marine Limit at 62 m at Tittut.

SIXTH STOP — SKÄPPARP

Our way then descends to an idyllic farm, Skäpparp, at which a short walk allows us to study the accession of the Harplinge terminal moraine to the rockside of the Steninge mountain ridge.

SEVENTH STOP — STENINGE

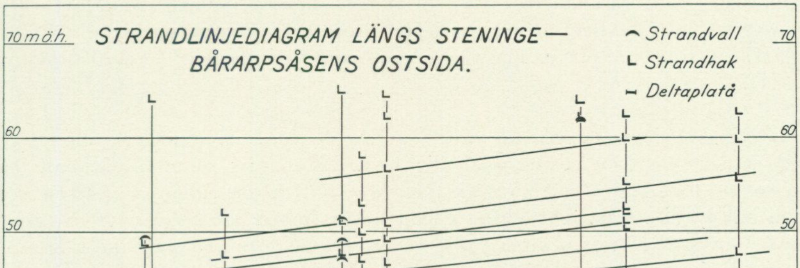

Fig. 11. Diagram of raised beaches at the Steninge—Bårarp mountain ridge (cfr. fig. 7). By C. CALDENIUS.

The road along the eastern slope of the Steninge mountain-ridge to Steninge church presents a good survey of young and old glacial topography in the Harplinge valley. The two isolated hills, Rydsberg and Aggaredsberg, which emerge in the valley are both extended in the same direction as the latest ice-movement and furnished with thick drumlin-shaped till deposits facing NE or towards the direction of the ice. On Rydsberg a broad rock-terrace, inclining to the SW, constitutes a remarkable topographic feature, which is probably due to the occurrence of a valley glaciation during the very beginning of the last Ice age.

EIGHTH STOP — GETINGE

From Steninge the road carries us out into the middle of the Harplinge valley to the small industrial village of Getinge where we visit the brick yard. In the clay pit at Getinge Gotiglacial marine clay is exposed below a thin cover of wave washed sand. Remnants of a rather rich arctic molluscan fauna have been found here, the shells being larger and thicker than those of the same species in the clay at Slottsmöllan *(4)*. Evidently the supply of nourishment had been more favourable here owing to richer amounts of salt plankton-bearing seawater. Only smaller meltwater rivers discharged their waters at distances of 3—3.5 km from the place. The clay is well stratified but without well developed varves.

Leaving Getinge we pass the bridge across the Suse river, which runs towards NW outside the foot of the main highland. Its sources come from small lakes far in the highland, and they seek their way out in the valleys with their common SW-ly direction. The obstacle which has forced the Suse river to turn its course towards NW is obviously the occurrence of terminal moraine ridges and glacio-fluvial deltas extending in a NW—SE direction.

From Getinge we follow the highway to Slöinge and have a good outlook over the immense terraced drumlins which embrace the NE end of the Steninge mountain-ridge. At Slöinge we turn to the south into the Eftra valley.

NINTH STOP — SKATTAGÅRD

We cross the valley and ascend the broad moraine-terrace along the western side in order to examine the type of till in a 5 m deep pit close to the road at Skattagård. As we already have noticed at Steninge this kind of moraine accumulation is a rather common feature along the valley sides facing the latest ice movement in this part of Halland.

Herewith the demonstrations of the geology of Halland based on the geological sheet "Halmstad" *(27)* are finished, and for the rest of the excursion route south of Gothenbourg there is gap of about 100 km where no modern detailed geological maps are available.

Continuing further north we will note a change in the landscape morphology: the high NE—SW mountain-ridges disappear and small isolated monadnocks replace them on a rather even coastal plain outside the highland. This change has been performed already south of the little town of Falkenberg (10 600 inh.) close to the mouth of the Ätran River, which is crossed on an old stone-bridge at the ruins of a fort on the southern shore.

TENTH STOP — FAJANS' BRICK YARD

We drive straight through the town and halt at a now abandoned clay pit, at Fajans' brick yard, partly filled with water, but where an interesting section in the Postglacial transgression sediments is still visible.

When the clay pit was still in operation, it had a total depth of about 12 m, the lowest 6 m consisting of Gotiglacial clay. In its uppermost part the clay layers are broken and strewn with scattered stones and blocks left as a residue while the shore line moved to lower levels and the waves attacked the former seabottom. The clay is disconformably overlain by a humified peat layer with oakstems, and on this soil layer a muddy clay rests covered by shore gravel and delta-sand, indicating the readvance of the sea over the dry land, the marine Postglacial transgression which here reached about 15 m above present sea level.

A sample of the humified 0.11 m thick peat layer, the upper surface of which is situated 4.64 m above the present sealevel is dated by means of natural radiocarbon measurements and the age found was 8200 ± 140 *(49)*.

Continuing further N on the even, open coast plain we make acquaintance with those long, low terminal moraine ranges, which Gerard De Geer *(13)* mapped already in 1890 and distinguished from the Postglacial transgression raised beaches which here commonly have the shape of sand bars. Our road follows while we drive north one of those straight terminal moraine-ridges and when we return to Falkenberg again our way goes on the Postglacial elevated beaches.

ELEVENTH STOP — LÅNGÅS

At Långås a cutting in the moraine-ridge will be studied. You may notice the flint content in the redeposited gravel, but you will not find any flint pebbles in the till.

TWELFTH STOP — HÄGARED

At Hägared two sections in the beach-deposits were found during the mapping of this region.

A sample of dark sand at Hägared, containing a fraction of organic material (mostly mould) and covered by a sand dune was analyzed by the C14-method. Age found was 1020 ± 80. The sample was situated at the Postglacial transgression limit, here at 16 m above present sea level; the formation of the dune was supposed to have begun in the 17th century. Evidently the C14-age does not apply to any of the known events, or else the dune was formed earlier than expected. No attempt has been made to extract humus by sodium hydroxide treatment, since the organic material itself seemed to be humus. On the other hand, it is not likely that modern contamination could be completely responsible for the very low age in comparison with the transgression *(49)*.

One cannot avoid noting that the old walls are built of stones and boulders gathered from each farmer's own ground in order to make it amenable to cultivation. The sandy soil then forms only a thin veneer on the underlying till.

FOURTH DAY — AUGUST 11

By C. Caldenius

Route: Falkenberg—Gothenburg

The landscape of the Swedish west coast changes on our way to Gothenburg. South of the town of Varberg we have travelled on the sand plain of the Halland coast region. North of the town we enter the rock and clay district of the West Coast. This district appears to be very uniform with deep fracture valleys in the main direction SW—NE and crossing coast fractures in NNW—SSE. The uncovered rock is about 55 % and the clay 20 %. The other components, sand and till, each form 10 % of the district *(29)*.

Starting from the hotel we go northwards. North of the windmill at Morup the highway runs along nearly straight terminal moraines at this level (8—11 m above present sea level) highly demolished by wave action and very similar to the terminal moraines at Långås. Near Tvååker we leave the highway and direct our way towards the border of the highland (fig. 12).

First stop — Klev

After passing a well marked terminal moraine at Ugglehult (cfr. fig. 12) we see in front of us a beautiful terrace with a gentle slope, facing west. The surface of the terrace at Klev lies at 59 m above present sea level and a small pit in the terrace shows sand and silt. The terrace then is a distal deposit of a glaciofluvial gravel delta of which a remnant still remains at the southern corner of the valley entrance and close to the Marine Limit at 70 m above present sea level.

Second stop — Dagsås

Further in the valley the road crosses a low moraine ridge and at Dagsås church a high terminal moraine ridge with a sharp crest and a well defined bow blocks the southwestern end of lake Ottersjön. Then at a certain stage of the ice recession an ice tongue has projected rather far out into the valley while the higher valley sides were already laid bare (fig. 12).

Third stop — Skärsjön

Still more pronounced is the terminal moraine morphology at the western end of the neigbouring lake Skärsjön, which is surrounded by a beautiful horseshoe formed terminal moraine, which between the lakes Skärsjön and

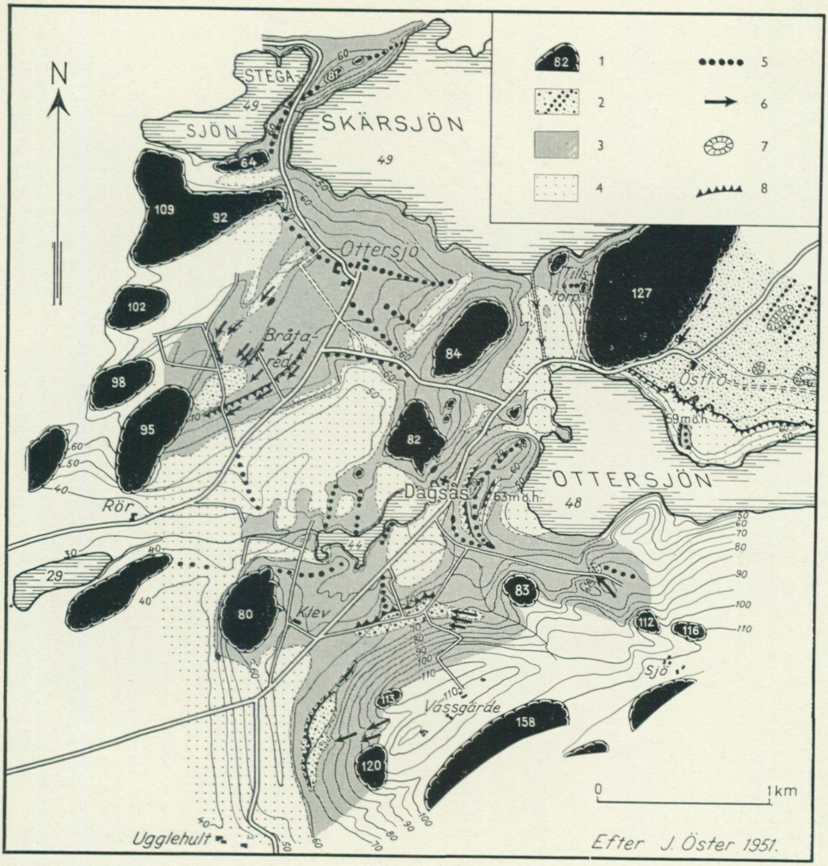

Fig. 12. Map of the Skärsjön—Ottersjön area. By J. Öster and C. Caldenius.

1. Exposed Archean bed rock
2. Glacio-fluvial deltas with feeding eskers
3. Moraine areas
4. Gotiglacial distal and younger sediments (sand, silt, clay, and peat)
5. Terminal moraine ridges
6. Lateral drainage channels
7. Kettle holes
8. Marine raised beaches

Contour lines with 5 metres equidistance.

För spridning godkänd i Rikets allm. kartverk den 20 maj 1960.

Stegasjön is composed of a single ridge while south of the lake Skärsjön at least three ridges can be distinguished. On the valley sides glacio-fluvial drainage channels are very common, but as they can be reached only by some tedious climbing they are not visited by the excursion (fig. 12).

Fig. 13. Stationary ice border stages in the surroundings of Varberg. Map by C. CALDENIUS.

1. Terminal moraines.
2. Glacio-fluvial deltas.
3. Region above the Marine Limit (MG) about 70 metres above present sea level.
4. Mainly exposed crystalline bedrock sometimes with a thin till cover.
5. Glacial—Postglacial sediments in general.

För spridning godkänd i Rikets allmänna kartverk den 20 maj 1960.

Returning westward along the northern side of the Dagsås valley, passing Rör, we round the border of the highland at the Nackhälle hill reaching 143 m above present sea level and to which many terminal moraines end as slightly bowed ridges (fig. 13). Our road ascends the biggest of them, which dams the vast Store mosse (peat bog), and follows it to the crossing east of Spannarp church. We turn inland on the broad till plateau which occupies a great portion of the coastal plain here in a vast angle penetrating into the highland. In front of us arises a forest clad steep slope belonging to a big glacio-fluvial delta, with the top 12 m above the Marine Limit. Our trip carries us right through a real landscape of terminal moraines, where their ridges lie with intervals of about 100 m. The ground undulates like a corrugated plate. A corresponding frequency of moraine ridges occurs only at Värö, further north in Halland, where it probably is of contemporaneous age (fig. 13).

FOURTH STOP — KALVALYCKAN

At Kalvalyckan we will walk along one of the most pronounced of the moraine ridges towards the peat bog into which it slopes like the other ones.

When turning to the left, at Grimeton church, we drive along the marginal moraines. The high wireless masts on the left hand side transmit radiotelephony to America.

FIFTH STOP — CASTLE OF VARBERG

The Castle of Varberg. Our lunch will be served in one of the old medieval houses, which since 1697 has been enclosed by the high and strong fortification walls erected by Christian IV, King of Denmark, and built of stones from the surrounding basic rock, a charnockite. The Varberg Museum is housed in another fortification building and among its collection one of the most remarkable finds here conserved is a human skeleton with a dress from the year 1360. It was encountered by harrowing on a peat-bog at Bocksten, 15 km NE of Varberg. Mr Sandklev, the director of the Museum, demonstrates this unique example of a nordic medieval dress and relates its story.

Leaving Varberg we cross the mouth of the Torpa valley, a deep tectonic valley filled with Glacial and Postglacial deposits to a depth of more than 100 m and running NNW—SSE or in the same direction as the steep escarpment north of Nackhälle.

Already at Varberg the landscape nature had changed and on our continued trip towards northwest outcropping bare rocks become common. The landscape loses the big lines that hitherto were such distinctive elements. There are only some marked valleys as the Viskan river valley and the valley occupied by a fjord like Lake Lygnern, which break a certain monotony in the landscape picture.

SIXTH STOP — GRAVE FIELD AT FJÄRÅS

Lake Lygnern is barred at its western end by a huge glacio-fluvial delta called Fjäråsbräcka intercalated by several till lenses and outcropping terminal moraine ridges. From the highway we turn eastward straight on the western slope and pause a moment at the foot where a vast grave field with raised flat stones from the Iron Age attracts our attention.

SEVENTH STOP — FJÄRÅS BRÄCKA

Ascending on the Fjärås bräcka terrace surface at 50 m above present sea level, we first visit the southern part, which is untouched by the gravel mining and where one can get a good idea of the great abrasion, to which the delta-terrace has been subjected in its exposed situation against the wave action on a 400 m long gravel ridge, extending along the western border of the terrace and reaching 11 m above the general level of its surface. Scattered big blocks indicate the presence of moraine on deeper levels, which has been verified by borings.

EIGHTH STOP — FJÄRÅS BRÄCKA

From the top of the Fjärås bräcka terrace in front of the lake Lygnern there are beautiful views towards the sea in the west and the lake in the east. Borings from the terrace surface have shown the occurrence of Gotiglacial clay overlain by wave washed gravel and underlain by glacio-fluvial gravel and sand *(34; 48)*. The original delta plain then is not preserved, and the whole deposit must have been greatly reaccumulated and diminished by later abrasion. The Marine Limit is situated at 77 m above present sea level.

From the big gravel pit at the western foot of the terrace 1 million m^3 of gravel have been removed during the years 1917—47.

The ice border stage to which the glacio-fluvial terrace at Lygnern belongs is to be found between the valleys of the Viskan and Göta rivers characterized by particularly large terminal moraines and glacio-fluvial deltas. For the main part it is evident that they have arisen in front of ice tongues located to the valleys.

We pass the town of Kungsbacka (4 360 inh.). You may notice that most of the older houses are built of wood. The foundation of stone houses is very difficult on the 80 m thick soft clay layers and needs extensive piling. You will find the same thing in Gothenburg, but there the ground floor is often made of stone; the upper stories, however, of wood.

NINTH STOP — LINDOME

The long terminal moraine at Lindome, however, has the shape of a straight ridge over the Lindome river valley and to the very foot of the highland. The land ice then still covered the neighbouring highland plateau.

FIFTH DAY — AUGUST 12

By B. JÄRNEFORS

Route: Gothenburg—Trollhättan

The Göta River valley between the towns of Gothenburg and Trollhättan (a distance of about 80 km) is an old fault-line valley, whose bottom is now covered with Quaternary deposits, sometimes more than 100 m in thickness. The sediments are mostly Lateglacial and Postglacial clays. The clay types and their different physical properties will be studied during the excursion. It may be remarked that the Göta River has the largest water volume of any river in Sweden.

As evidenced by the scars, at least seventeen large landslides have occurred in the valley. The two most recent slides occurred at Surte in the year 1950 and at Göta in 1957. The unfavorable stability conditions of the natural slopes in the valley depend on several factors, of which the most active one seems to be the erosion by the river. In some places such erosion is noticeable both in the banks and the bottom of the river. The transportation of suspended material by the river is calculated to amount to more than 100 000 m^3 annually. In this part of the country the present land uplift is about 25 cm per century.

In several places a high artesian water pressure prevails in gravel and sand layers under and in the clay strata, which causes a decrease in the shear strength of the clay. The slide bottom has been found to be largely plane, with a gentle inclination towards the river. There are grounds for assuming that during the evolution of a slide, the slip surfaces will follow a zone of weakness in the soil strata. These potential geological slip surfaces have a tendency to appear at interfaces between different clay layers.

FIRST STOP — KYRKÅSEN

Lee-side moraines (crag and tail) are a special form of deposits in the region north of Gothenburg. They consist of till but sometimes also of material of glacio-fluvial origin on the western side of some of the bedrock slopes — the lee-side in relation to the ice-stream direction. They are common, but as we now go inland we only meet with one of them at Kyrkåsen in Gothenburg, belonging to the same stationary stage as the one at Lindome and Fjärås.

In 1922 the following section was found

1. Glacial clay 2 m
2. Sandy gravelly till, partly stratified 2 m
3. Stratified glacial sand, with thin layers of clay 4—5 m
4. Sandy till 2 m
5. Stratified sand 0.3 m +

According to Munthe, Sandegren and Björsjö *(32; 39; 5)* the drift was discharged at the ice border out over the western submerged slopes of the mountain into the sea water which at that time had a depth of about 70 m. Probably the ice border also oscillated with an amplitude that is supposed to have been very small.

SECOND STOP — SURTE

In Surte a large landslide occurred in 1950. The slide developed in the thick series of Lateglacial clay which covered this part of the valley. These clays, also called fiord sediment (see map of the Quaternary deposits in the Göta River valley) *(24)*, have been deposited in deep and calm, oxygen deficient sea water. The clay content is generally high, *e. g.*, about 60 per cent of the material is $< 2\ \mu$. The clay is generally rich in iron sulphides, often visible as dark bands or varves. In some layers of the sulphide clay the sensitivity is very high (quick clay).

The salt content of the clay strata varies in a regular manner in a section across the valley. At places on the valley sides remote from the river, the salt in undisturbed clay is almost completely leached out to the full depth of the clay strata; however, the salt content increases markedly towards the river. When a slide occurs, leached clay in general will be thrust over clay with a higher salt content. Thus, by measuring continuously the salt content of the clay in a vertical profile through the slide area, the position of the slip surface will be revealed by a sudden step in the salt content curve *(23)*.

Such conditions can be investigated by means of a sonde for determination of the electrical resistance of the clay *(43; 44)* which will be demonstrated.

The clay strata and slide bottom of the slide will also be demonstrated in a clay core taken by means of a soil sampler, which is provided with metal foils surrounding the core. This sampler was constructed by the Swedish Geotechnical Institute *(25)* and is able to take undisturbed samples of a length up to 11 m. The boring method is also very suitable for making varve measurements in localities where it is not possible using the "classical" method of digging pits.

One of the main causes of this particular slide seems to have been a very high pore water pressure in the sensitive clay on the valley side. The slide has been described by B. Jakobson *(19)*, and C. Caldenius and R. Lundström *(9)*.

Third stop — Jordfallet

At Jordfallet *(The Soil Slump)*. A large, flask-shaped landslide scar is visible at the valley side. The sensitive clay of the slide area flowed to the river, which now is relatively narrow and curves at this point. Near the river bank the former soil surface was revealed 5 m under the overthrust clay and contained large pieces of the stump of an oak, which had apparently been growing at the time of the slide and had been broken by it. Radiocarbon dating of the stump revealed that the slide occurred about 1150 A. D.

Fourth stop — Nol

View of the Dösebacka gravel-pit on the west side of the valley.

The Quaternary stratigraphy of the Dösebacka plateau is summarized as follows from the top to the bottom of the gravel-pit.

A 1.	6—21 m	A very hard, grey, tillite-like till with few boulders.
A 2.	4— 5 m	Glacio-fluvial gravel and sand.
A 3.	9 m	Till of about the same composition as the upper till.
B.	6—12 m	Stratified yellow gravel and sand. In this layer fragments of musk-ox and mammoth bones have been found (*30*).
C.	ca 1/2 m	Grey, gravelly sand, possibly indicating an interglacial land surface.
D 1.	ca 5 m	Red gravel with well rounded boulders, probably wave-washed till (D 2).
D 2.	ca 3 m	Red local till with a high proportion of angular rock fragments and boulders.
E.	ca 1/2 m	Stratified reddish yellow sand and gravel in depressions in the underlying solid rock.

Fifth stop — Älvängen

Lunch.

Sixth stop — Göta

On the 7th of June 1957 the largest landslide in modern times in Sweden occurred at Göta on the side of the Göta River. The area of the landslide has a length of 1 1/2 km along the river and a width of up to 250 m.

The river bank was displaced up to 60 to 70 m towards the river, and the ground surface sank up to 7 to 8 m within the slide area *(36)*.

Large parts of a pulp-mill factory were destroyed but fortunately only three men were killed of the 200 working within the factory area. The Trollhätte Canal was blocked up for a month.

The banks of the river at Göta consisted of Postglacial clay with a low sensitivity. But behind the hard river bank there was an area with Lateglacial, highly sensitive clay. Also, artesian water was found in sandy layers in or below the clay.

The initial slide occurred in the south end of the slide area, where the thickness of the clay layer was smallest. There was a very high ground water pressure in a permeable layer of gravel and sand under this clay. This fact, and an increasing erosion in the river bottom outside the initial slide area, must have caused such unfavorable stability conditions that the slide started.

SEVENTH STOP — LILLA EDET

By means of the soil sampler mentioned above the clay strata near the Göta River in Lilla Edet have been investigated. Some physical properties of the clays are presented in fig. 14. Profiles 16 and P are situated 135 m and 34 m east of the river shore and 11 m and 9 m above present sealevel respectively.

The Gotiglacial clay at the bottom of the series is only diffusely varved and has been deposited in brackish water in front of the retreating ice. During Finiglacial (also locally named Lateglacial) time the sealevel sank from about 100 m to about 15 m above the present, due to the local upwarping of the crust, and sedimentation of clay material during this fiord-stage of the valley was intense. During the subsequent Postglacial age the water level rose to about 30 m above the present sealevel and the sediments settled with increasing grain sizes in a water with decreasing salinity in this section of the river valley. Alluvial deposits, mostly sand and silt from the delta stage of the river, complete the sediment series.

By means of the foraminiferal fauna (investigated by F. Brotzen, Geological Survey of Sweden), the profiles are divided into three sharply defined zones, of which two belong to the Lateglacial time (LGL I and LGL II) and the third to the Postglacial time (PGL). In profile 16 the transgression of the sea between Lateglacial and Postglacial time is represented by a layer of sand, 2 m in thickness, at the top of which thin sand and clay layers alternate. The Lateglacial clay LGL II has been removed by erosion.

In both profiles the salt content of the pore water is very low (< 4 g Na/l pore water). But only the Lateglacial clay LGL I in profile 16 is a quick clay, and in these clay strata there is no relation between the lowering of the salt content of the pore water and the sensitivity of the clay.

The variations of the Atterberg limits (plastic and liquid limit) probably do not depend on the content of Na and organic C in the profiles. A certain relation between the Atterberg limits, content of clay and clay type is visible from the analyses.

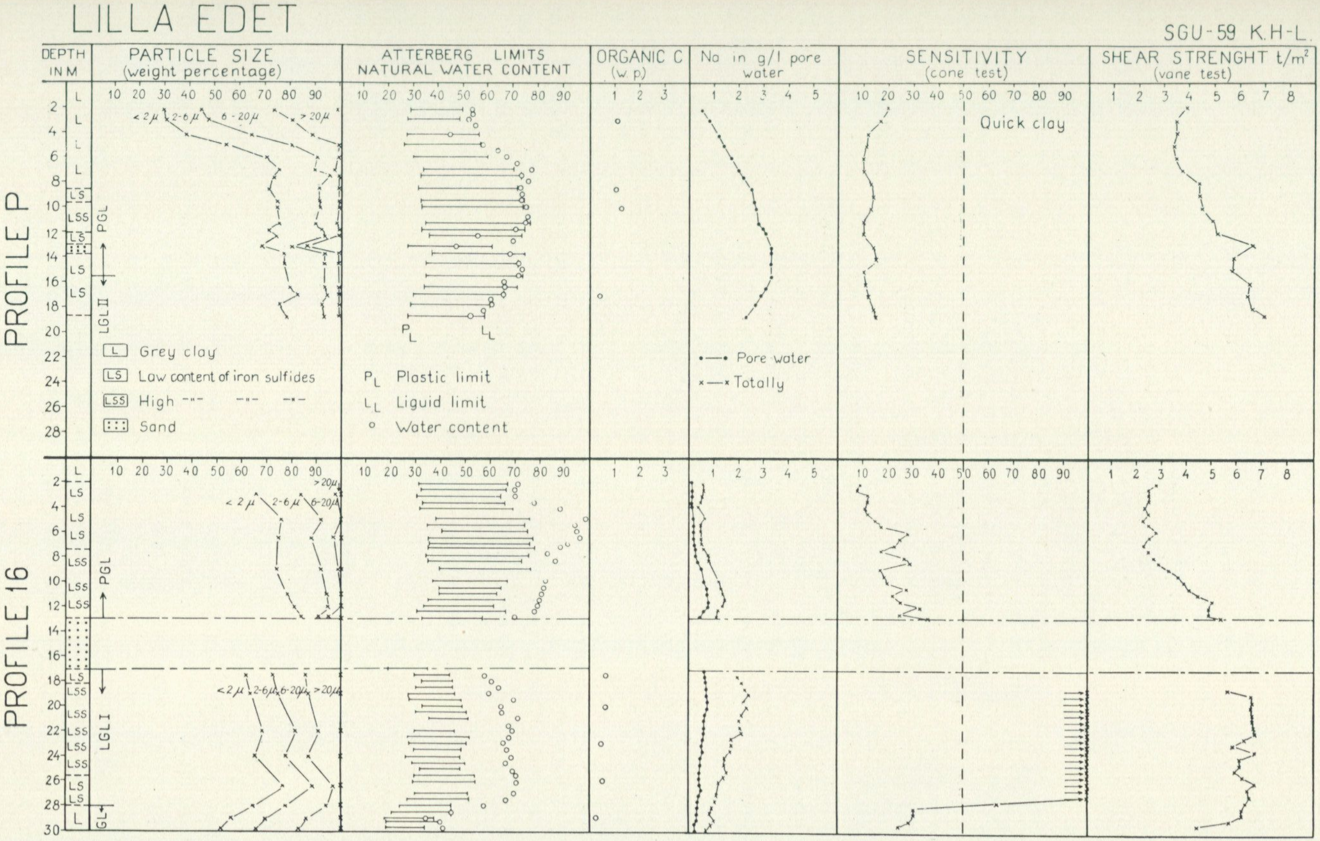

Fig. 14. Some physical properties of the clay at Lilla Edet (Göta River valley). By KIRSTEN HEIEN-LARSSEN and B. JÄRNEFORS.

The water content is lowest in the upper part of the Postglacial clay in profile P near the river bank. The clay is drained by the river, and the shear strength is relatively high. In this clay, in profile 16, the water content at the same depth is higher, but there must once have been a high water pressure in the sandy layer under the clay.

EIGHTH STOP — TORPA

Southwest of the farmyard at Torpa we find a flask-shaped land slide scar. The slide occurred, as established by studies of old maps, sometime between the years 1686—1719. The river bank of the Slumpån River must have been broken down by erosion, and the quick clay inside the bank flowed into the river.

North of the farmyard a large landslide scar is visible. This slide was stopped by a ravine situated immediately south of the scar. The ravine was eroded into the silty, Postglacial clay.

In this part of the valley the present erosional phenomena are clearly visible in the form of small slide scars on the river banks. The erosional processes are accelerated both by the periodically varying flow of water in the river and by the waves and currents caused by passing ships (investigated by Å. Sundborg, Geographical Institute of Uppsala).

NINTH STOP — INTAGAN

In 1648 a large landslide occurred at Intagan on the west side of the Göta River. The slide caused the death of 85 persons and moved a piece of land across the river, which at that time formed the frontier between Norway and Sweden.

The southern part of the landslide scar is well-preserved. The direction of the slide was turned to the north, which preserved some hills, partly covered with alluvial sediments. At the river about 120 m north of the northeast hill, the old slip surface is located at a depth of about 7.5 m *(22)*. Immediately south of the scar there is a ravine, 300 m long and about 8 m deep, which probably developed at the same time the water left the area. The present fluvial erosion is rather active, causing small slips on the river banks every year.

SIXTH DAY — AUGUST 13

By E. MOHRÉN

Route: Trollhättan—Lidköping—Gothenburg by bus; Gothenburg—Copenhagen by train

The main purpose of this day will be to follow the ice retreat further to the North under those special conditions which existed here. The general features of the nature of the landscape are determined by the configuration of the Archean bed-rock, consisting of gneisses. Its strike generally is N—S, NNE—SSW, which has determined the recent course of brooks and rivers. An intense erosion in pre-Cambrian time created a peneplain, the sub-Cambrian peneplain, which can be recognized in the even horizon level as well as in details on the rocks.

Upon this peneplain the Cambrian series were deposited, still preserved at the bottom of the plateau mountains (Taffelberge), two of which (Halle- and Hunneberg) we shall go between. Probably the Cambrian—Silurian rocks have rested all over the West-Gothian plain. Now they are left only below the dolerite caps, injected into different stratigraphic levels; elsewhere they are removed by erosion.

The region south of Lake Vener is characterized by an almost total absence of till. Probably earlier glaciations have removed all previous débris. The latest ice stream came from N 30—45° E with a deviation to the right *i. e.* from a more easterly direction, N 50—60° E, in the southeastern parts.

After the melting of the land-ice the Sea occupied a nearly naked rock floor upon which the clay mud was deposited in salt water. Even if it must be kept in mind that the Marine Limit is a metachronic shore line, a wide bay of the Sea covered this region from the Oslofjord in the W to the water shed between Lake Vener and Lake Vättern in the E, reaching as far to the N as to the middle of Värmland. The figures of the marine limit are for some places: Gothenburg 95, Hunneberg 128, Kinnekulle 127, N. Billingen 145, SE Värmland 190, Middle Värmland 220—230 m above present sea level.

During the regression of the Sea a growing archipelago on the boundary between Norway and Sweden to the middle part of Bohuslän formed a barrier against the open Sea and made the outlet narrower and narrower until at last the rock thresholds were so near the water surface that the salt or brackish Venerfjord passed into the Lake "Great-Vener" with a surface 49 m above present sea level at Mt. Halleberg.

This is a schematic and strongly abbreviated presentation of von Post's thorough investigation of the development of the Vener basin *(38)*. Indeed, objections have been made to the details of this investigation *(16)*.

Our main interest may be concentrated to traces of the intermittent retreat of the land ice as they are to be parallelized with the Norwegian Raer and the great Salpausselkä of Southern Finland. As far as we know, the age of these Fennoscandian moraines determined by radiocarbon measurements is about 11 000 years before present = Alleröd stage.

From Trollhättan we first go towards the East and later towards the North on a plain of glacial clays W of Mount Hunneberg, the dolerite precipices of which are to be noted. At its western foot it may be possible to observe the obscure entrances of ancient limestone (stinkstone) quarries. At Forstena we cross a smaller ridge which may be a unilateral moraine of an ice tongue from the narrow valley between Mts. Halleberg and Hunneberg.

From Vargön (smokes of the factories) we turn eastwards towards this valley, a fault valley as can be concluded by levelling the Archean floor of the Cambrian sandstone on each side. The down warp of the southern side is 30 metres.

FIRST STOP — HÄSTEVADET

At the entrance of the valley some gravel pits are opened in a marginal delta of a glacier tongue of a younger stage than that of which we have seen the lateral moraine in front of the valley. The morphologic features and the stratification are to be observed.

On the route along the valley two other similar terminal moraines can be observed. Further the parallelepipedic jointings of the dolerite are to be noted.

The most prominent terminal moraine lies at the eastern end of the valley, at Munkesten, where the road crosses over to the southern side. It has been dug away for the major part. As at Hästevadet, the glacial marginal features are smoothened by the current and wave action of the Vener fiord waters. The thresholds are situated at 64 m above present sea level. (The level of the present Lake Vener is 44.2 m.)

SECOND STOP — KVILLAN

At Kvillan, at the SE-corner of the triangular Mt. Halleberg, a terrace with well rounded boulders of about 10—20 cm width can be seen. The boulders mainly consist of the local rocks: dolerite and Cambrian sandstone. The raised beach lies 64 metres above present sea level *i. e.* 20 metres above the level of the Lake Vener. The floor of the beach is a blue glacial clay with arctic fossil shells such as *Portlandia arctica, Saxicava arctica, Astarte borealis, Macoma calcaria.*

South of the road between the farmyards Kvillan and Grytet cairns and piles of boulders as well as settlements are also to be seen. The implements suggest a Young Neolithic Age. The level of the grave field is 40—50 metres above present sea, the settlements reach + 57. — Owing to its topographical forms Mt. Halleberg has been a position of defense and a natural castle during several older periods.

THIRD STOP — MOSSEBO

At Mossebo, at the NE corner of Mt. Hunneberg, we have an opportunity to get a view of the stratification of the West-Gothic mountains. At the right side of the main road the Cambrian sandstone banks are exposed. Near the dolerite quarry the Cambrian-Ordovician sequence is as follows:

1. Dolerite (average thickness 60 metres)
2. Marly shales (10 metres; contact metamorphosed)
3. Ceratopyge limestone (1.5 metres)
4. Alum (Olenid) shales (about 10 metres)
5. Cambrian sandstone (24 metres)

Before this quarry was opened (in 1950) the foot of this mountain was covered with an immense scree consisting of dolerite boulders. When this material was removed, remains of a raised beach were exposed. Some of its rounded — subangular pebbles rest on a small shelf on the steep dolerite wall at about 95 metres above present sea level. As this beach must be of a Lateglacial (Gotiglacial) age, the talus material indicates the extent of the frost weathering since that time.

On our way to Grästorp we get an impression of the glacial clay plain. As already mentioned the till usually is lacking, and the heavy glacial clay rests directly on Archean rock. The clay cover, as indicated by well borings, seldom exceeds 5—10 metres. The bedrock surface is rather even. When mapping the area several rock exposures were found, but they are difficult to observe from the bus as they emerge only half a metre through the clay. This bedrock surface is the sub-Cambrian peneplain *(18)*.

On the clay thin sheets or strings of fine sand are sometimes found. The neighbourhood of Lake Vener reveals their nature as beach sand. Two levels can be distinguished, at + 52 and + 49 metres. The former probably corresponds to the latest outlet channel of the earlier stage, the Lake Great Vener, south of Mt. Hunneberg at a threshold of + 51 m.

But similar thin covers of fine sand of an other nature are found, especially visible on account of their obscure colour against the lighter clay in the springtime when the fields are naked. One type appears along the rivers as a high-water river sediment, another type often is found NE—E of protruding rocks and may be interpreted as redeposited moraine or sandy clay on the lee-side of the rock. If this is the right interpretation the main wind directions at the age of the Venerfiord seem to have been SW—W.

FOURTH STOP — GRÄSTORP

At Grästorp we stop in order nearer to study the details of whaleback rocks and striae, and their occurrence on different rocks.

If time permits we pay a visit to a clay cliff in the Karaby brook, where about 6 metres of glacial clay (with *Portlandia arctica*) are resting on glacially polished Archean rock.

FIFTH STOP — TUN

The end moraine hill at Tun is the most visible part of the southernmost of the Fennoscandian moraines, which can be followed from the Vänersnäs peninsula at Lake Vener towards the SE to the southern part of Mt. Ålleberg, a distance of 80 kilometres. These moraines indicate a longer pause in the ice recession. They are a complex of till, glacio-fluvial sand and gravel, and varved glacial clay. Sometimes this interrupted ridge is doubled or tripled. Its height above the clay plain seldom exceeds a few metres.

N of Friel, about 4 kilometres NE of Tun, another end moraine can be traced. This is only 1 kilometre long and is not easy to connect with other end moraines to the SE.

From Friel the road runs along an insignificant glacio-fluvial esker, now dug away for the most part.

SIXTH STOP — SKALUNDA

The end moraine at Skalunda also belongs to the Fennoscandian terminal moraines *s. str.*, the Swedish counterpart to the Norwegian Raer and the Finnish Salpausselkä. These represent an interruption of the ice recession of 600—700 years. The moraine at Skalunda reaches a level of + 65 to + 70 metres (Lake

Vener + 44, surrounding clay plain about + 50). To the west it can be followed to the Norwegian frontier. It protrudes into Lake Vener as two capes: "Hjortens udde" and "Hindens udde". Even in the lake it can be traced on the bottom contour lines.

On the end moraine W of the church of Skalunda is a sepulchral mound of unknown age.

In the northwestern part of the cemetery there are two runestones from the last period of the heathen time *i. e.* 9th—10th century.

SEVENTH STOP — RACKEBY

Rackeby is a village where the ancient architecture from about the 16th and 17th century and the peasant's old manner of living remained till the 19th century. Usually the timber walls of the houses were only 2 metres high and without windows. The latter were placed on the roof often faced with turfs. Now the farms have been rebuilt at the museum of Skara, the old cultural centre of Västergötland.

The terminal moraine at Rackeby is the northernmost of the Fennoscandian moraines. In this connection it may be mentioned that the reason why these moraines in this part of Scandinavia are quantitatively small compared with those of other parts along the same termini is probably the lack of morainic material in the source region *(29)*.

Following the younger terminal moraine from Rackeby to Gösslunda we visit the town of Lidköping at the Vener coast on the mouth of the Lidan river.

EIGHTH STOP — RÅDA

The fault line of the Kålland peninsula can be traced to the North across Lake Vener and to the South to the Sea, south of Gothenburg. It has a very steep eastern slope with a down-throw to the E of 40—50 metres. The land ice tongue in the depression between Mt. Kinnekulle (Cambrian-Silurian) in the E and the fault line in the W became fissured because of the stress on the right flank. The fissures were occupied by glacial melt water streams. The outwash plain at Råda was thus built up. Feeding eskers have been found by well borings even if they are not visible between Råda and Lake Vener.

At Råda we may observe the ice-contact slope on the northeast side of the marginal plain reaching about 100 m above present sea level. At the foot of the slope raised beaches of the Lake Great Vener can be found at 49 and 55 m above sea level.

Huge and deep gravel pits in the north-eastern part permit us to study the intricate structure of this marginal delta. Between beds of glaciofluvial sand and gravel, often with folded layers, we find beds or lenses of till and even lumps of varved glacial clay revealing oscillations of the ice border over earlier deposited clay *(20)*. In the topmost parts a layer of well rounded wave washed pebbles and boulders are to be noted as well as erratics, several tons of weight. The marine limit should be sought at + 125 *i. e.* about 25 metres above the top.

These two terminal ranges: Skalunda—Råda resp. Rackeby—Gösslunda, can be followed towards the East to the northern end of Mount Billingen. There the Baltic Ice Lake was drained between the mountain cliff and the ice border. According to G. De Geer this event is the limit of Gotiglacial and Finiglacial time.

In the year 1947—50 a gravel pit was accessible at Mellby, 8 kilometres SW of Råda. In this pit the following stratification could be observed:

Wave washed coarse gravel 1—1.5 metres.
Glacio-fluvial gravel and sand, well stratified as a rule.
Glacial clay with molluscs as *Saxicava arctica*, *Astarte borealis*, *Neptunea sp*. etc.

In its distal parts the superficial gravel rests upon glacial clay but is also covered with glacial clay. This is a test of a real ice oscillation which may have been quite important, as the shells of clay are not high-arctic species.

NINTH STOP — TÄNG

At Täng we find the continuation of the terminal moraine at Tun. In a gravel pit, the interior of it will be studied. In the bottom of the pit the bed rock has been observed with a thin cover of till. Upon this a complex rests of stratified gravel and sand (bottom), thin moraine beds (one or two), separated from each other and covered by gravel. In the moraine beds, as also in the gravel, lumps of varved reddish clay can be found, sometimes folded and pressed, and possibly transported in a frozen state.

The clay cover of the plain rests upon the youngest glacio-fluvial layer but sometimes has a veneer of wave washed sand.

En route to the next two stops several gravel pits can be observed. They are generally very shallow, as the layers of exploitable gravel are thin and limited in space because of intercalating moraine beds.

TENTH STOP — SALEM

The so-called Sparlösa runestone on the churchyard of Salem, which was found when the church was restored, is one of the most peculiar runestones in Sweden. It is dated to about 800 A. D. Whereas most runestones are monuments with short stereotypic inscriptions and fairly easy to interpret, this stone has been an object of several attempts of interpretation. Of interest is the size of the runic signs, their different types and the excellent figures.

ELEVENTH STOP — LEVENE

At the church of Levene a younger 4.6 m high runestone is raised. The inscription dates from the earliest Christian time (about 1 100 A.D.).

A marginal delta like that of Råda and in a similar position E of the Kålland fault extends NE of the village of Levene. The interior structure is indeed simpler.

From Levene we follow the tiny continuation of the Tun moraine range for some kilometres. The road runs upon the range that arises 2—5 metres above the clay cover. Borings have shown that the clay has a thickness of about 20 metres outside the morainic hills.

From Skatofta our route turns SW-wards over a monotonous plain with heavy glacial clay containing *Portlandia arctica* between outcropping tops of the bedrock. The thickness of the clay is 20—30 m. This clay is exploited in a brick yard W of Vara.

About 3 kilometres SW of Vara we suddenly enter into a landscape where the clay is covered by a cap of 1—2 m sand, partly with dune forms. The sand may be a regressional sediment, washed out from the hills below the Marine Limit (at + 120 m).

SW of Lagmanstorp the plain of the Säve valley is characterized by ramifying ravines. The soil consists mainly of silt.

TWELFTH STOP — BROBACKEN

Brobacken, 8 kilometres NW Alingsås, between the two lakes Anten and Mjörn, is the site of a great number of pot-holes *(1)*. At the southern end of the small lake Ålandasjön at a level of + 59 m they appear from the lake surface to a level of at least + 115. The Marine Limit is here situated at + 105 *(16)*. The presence of the pot-holes may be explained in the following manner: From the flat plain NE of Lake Anten the ice was pressed obliquely into the rock funnel, now occupied by that lake. At the narrowest point, on the threshold between the two lakes, rifts and fissures were generated through which melt water was pressed forth with great power. As most of the pot-holes are completely developed and symmetric only in their eastern part, it seems probable that the western wall of the pot-holes was once the land ice. About twenty real pot-holes are found, the greatest having a diameter of 19 m and a virtual depth from the upper margin to the boulder filled bottom of 11.3 m. The real depth indeed is greater *(35; 42)*. The field with pot-holes is bounded in the east by a rocky precipice mounting to about 140 m above present sea level.

Lake Anten is dammed by a terminal moraine at its southern end.

The road across the outlet from Lake Ålandasjön into Lake Mjörn also runs on a small terminal moraine. In connection with this some rests have been found of shell banks with *i. a. Saxicava arctica, Mya truncata,* and *Buccinum groenlandicum* mixed with *Litorina litorea, L. rudis, Zirphaea crispata, Balanus hameri.* These banks are situated at approximately 65 m above present sea level.

Along the northwestern side of the Lake Mjörn we return to Gothenburg where the excursion will be brought to an end.

After finishing our last dinner in Sweden we go to the railway station to the waiting sleeping-car which will bring us back to Copenhagen.

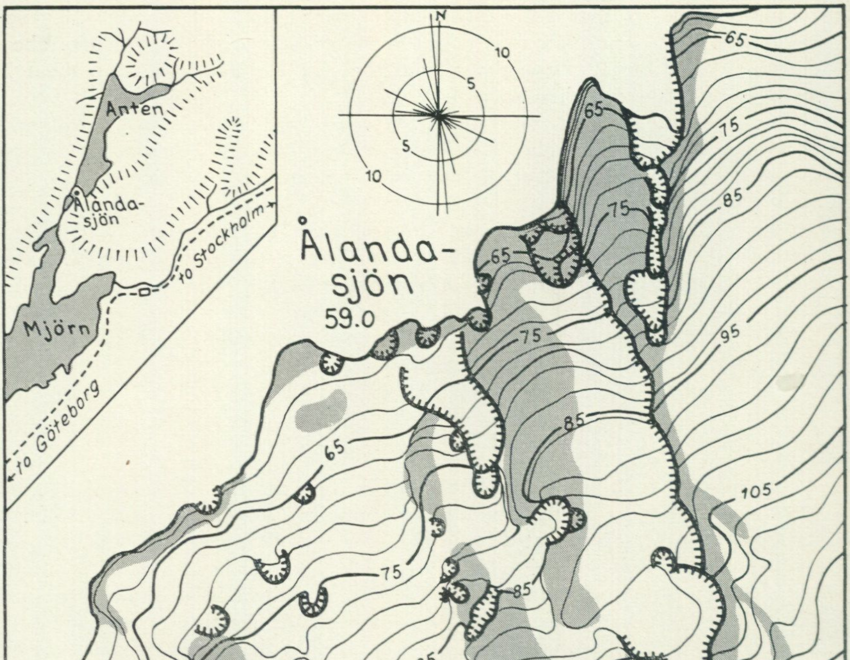

Fig. 15. The pot-hole area south of Lake Ålandasjön. Pot-holes and excavations indicated by saw-tooth lines. Grey areas = outcropping Archean rocks of which the fissure directions are seen in the diagram on the top. Contour lines in metres above present sea level. — After C. F. All 1954. För spridning godkänd i Rikets allm. kartverk den 20 maj 1960.

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Abbreviations: SGU = Sveriges geologiska undersökning.
GFF = Geologiska föreningens i Stockholm förhandlingar.

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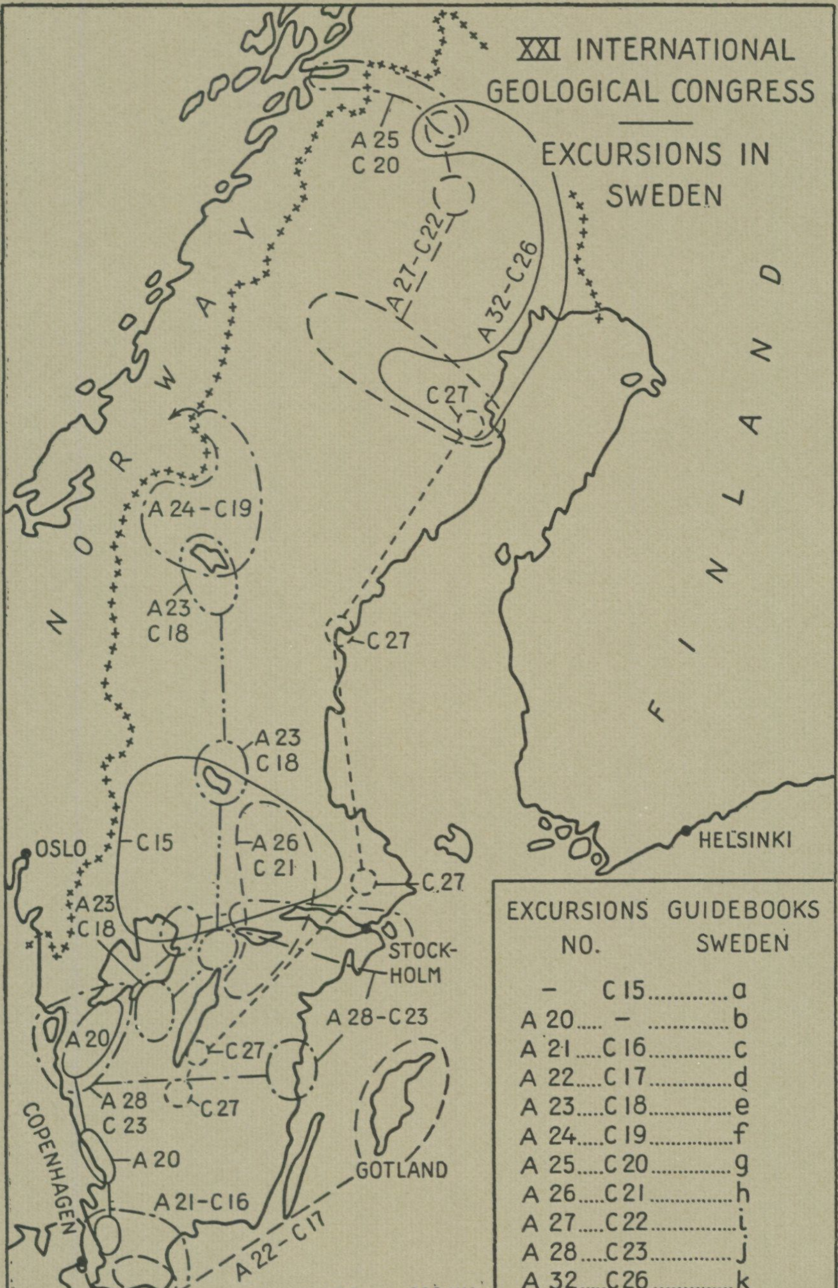

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