SVERIGES GEOLOGISKA UNDERSÖKNING

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EXPLANATION

OF

MAP OF LAND-FORMS IN THE SURROUNDINGS OF THE GREAT SWEDISH LAKES

BY

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1910

Professor J. G. ANDERSSON has proposed that a general view of the topography of central Sweden should be published in connection with the meeting of the XI[th] Geological Congress at Stockholm. Professor GERARD DE GEER, who has already paid much attention to this question, had not time to prepare such a publication. This work therefore was confided to me, and I beg here to express my gratitude to Professor DE GEER for placing at my disposal his manuscript sketch maps on a scale of 1 : 100 000 and a smaller map of the lake districts.

Fennoscandian mountain chain and Archaean plains.

As is well known, almost the whole of Sweden belongs to the *Fennoscandian Archaean territory*, which also includes Norway and Finland with Russian Carelia and the peninsula of Kola (A). By its enormous extension and its concentrated oval form, this natural territory to a certain degree dominates the geological architecture of Northern Europe in a manner closely analogous to the relations between Laurentia or the great Archaean territory, and the rest of North-America.

To the northwest of Scandinavia, comparatively near the great Atlantic Basin, lies the large mountainous area of the peninsula. Its highest massives are grouped in a kind of

dissected mountain chain, the northern part of which is situated in Swedish Lappland, but its southern part lies in Norway. The character of this region is shown on photographs in some modern works (1). In height the *Scandinavian Mountains* are far below the Alps. Their summits only rise a little above 2000 metres, e. g. in Lappland the Kebnekaisse of 2123 m. and Sarek of 2090 m., and in Norway the Galdhöpiggen of 2560 m. But the Scandinavian mountains are incomparably older, being of post-Silurian or probably Devonian age. The topography of the high mountains, often with slopes 1000 m. height, ceases as a rule somewhat east of the great tectonic overthrust-lines, which have been traced through Lappland and Jämtland (2, 3). The mountainous overthrust-region is in great part built up of Algonkian and Cambro-Silurian rocks, but to the east of it the large, more monotonous *Archaean territory* begins.

Within this Archaean geological province two morphological types are to be distinguished. The one is characterized by a rougher topography and occupies Norrland (Nordland), Dalarna (Dalecarlia) and Värmland,[1] the other is the flat-country type found in Uppland and in the provinces around the great lakes Vänern, Vättern, Mälaren and Hjälmaren. The latter kind of topography may be considered as the most specifically Swedish; it is characterized by an infinite number of small Archaean hills and rocks, from a few metres up to 50 m. high, but very seldom reaching 100 m. These small rocky hills occur in swarms but are separated by a net-work of clay covered depressions. It is therefore often somewhat difficult to realise, that, though uneven in details, the country is still extremely smooth to its general features.

Besides, within several large districts the land surface is really everywhere almost as level as a floor; that is the case especially in the surroundings of the four great lakes.

[1] Its limit past Gäfle, Örebro, and Karlstad is fairly distinct on the plate "Süd-Skandinavien" in Stielers Handatlas 1908.

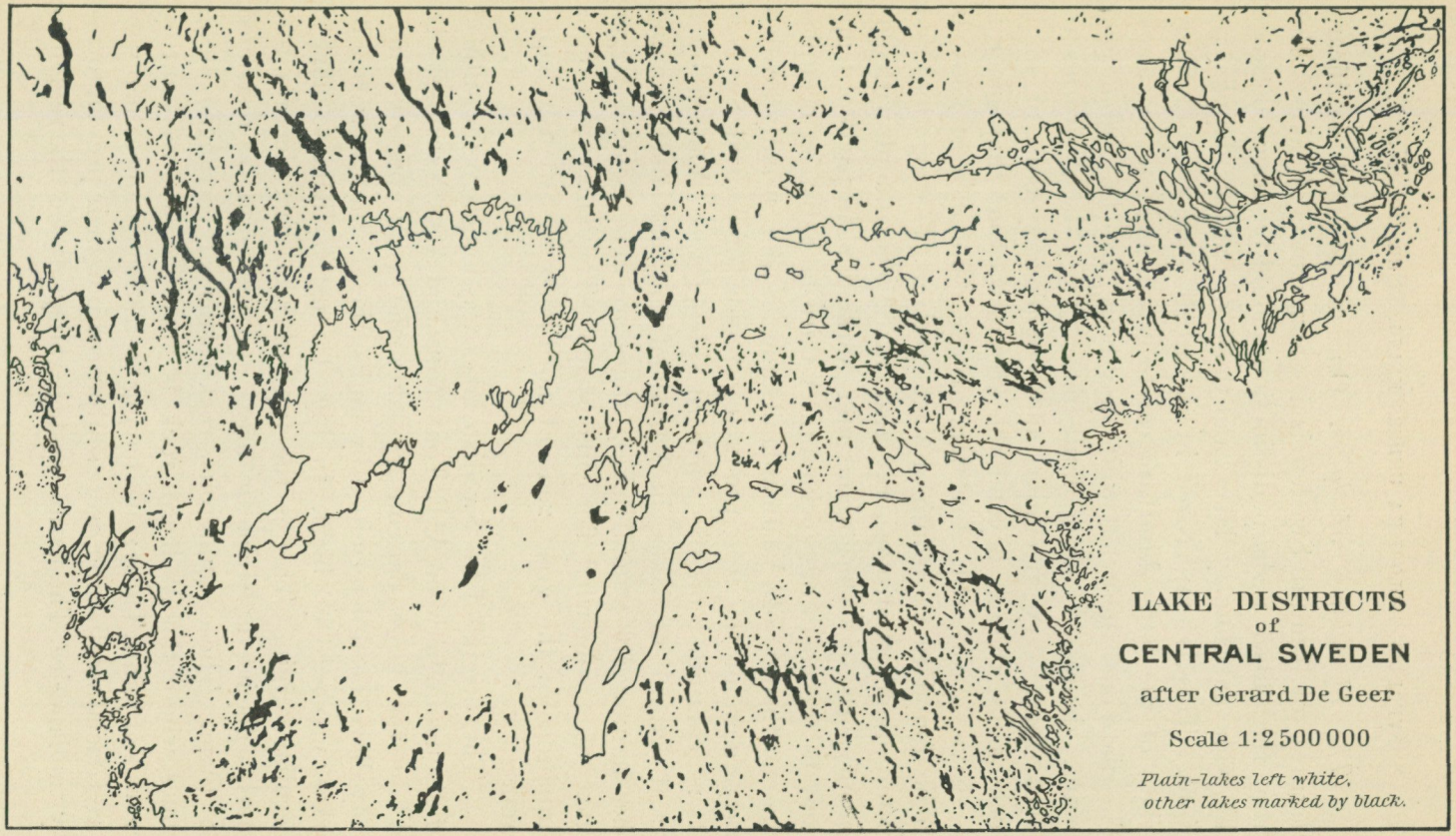
LAKE DISTRICTS
of
CENTRAL SWEDEN
after Gerard De Geer
Scale 1:2 500 000
Plain-lakes left white,
other lakes marked by black.

Fig. 1.

The abundance of lakes. One of the most significant features of central Sweden is its abundance of lakes. But from the outset a sharp distinction should be drawn between the wide flat-country lakes, and those of the lake dappled regions. This is emphasized in the small map, Fig. 1, where lakes of the latter kind are carefully marked out by black. The flat-lakes there left white may be regarded as submerged plains, depressed along fault-lines. The black swarms of lakes form very irregular and complex systems of small rock-basins, though beyond the area of the map they generally have a NW—SE direction. Such abundance of lakes is to be found in the south of Västergötland (Vestrogothia) and Östergötland (Ostrogothia), also in Södermanland with adjacent parts of Östergötland and Närke and in parts of Uppland to the north of Stockholm. A third lake district occupies the northwest of Västmanland and Närke usually called *Bergslagen* or the iron producing region of central Sweden. It is continued on the northern side of Lake Vänern by a great crowd of lakes in Värmland and Dalsland. Among the innumerable small lakes, there are here several larger ones of a somewhat fiord-like shape. They may be a continuation of the great zone of fiord lakes in Swedish Lappland.

The origin of the Swedish lakes was long ago the subject of discussion between A. E. TÖRNEBOHM and A. G. NATHORST (4). While the large flat-country lakes and a number of others may have been determined by faults, the enormous swarms of lakes marked by black in Fig. 1 must be held to have a peculiar origin. This is the type of lake, that denotes formerly glaciated Archaean areas and seems to be restricted to them. These numerous rock-basins are arranged along zones, where the Archaean rock is rendered less resistant by crowds of joints. These zones having been affected more deeply by pre-Glacial weathering, were sculptured into their present forms by the land-ice. The fissure-system-valleys dissect the region in

different directions, though many of them often have a parallel arrangement.

As already indicated, many of the lakes probably occupy rock basins, but a considerable number, no doubt, owe their basins wholly or partly to the inequalities of the Quaternary deposits and particularly to those of the moraine-covering.

The great difference between solid rock and loose soil. In nearly the whole of Sweden most of the post-Archaean geological systems are entirely wanting. Only small areas of the dislocated plains, marked on the annexed maps, are covered by older Palaeozoic beds. Everywhere else Archaean granites and gneisses constitute the rock-ground (*berggrunden*). Because the land-ice has completely worn away all products of weathering, the rock presents a smooth, weather-resisting surface. Immediately on the solid rock rest loose Quaternary deposits, in which the firm masses are only those due to the occasional consolidation of the hard, stony moraine-material. During the 9000 years since the recession of the great land-ice or even since the emergence of the Swedish lowlands from below the surface of the sea, running water has already cut out the sand- and clay-deposits into marked surface-forms, but the work of the rivers on the hard Archaean rocks has rarely produced results that can be detected.

The thickness of the Quaternary beds is very irregular. Generally they do not conceal the forms of the solid rock, but several deposits, such as *osar* (eskers) and drumlins, often dominate the land-forms of the plains.

The upper limit of the late glacial sea (5). At the melting of the ice, the centre of Fennoscandia was still depressed 280 meters below its present level, and the corresponding figure for the region now under consideration may be on an average 150 m. The mapping of the highest shore line of this late glacial ice-sea has a certain physiographical interest, because of the different nature of the

land-surface above and below it. Below this line occur all the great deposits of sand and clay, and here are all the agricultural districts of Sweden. During the rising of the land, the waves washed away all the fine soils and concentrated them on the lower levels. Above the limit of the sea the whole land is covered by stony moraine, which forms the soil of the huge forests of Sweden (C).

The map of the land-forms.

The chief source of our knowledge of Swedish land-forms is the topographical map of the Swedish Ordnance Survey on a scale of 1 : 100 000, where they are marked by hachures and figures of height (D). We may further note the hypsometrical map on a scale of 1 : 500 000, and for the depths of the sea and the great lakes the charts of the Sea Surveying Office (E, F).

Several geologists have discussed the geological origin of the leading features of central Sweden. Most of what is here mentioned and represented on the annexed map, is commonly known among Swedish geologists, although the literature of the subject is small or at least somewhat scattered (6). It is not intended to give here any account of the contributions of different investigators. Many papers are to be found in Geologiska Föreningens Förhandlingar, but reference is made here only to some authors, who have illustrated their papers by maps of the faults or other leading topographic lines. In 1887 E. SVEDMARK published a map of the fissure-valleys of eastern Uppland (7); in 1897 GERARD DE GEER, a map of the fault-lines of the lakes Mälaren and Hjälmaren (8); in 1899 A. G. HÖGBOM, a map of the fault-lines in central Sweden (9); in 1903 GUNNAR ANDERSSON, a map of the faults and other geographical features of the surroundings of Lake Mälaren (10), and in 1906 A. LARSSON, a map of the fault-lines of the archipelago (*skärgård*) of Stockholm (11).

In close connection with the subject are further a paper of NATHORST in 1887 on the occurence of faults in Sweden (12) and a series of unpublished map-pictures of central Sweden by GERARD DE GEER, where fault-lines, valleys and the extension of plains are represented.

Of course all these papers and maps have been of great importance in working out of the annexed map and especially in checking any tendency to insert results founded only on personal opinions. However, I have based the map directly on the primary material mentioned above. On 35 topographical map-sections all prominent escarpments of at least about 50 m. height have been selected and are now marked by black lines, which, after reduction to a scale of 1 : 500 000, represent by every millimetre of their breadth a steep slope 100 m. in height. This map and the hypsometrical one of the Ordnance Survey may thus supplement each other in giving a view of the land-forms. Here the first time are published more detailed isobathic maps of the four great lakes and parts of the sea coast.

Basin of Lake Vänern.

Lake Vänern, being one of the greatest lakes of Europe, occupies 5600 km^2. Formerly, it was much larger, and has been diminished by the unequal upheaval of land, which here was greater in the north. The position of the outlet at the southern end has caused a discharge of the lake in this direction. Lake Vänern lies at a height of 44 meters above sea-level. Its outlet-river, the Göta Älf, descends the greater part, or 33 m. of this height at the famous cataract of Trollhättan, and has then but little further fall on its way to the sea at Göteborg. The very form of L. Vänern with no very decided direction of length, indicates its origin as a submerged plain. As shown by the isobathic map, L. Vänern consists of two nearly separated lake basins, East Vä-

nern and Dalbosjön. In a section from east to west we find a gentle descent down to the depth of 20 and 40 m., then the bottom is level, and when coming nearer *Näset* it descends again to 60 and 80 m. Here is the deepest point of the lake, 92 m. below the lake-surface. Of the ascent 60 m. are concentrated close to the east coast of Näset. We thus find East Vänern somewhat one-sided, with the deeper parts near the western shore. Yet, the wedge-shaped southern end of the greater depth is also limited by an escarpment on the eastern side along the islands of Djurö. The west-basin, Dalbosjön, is separated by the isobath of 20 m. Here we also find the depths of more than 60 m. and the maximum depth of 83 m. toward the west, but not to so pronounced an extent as in the east basin. Both basins are extremely smooth and shallow in their southernmost parts, being a continuation of the adjacent plains.

Fault-lines. From analogies in other parts of central Sweden, we know, that the marked western limit of East Vänern is a fault-line with the downthrow side to the east. At the northern end of Näset it is followed by a narrow channel in the lake, more than 60 m. deep, and more southerly by the great deep-basin mentioned above. The whole of Näset and the corresponding peninsula at Lidköping are due to this fault. The map shows the difference between their smooth east coasts, somewhat convex towards the depressed area and bordered by a line of cliffs, and their low and irregular west coasts with their multitude of small islands. The amount of downthrow is 110 m., in addition to the thickness of any remains of Palaeozoic beds that may occur on the lake bottom. Very similar in direction and character are some other fault-lines in Västergötland and Dalsland. On the islands of L. Vänern at Mariestad we find three faults, of which one possibly continues through Västergötland on the west side of the Silurian mountain of Billingen. Further westward we cross the southern part of the Näset fault. Between the mountains Halleberg and Hunneberg also occurs

a fault, which continues on a little peninsula following the west shore of a bay of L. Vänern. In a similar manner the next of the fault-lines follows the west shore of the Vänersborg bay. The westernmost fault of this series coincides with the abrupt declivity of 50 to 100 metres' height, that bounds the plain of Dalsland towards the broken grounds of the west. All these seven parallel fault-lines have their downthrow sides to the East and may be put together as the "Vänern fault system".

Silurian plateau mountains. The plains of Västergötland are dominated by a number of terraced table mountains, built up of horizontal Cambrian and Silurian sediments and covered by a sheet of diabase. One of these mountains, the renowned Kinnekulle (13), lies somewhat isolated on the south border of East Vänern. Its height above the lake is 262 m. and above the sea 307 m. The chief strata are, Cambrian sandstone with a mean thickness of 34 m., Cambrian alum shale 22 m., Ordovician limestones 73 m., Ordovician and Gothlandian clay shales 93 m., and diabase 30 m. On the map two escarpments are marked. The upper and far greater one is caused by the hard diabase on the very top and the underlying clay shale; the lower escarpment is due to a hard bank in the limestone. Southeast from Kinnekulle, corresponding strata and escarpments are to be found in the mountains of Falbygden (14). On a vast base of sandstone rest three plateaus of limestone, supporting 11 diabase-tables, of which the largest is the triple Billingen, and the highest is Ålleberg, which reaches a height of 334 m. above sea-level. The height of Billingen above the plain is about 160 m. North of this mountain lies the little Cambrian hill of Lugnås, without diabase. Far west of Kinnekulle and the plateau group of Billingen at the very outlet of L. Vänern lie Halleberg and Hunneberg (15). They also are table-mountains, but the diabase cover here rests directly upon the alum slate. Halleberg reaches a height above the plain of little over 100 m. A deep valley along one of the

Vänern faults separates it from the somewhat subsided table of Hunneberg. It is obvious that the whole land was once covered by Silurian strata, of which the scattered remains are preserved in the plateau-mountains, protected against denudation partly by the resistant diabase and partly by subsidence along faults.

The pre-Cambrian plain. The Cambrian sediments rest immediately on Archaean gneiss, and the entire absence of the Algonkian system indicates an immense unconformity. The underlying Archaean rock-surface is weathered to a depth of one or two metres, and, apart from undulations of only a few m., it forms an extremely smooth plain. Not only does it form a base for the table-mountains, but continues, where not dissected by faults, without interruption into their sorroundings as vast plains. Here the weathered covering is always worn down, and the surface may perhaps have been denudated about 10 m. It will, however, be admitted that the plain is strikingly level and very little denuded. It must have been protected by Silurian strata for long periods, perhaps even into Tertiary time. While the remains of Palaeozoic beds now only occur in depressions, along downthrow sides of faults or in connection with diabase, they once occupied the whole basin of L. Vänern and other flat country lakes as well as all the smooth plains of central Sweden. GERARD DE GEER has directed attention to the nature of these smooth plains, entirely wanting in any lake basins of the Archaean type but surrounded by hilly regions with thousands of lakes. The typical lake-dappled districts mentioned above only occur in territories long free from the Palaeozoic cover and thus more exposed to weathering. As shown by the map, the plains of Vänern comprise a great part of Västergötland and the coast land of Dalsland and Värmland, in all about 15400 km^2. It is an interesting fact, that minute remnants of Cambrian beds have been recently noticed even on the west coast of the

Vänern, occurring as narrow dikes of fossiliferous sandstone in the Archaean rock.

Broken ground of the surrounding territories. Along some lines, to the East as well as to the West, the plains of Vänern are abruptly separated from the broken grounds by faults, but generally there is a gradual transition. To the south of Västergötland the plain, in many places smooth as a floor, becomes somewhat uneven. Outside the border of the plain we find the first lakes, often situated in marked fissure valleys, with a direction at Ulricehamn towards the south and at Alingsås towards the southwest, or about parallel with the Vänern fault-lines. In Värmland, north of L. Vänern, it is difficult to fix the limit of the plain, and even within its boundary some small hills rise to a height of 50 m. Close to the margin of the map is a district characterized by isolated hills, some of the larger consisting of old, resistant hyperite (hypersthene-diabase) and reaching a relative height of 140 m. Northwest of L. Vänern the large border-land of Värmland and Dalsland is the most broken ground of the whole region covered by the map. Everywhere differences in height of 150 m. occur, and the land is entirely dissected by a network of irregular broad and narrow valleys of the fissure type. Their predominant direction is towards the South. Some of them are occupied by the greater lakes of the district. Of these we need only mention Lake Stora Le, lying near the Norwegian boundary and reaching a length of 67 km. and a depth of just 100 m. The country is also broken on a smaller scale, and mountains as well as valleys are overspread by thousands of small lakes.

Bohuslän, the Skagerak coast province, is famous for its remarkably dissected coast line and great *skärgård*. It is really a classic fissure land (16). A meridional valley system — the coast fissures — crosses at sharp angles another more predominating southwestward one — the fjord fissures. The chief fissure-zones may have predisposed the erosion of the Göta

Älf valley above Göteborg, as well as of the Gullmarfjord in the middle of the province, 142 m. deep and 25 km. long, and of the right-angled Idefjord on the Norwegian boundary, bordered on the Swedish side by steep rock-slopes of 224 m. Along the very coast there is a remarkable channel, 365 m. deep and probable due to a fissure-zone. Though below the surface of the sea, it is one of the most pronounced surface forms of central Sweden. The interior of the province is dissected for the most part by some straight valleys, that communicate with the valley of the Stora Le in Dalsland. The relative heights of land in Bohuslän are about 100 m., and in the southern parts only a little above 50 m. The whole coast land is separated by a fault from the Skagerak, the bottom of which is supposed to consist partly of Cretaceous sediments.

Topography of loose soils. Late-Glacial clay and sand cover the plains and partly fill all valleys lying below the limit of the sea at the time of their deposition, but they do not as a rule conceal the forms of the underlying rock. The most remarkable accumulation of soil is the great terminal moraine which from Lidköping crosses Dalbosjön and the south end of the lake Stora Le. Some delta terraces and other fluvio-glacial deposits of very irregular form occur on the plain of Västergötland, but are not high enough to be indicated on the map.

Basin of Lake Vättern.

Lake Vättern covers an area of 1900 km^2. Though in size only a third of L. Vänern, L. Vättern is still the fourth largest in Europe. Among the great Swedish lakes, this is the most imposing, thanks to its marked basin and high shores, as well as to its large deep area. It reaches a length of 128 km., and the breadth is generally about 20 km. L. Vättern lies at 88 m. above sea-level or at double the height

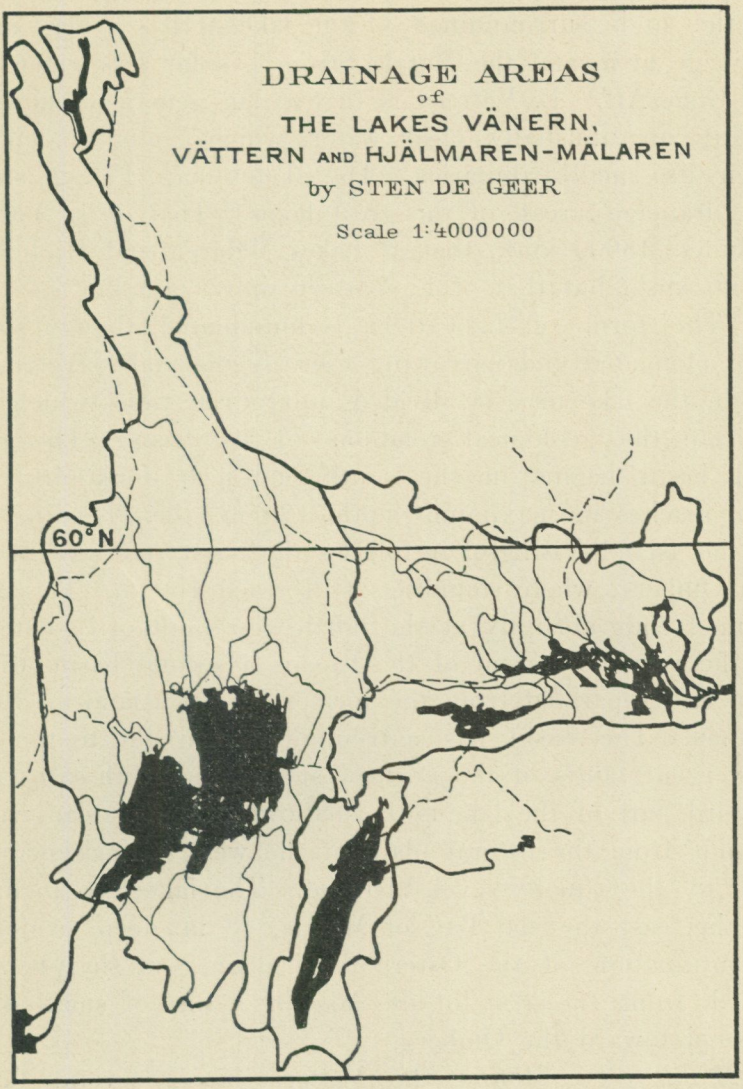
DRAINAGE AREAS
of
THE LAKES VÄNERN,
VÄTTERN AND HJÄLMAREN-MÄLAREN
by STEN DE GEER
Scale 1:4000000
60° N

Fig. 2.

of L. Vänern, and its outlet river, the Motala Ström, turns eastwards and flows into the Baltic at Norrköping. Owing to the high surroundings of the lake, it has a very small drainage area, and the Motala Ström has far less water than the Göta Älf. L. Vättern is in Sweden generally known as having an unusually clear water, which evidently depends upon its small tributaries. The sketch-map, Fig. 2, shows the drainage areas of the great lakes. That of L. Vänern includes 48000 km^2., that of Lakes Mälaren and Hjälmaren 21000 km^2., but that of L. Vättern only 6000 km^2.

The form of L. Vättern is unindented, though somewhat elongated and narrowing towards the ends. As regard depth, the lake may be divided into four sections, which also indicate the geological relations of its basin. The great deep basin begins in the south end near Jönköping and soon reaches its maximum depth, 120 m., then, bending east of the island Visingsö, it follows the coast past the mountain Omberg, where soundings still reach 100 m. This deep channel ends abruptly at the north-west fault of L. Vättern. At the very north end of the lake is a second basin, 67 m. deep and separated from the former by the island of Stora Röknen. The basin has a triangular form due to the two convergent faults of the north-west and the north-east coast. A third part of the lake is the shallow bottom plateau, which extends from the littoral plain of the west at Karlsborg and Hjo to the equally level Visingsö. The lake also includes on the east the flat Bay of Motala, 48 m. deep, evidently a continuation of the Östergötland plain, and sharply separated from the rest of the lake by a line of small islets directed toward the Omberg.

Fault-lines. Round the Vättern basin, several faults occur parallel to the lake. Southward from Omberg a large one follows the east coast. The granite cliffs become gradually higher as the land rises, and at Grenna the fault appears as a mountain-wall 228 m. high. It still rises a little, and reaches the greatest relative height of central and South

Sweden, namely 273 m., added to the depth of the adjacent part of the lake, 360 m. Probably the amount of down-throw is nearly twice this height, because of the thick sediments on the lake bottom. This fault line makes, as is shown by the map, a slight bend towards the west, and then it follows a decided crush zone in the Archaean granite south-east of Jönköping. The western shore of L. Vättern is also marked by a fault-line, which divides into three near the southern end of the lake. As a horst-like mountain also rises between Jönköping and the valley of the eastern fault-line, the Vättern basin should be regarded as ending in four short fault-valleys, of which the small, triangular plain of Jönköping is the chief.

The range of hills west of L. Vättern has the character of a long horst, which with a relative height of about 150 m. unites the broken plateau of Småland with that of Närke. A continuous, bold escarpment separates it from the plain of the Vänern region. On the latitude of Visingsö and towards the South, the horst becomes broader. From its higher western part one descends over what is probably a fault escarpment, hitherto little noticed, before arriving at the edge of the Vättern coast faults. It has already been mentioned that the great lake basin is terminated at its northern end by two straight, converging fault declivities. It only remains for us to elucidate its relations to the plain of Östergötland, and to mention a geological system found in the district of L. Vättern.

The series of Visingsö. At several places within the basin of L. Vättern a series of sedimentary strata occurs. It consists mainly of sandstones, in the upper part also of clay slates, and the whole series attains a thickness of about 300 m. It entirely builds up the island Visingsö, from which the series derives its name. The small depressed plains of Grenna and Jönköping also lie on the Visingsö-series, which is found at several other places at the base of the fault escarpments and even at the northern end of the

lake. On the flat, western coastal plain at Karlsborg and Hjo its rocks are covered by loose soil, and the great shallow part of the Vättern, that connects Visingsö with this coast, evidently consists of them. Probably the whole floor of the lake is occupied by this series. It rests immediately on the Archaean rocks, and since it contains no fossils, its geological age is rather uncertain. Once having had a far greater extension in central Sweden, it has been protected against denudation only within areas depressed between faults. This has been confirmed by finds of some small sandstone areas outside the Vättern basin itself.

Continuation of the fault-system of L. Vättern. A somewhat tilted region, or at least two doubtless one-sided fault-valleys occur east of the great Grenna fault-line. In both these depressions remains of the Visingsö series are left.

The fault-system of L. Vättern, seems to continue also towards the north, from the district round Karlsborg and including the Lakes Unden (100 km.^{2}), Skagern (130 km.^{2}), and Möckeln (20 km.^{2}). All these lakes are to a considerable extent limited by fault-escarpments. Through fault- and fissure-valleys, the leading topographic features of the tract, their basins communicate with each other, with the great plain of Närke, and in the first place with the fault-basin of L. Vättern. Within the depressed area of Skagern occur remains of the Visingsö sandstone, and the same is the case even at the remote Lake Möckeln, the surface of which only occupies the southern end of a triangular sunk area.

Another great fault-declivity appears somewhat west of the Skagern and continues past Kristinehamn. Bounding the plain of Vänern, its downthrow side is to the west, contrary to that of all the Vänern faults. Therefore it may rather be referred to the more irregularly tilted fault-zone of L. Vättern.

Mount Omberg. The great fault-line of Grenna continues northwards, separating the basin of L. Vättern from the

plain of Östergötland. This fissure, however, divides into two, embracing Mount Omberg, which rises 175 m. above the level of L. Vättern, or 263 m. above the sea. Though only covering an area of 22 km.^{2}, its isolated situation and sharply marked contours render it one of the most accentuated objects on the whole topographical map of the Swedish lowlands. Omberg is a true "horst", consisting of Archaean granite. Once it was covered by Silurian strata. Then at the end of Silurian time the older fault on the eastern side occurred, the plain of Östergötland and the Bay of Motala subsided, and now we find horizontal Cambro-Silurian beds lying close to the eastern base of the mountain, as shown by the section accompanying the map. The Silurian unprotected by subsidence was soon worn away, and a new series, that of Visingsö, was deposited over the whole area. Within the area of the present Vättern basin it thus was deposited immediately on Archaean rocks, and is nowhere in contact with the Silurian. Yet it has been pointed out that the Visingsö series must be younger than Silurian, because the basin of L. Vättern abruptly cuts off the pre-Cambrian plain along the shore of the lake, south of the Omberg. Whether the series is to be referred to the Devonian or to the Trias is not decided.

The faults of the Omberg and southern Vättern are the greatest, topographically most dominant, and therefore considered, probably with reason, to be youngest of central Sweden. Often also they are marked by a fault-breccia, and the western walls of the Omberg are covered with beds of Visingsö sandstone, brought by dislocation into a nearly vertical position.

The plain of Östergötland.

Fault-lines and lakes. The fault-systems of Lakes Vänern and Vättern both have a main direction from north to

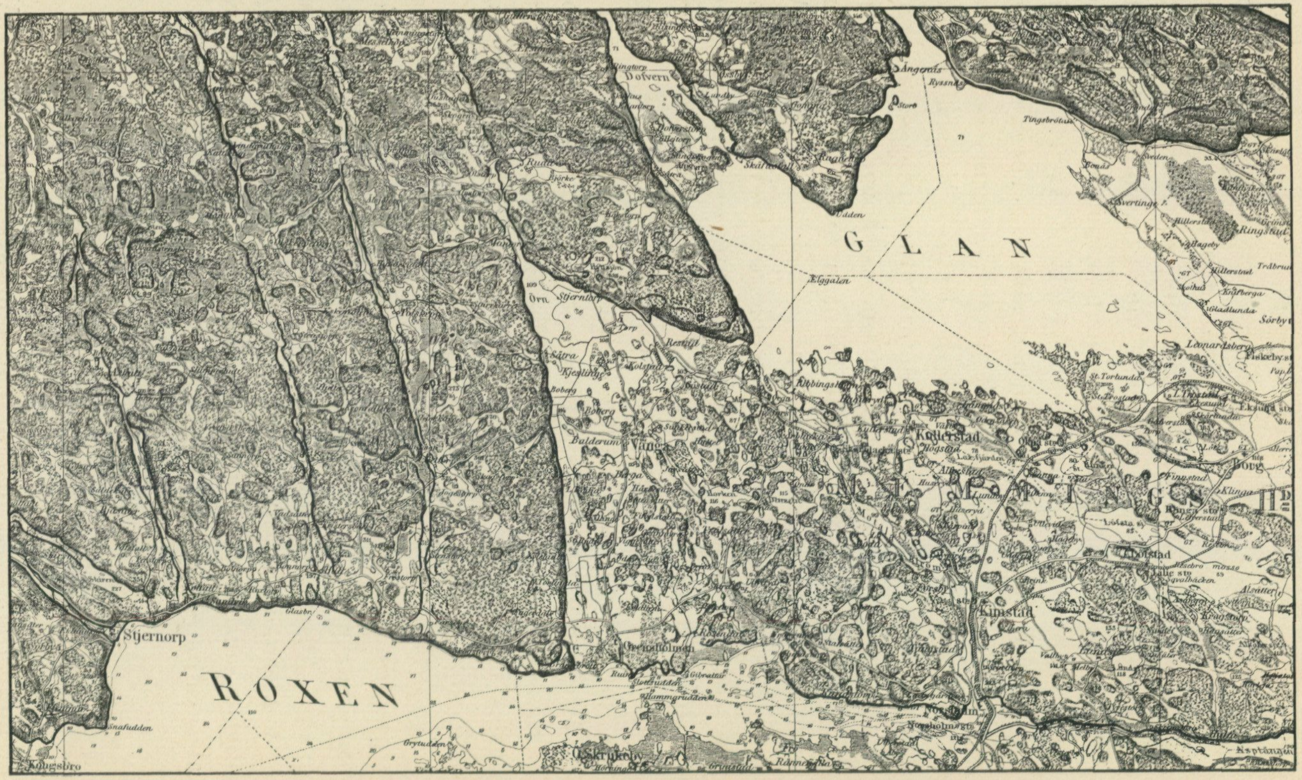

FIG.3. FAULTS IN ÖSTERGÖTLAND
reduced from the map of the Ordnance Survey
Scale 1: 200 000

south. But east of the line marked by the double fault of Omberg and the western limit of the plain of Närke, we find two systems of faults running west and east. Their centre is the lake plateau of Södermanland, from which their downthrow sides look away, northwards in the region of Mälaren—Hjälmaren and southwards within Östergötland (Ostrogothia).

The northern part of Östergötland belongs to this lake district, but is abruptly cut off by the main fault of the province running from L. Vättern all the way to the Baltic. Perhaps the most remarkable land form of this district is a system of narrow, well sculptured fissure-valleys, all coming from the NNW and also being cut off by the dislocation. The great fault escarpment itself, is to a large extent influenced by these fissures. Fig. 3 shows its most broken middle part, where the fault partly follows three of them. Thus the lake plateau ends by three sharp-angled projections, abruptly rising 90 m. above the interjacent parts of the plain, which seem to have subsided most in their very angles. A typical example of such a broken- in area within an angle-fault is that of Vånga. The two others have caused the basin of Lake Glan; but, within the northern lake and fissure region, also there are analogous angle-faults at Finspång, Hällestad, and Tjällmo. At the two last places we even find remnants of Cambrian sandstone.

The eastern part of the main fault appears as a straight wall, 90 m. high, limiting the plateau of Kolmården. Close to the southern side of this line, the pre-Cambrian plain of Vikbolandet is submerged by the sea, thus forming the Bay of Bråviken, which really is a one sided fault basin, 60 m. deep. Lake Glan, already mentioned, occupies 80 km^2. The western part of the fault-escarpment from L. Vättern toward Norsholm varies in height from about 10 m. to 135 m. Along its southern side lie the flat but none the less somewhat one-sided lakes Boren and Roxen, of 30 and 100 km^2. respectively. Their depths are only 14 m. and 8 m. Another

fault continues this one in a straight line past Söderköping, forms the southern limit of Vikbolandet, reaching a height of 75 m., and thus tilting the district towards the North.

Pre-Cambrian plain and Silurian territory. Vikbolandet is a part of the pre-Cambrian plain, though it has lost its Palaeozoic cover even in the north. To the south, along the fault of Söderköping, it has already become somewhat broken. The main part of the plain of Östergötland, however, extends from the Boren—Roxen fault and towards the south. These plains, together with the doubtless equally level Archaean foundation of the Visingsö series, occupy 5100 km^2.

A considerable area is still covered by Silurian beds (17). They have been protected by the eastern Omberg fault and by the Boren—Roxen fault, along which they also are bent up. The Cambrian sandstone extends from the faults to Mjölby and Linköping, the alum shale not quite so far, and the Ordovician limestone only to Skeninge and the northern border of the extremely flat basin of Lake Tåkern. Silurian clay shale also is to be found on some smaller areas nearer the faults. The Silurian rock-ground being throughout flat, the forms of the drift deposits, such as drumlins, terminal moraines, and osar, are more dominanting than usual.

From plain to broken ground. It is impossible to draw a definite line separating the plain of Östergötland from the broken southern part of the Province. The limit of the white on the map only shows where the lakes and the first relative heights of 50 m. begin to occur. Yet the uneven topography begins imperceptibly and increases by degrees. The south of the province, between the lakes Sommen and Åsunden, is one of the most broken grounds in central Sweden. Differences of height amounting to 100 m. are common, and in the centre of this tract the steep slopes even rise to 150 m. The land is closely dissected by two systems of fissure-zones, actually appearing as valleys through the work of erosion and excavation. They may be followed to the limit

of the plain, one towards the northwest, the other in northerly direction.

In the Baltic coast region the granites of Östergötland are succeeded by gneiss, the parallel structure of which has determined the course of a number of straight valleys. The biggest begins near Linköping, and, like the others, runs south-eastwards right out into the *skärgård* of the coast.

Of the inequalities of the surface in the *skärgård*-region there are some deeper channels, as at the mouth of Bråviken and east of Stockholm (Kanholmsfjärden 107 m. deep). The deepest point of the whole Baltic, over 463 m., lies close to the coast near Landsort. This small basin really represents the greatest height-difference of central Sweden.

Lakes Mälaren and Hjälmaren.

The lake-plateau of Södermanland. As mentioned in reference to the faults of Östergötland, the lake district of Södermanland is to be considered as a kind of horst, limited by faults on the north and south. It is somewhat higher along its margins, especially in its continuation into Närke and Östergötland, though hardly reaching 100 m. The centre is still lower. Many of the greater lakes lie only about 10 m. above the sea, and even the hills are seldom 50 m. high. However, like most formerly glaciated Archaean districts, Södermanland is uneven in its details and overspread by innumerable rock-basins and small rock-hills. The main direction of valleys, lakes, and depressions is NW—SE, as is especially marked by the valley of the lakes Klemmingen and Sillen (from Strängnäs to Trosa) and by the valley of Södertälje.

In Södertörn, east of this valley, and in the large *skärgård* of Stockholm nearly all rock hills and islands are elongated in the direction of the parallel structure of the gneiss, which thus governs the whole topography of this

broken plain. The highest points of this parallel-ridged district lie at 50—80 m. above the sea.

The Mälaren—Hjälmaren fault-system consists of four approximately parallel main faults, and is best developed in Närke (compare profile 2 of the map). They all have their downthrow sides towards the north. Only the two middle faults reach to the neighbourhood of Stockholm, where their continuation forms the abrupt escarpment, that skirts the inlet from the *skärgården* to Stockholm and separates the southern quarters of the capital from the main parts of the town. Other obvious faults, with different directions, also occur in the surroundings of Stockholm (8, 10, 11). Of the four fault-lines of Närke the southernmost is short but topographically very marked by a scarp of 102 m. on the south side of the pronouncedly one-sided lakes Tisaren and Sottern; section 2 on the map. The other three fault-lines influence the present form of Lakes Mälaren and Hjälmaren making parts of them one-sided.

Lakes Mälaren and Hjälmaren (10, 8). Of these two lakes, L. *Hjälmaren* has by far the most simple construction. It is a flat plain lake, divided into two one-sided basins by the third of the Närke faults. The maximum depth of the Great Hjälmaren is 20 m. and lies closely along a line of small islets, marking the upcast side of this fault. The basin of South Hjälmaren is also somewhat excentric, reaching a depth of 18 m. near the second fault-line of Närke. Thus the geological as well as the geographical relations of the whole of L. Hjälmaren are closely analogous to those of L. Vänern, though on a smaller scale. L. Hjälmaren still covers an area of 480 km.^{2}, that is, nearly as much as the *Bodensee* (540 km^2.). The height above the sea is 23 m.

Lake *Mälaren* has a morphological character quite different from the lakes already mentioned. Its geological situation, however, is similar to that of L. Hjälmaren. The three northerly Närke faults follow parts of the southern border of L. Mälaren, as shown by the map, and influence its form,

giving to the bay of Mariefred and the bay west of Strängnäs their triangular shape. The western half of Mälaren may be regarded as a plain lake, but eastwards the plain becomes gradually more uneven, and the eastern half of the lake is really a part of the lake plateau of Södermanland sculptured by NW—SE fissure valleys. It is this valley system, that gives the lake its greatest breadth towards the east.

Lake Mälaren has no large lake basin, but it is composed of a great number of small ones, connected with one another, so as to form a net-work of sounds and *fjärdar* (that is, wider water surfaces), thus also giving rise to several considerable islands as well as swarms of smaller ones. It is obvious, that the existence of such a composite lake as Mälaren with a connected water surface of 1200 km.^{2} is only possible when a large area of a slightly sculptured Archaean plain is quite horizontal. This is here the case, and as the land beyond the faults in the south and the east is somewhat higher, L. Mälaren has received its present boundaries. The vast lake surface lies at an average only 0.3 m. above the sea level, and its short outlet river, the Norrström at Stockholm, often flows in a reversed direction carrying Baltic brackish water into the deeper basins of the lake. As shown by the isobaths of the map, the greater depths of Mälaren occur in the eastern half of the lake. Here are all the 12 basins that have a depth of more than 40 m. They are all elongated in form and are arranged in seven lines of the same character as the fissure valleys of Södermanland. The maximum depths of these basins are respectively 64 m., 62, 60, 58, 53, 53, 53, 53, 48, 48, 46, and 46 m. The whole bottom configuration of the lake shows a striking resemblance to that of the Finnish lakes, e. g. lake Päijänne (18). The western parts of Mälaren are shallow, the greatest depth being 35 m., and in the basin of Galten only 18 m.

Plains and Post-Archaean beds (19). Round the western part of Mälaren lies the flat base-level plain also named the

pre-Cambrian plain. From Mariefred it stretches beyond the northern limit of the map and westwards along the tilted fault region all the way to Närke, occupying an area of 7700 km^2.

Of the sedimentary rocks, that formerly protected it, there are small remnants of Algonkian (Jotnian) sandstone on some islets north of Södertälje and Torshälla, and in Närke occur considerable remains of Silurian beds. A great part of this province is covered by Cambrian sandstone, which also is found as blocks along the southern borders of L. Hjälmaren. The relations between the four fault-lines and the present distribution of the sandstone may be seen on the map, section 2. On the sandstone rest Cambrian alum shale and Ordovician Ortoceras limestone, but they have only been preserved as a terrace 30 m. high close to the most dominant fault-escarpments. The whole Silurian territory of Närke has the character of a triangle broken in area, limited on the south by the 80 m. high wall of the second fault of the Närke system. The plain, as well as this fault-system, is in Western Närke abruptly cut off by a fault belonging to the Vättern system and marked by the 150—180 m. high eastern slope of the dominating lake plateau of Kilsbergen.

The forms of the Drift. In broken and uneven districts the Archaean rock surface gives form and character to the land. Even on the plains fissure-valleys and fault-escarpments are often the leading features of the topography, presenting height differences of more than 50 m. The smoother the bed rocks are, however, the more do other kinds of landforms, especially those of the Drift, become dominant, though seldom reaching a height of 50 m.

All the innumerable rock hills of the lowlands are worn on their northern side by glacial action to hummocky bosses. This is particularly to be seen along the coasts, where the *skärgårdar* are examples of vast areas sculptured as *roches moutonnées*.

The *morainic covering* influences the surface forms of the land in different ways. Now we need only pay attention to the *Drumlin Topography*. In central Sweden this form of morainic deposits is best developed on the plain of Närke, where numerous Elongated Ridges running N—S, and other kinds of Drumlins are the prevalent topographic forms (20).

The most dominating of all surface forms due to Drift are those of the *osar* (eskers). Over the whole of central Sweden these fluvio-glacial deposits of gravel and sand occur, building up chains of mounds or long, narrow ridges (6). Especially in the provinces north of L. Mälaren do the osar dominate the whole topography (21, 22).

The finer sediments, sand and clay, generally form smooth plains, being either deposited on an even surface of the underlying solid rock, or concentrated in the depressions and valleys of a more broken district. The plains of fine sand are, however, often dissected by systems of small, V-shaped, *branching valleys* formed by the erosion of brooks and solifluction together (23). Further, *flood-plains* are sculptured on the surfaces of clay and sand by the meandering of brooks and rivers (23).

The topographic forms of the Drift are of great importance in Swedish scenery and they appear fairly well on the map-sections on the scale 1 : 100 000 of the Ordnance Survey. But they could not be represented on the map in 1 : 500 000 now worked out. This map only tries to show the main traits of topography as indicated by escarpments of more than 50 m. height, and to fix the distribution of plains, and areas with land-sculpture of different reliefs.

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C. *Swed. Geol. Survey*, »Öfversigtskarta angifvande de kvartära hafsaflagringarnas område samt kalkstens- och mergelförekomsters utbredning i Sverige», Sver. Geol. Unders. Ser. Ba, N:o 5. 1898. Scale 1 : 2 000 000. (Price 2 kr.)

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E. *H. Byström*, »Våra kartor» ("Our Maps") 1899, edited by the Lithographic Printing Office of the Swedish General Staff, with information and samples of maps. (Price 1: 50 kr.)

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