1. Precambrian geology of Sweden

by

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(With a map.)

Introduction.

This paper is especially addressed to the foreign geologists who intend to visite Sweden at the congress in Stockholm 1910 and take part in the excursions arranged at this occasion. I will here, without much entering into details, give a summary of the most striking features of the Precambrian of Sweden. Further information about the districts which are to be visited will be given in the congress-guide-books and, besides, the chief literature concerning the subjects which are to be dealt with is cited at the end of this paper. Beside the sketch map accompanying this treatise the survey map by A. E. TÖRNEBOHM, »Geologisk öfversiktskarta öfver Sveriges berggrund» (1) can be recommended. Another map, embracing the whole of Fennoscandia, which is suitable for this purpose is published by J. SEDERHOLM in his paper »Om granit och gneis» (2). From the classifications and theoretical views of these authorities I, however, must differ in some essential points. In the following scheme I have made up the chronological division of the Precambrian which I will follow in this paper. In this scheme I have not taken into consideration the Precambrian of the Highlands of Sweden, which is developed with somewhat different facies and, moreover, has received prominent secondary characters by the postsilurian foldings and overthrust movements. Some remarks on the Precambrian of that region will be found in another paper [3].

The new terms introduced in the scheme here adjoined, are nearly connected with the terminology already existing and ought to be understood without explanation. Besides, their bearing will be illustrated in the following. As to the subdivisions *Upper*, *Middle*, and *Lower Precambrian*, they may be regarded as provisional only. Their chronological equivalence to *Palæozoic*, for instance, can naturally be disputed, and I will not take

a position with regard to this question. The term Precambrian itself is not happily chosen to signify a great series of geological æras, but as it is in common use both in Europe and America, it may be most practical to accept the term also in this paper which is to be considered more as a review of our present stage of knowledge than as an attempt to bring forth new terminological propositions.

Chronological scheme for the Swedish Precambrian.

Palæozoic	**Silurian** { *Gothlandian*, *Ordovician*, *Cambrian* }
	Subcambrian landsurface, Subcambrian denudation
Uppper Precambrian	*Epijotnian dislocations*
	Jotnian
	Subjotnian landsurface, Subjotnian denudation, Subjotnian igneous rocks
Middle Precambrian	*Epijatulian folding*
	Jatulian
	Subjatulian landsurface, Subjatulian denudation
Lower Precambrian	*Serarchean granites*
	Archean [No chronological subdivisions of general significance, the archean subdivisions mostly representing only different stages of metamorphism.]

Remarks on the Palæozoic.

Over the vast precambrian area of Sweden small palæozoic areas are scattered as residua of the originally continuous cowering which these systems once formed. They have mostly been preserved from denudation either by overlying and intercalated beds of diabases or by faults along which they are sunken in relation to their surroundings. The former manner of occurrence is very well illustrated by the table mountains of Westgothland, on the east side of the lake Wänern, where intrusive sheets of diabase now form the tops and top-plateaus of the underlying Silurian. The latter is found in mostly all other silurian areas of middle and southern Sweden, for instance in Dalecarlia (at the lake Siljan), in Närike (south of the lake Hjälmaren), in the silurian plain of Ostgothland and in Scania. In northern Sweden the Silurian occurs as a belt close to the eastern border of the highland range, lying there in the same relation to the great overthrusts as the Silurian of the Northwest of Scotland to the overthrusts of that country. In Jämtland this silurian belt is broader than elsewere, and around the lake Storsjön it extends over a great area, the largest of this system in Sweden. Here the Silurian is disturbed by

the same folding which has seized the highlands, and remainders of the older overthrust rocks lie on the folded Silurian as conspicuous table-mountains, or they rise with their front over the silurian belt [3]. Except some occurences of a possibly devonian sandstone in Orsa (Dalecarlia) and in Scania and the much disputed Visingsöseries (Lake Wättern), the age of which is not stated, the Palæozoic of Sweden is represented only by silurian and cambrian strata. The Cambrian is, owing to its insignificant thickness and its close geographical and geological connection to the lower Silurian, by the Swedish geologists regarded as a subdivision of the Silurian, this system being consequently divided into *Cambrian*, *Ordovician* (»lower Silurian») and *Gotlandian* (»upper Silurian»).

Generally the stratigraphy shows very great resemblances in the different areas of southern and middle Sweden; the Gotlandian, however, is wanting in many areas because of denudation. In Dalacarlia (Siljan area) the Cambrian is not at all developed, and in the northern Sweden the Silurian is characterized by the predominance of littoral facies, especially in the western parts.

For the present purpose it is not necessary to give a more detailed description of the Silurian of Sweden; only some remarks on its lowest subdivision, the Cambrian, may be made, inasmuch as its petrography and stratigraphy are of some significance for the understanding of the præcambrian history of Sweden.

The *Cambrian* in middle Sweden reaches an average thickness of 50 meters. Of these the upper 15—20 meters consist of black, mostly bitouminous shales, with concretionary ellipsoids and seams of limestone, sometimes also with small nodules and layers of chert. Palæontologically these shales are divided into *Paradoxides*- and *Olenid*-beds.

The lower part of the Cambrian in the same districts consists of sandstone, with a total thickness of about 30 meters. Petrographically one can distinguish some subdivisions of this sandstone; they are however mainly of local significance. Small layers of conglomerate occur at the base of the sandstone. In Westgothland the quartz-pebbles of this conglomerate often show typical windworn forms (»Dreikanter»). The sandstone itself is mostly of a light yellowish or grayish colour, but red and greenish varieties also occur. Ripple marks and current bedding are not uncommun. The bottom layers sometimes grade to arkoses and are nearly connected with the underlying weathered Archean.

Palæontologically the cambrian sandstone belongs to the *Olenellus*-group, *Olenellus* being, however, found only in Scania and at some localities in the North of Sweden. In the cambrian areas of middle Sweden the sandstone contains *brachiopods (Mickwitzia monilifera, Discinella Holsti, Lingulella* a. o.), *pteropods*, *annelide*-tracks *(Scolithus, Diplocraterium)* and other tracks *(Cruziana, Spiroscolax)*. Further, there are to be noted some *hydroids (Medusites Lindströmi* and *M. radiatus)* which have been found in the lowest horizon of the cambrian sandstone of Westgothland, in the

so called »*Eophyton*»-sandstone. Stratigraphical zones in the sandstone can only exceptionally be followed from one area to another; they are mostly of a more local value.

The subcambrian landsurface.

In most of the localities where the immediate contact between the cambrian sandstone and the substratum of the same is possible to see one finds the bottom-layers resting on a weathering breccia of the subjacent Archean. The breccia turns into a kaolinized gneiss which continues to a depth of one or two meters.

The topography of this old landsurface seems to be somewath knobby with small prominences, rising only a few meters above the average level. No valleys are dissected out in this subcambrian plateau which, broadly considered, is characterized by its eveness. In the vicinity of the silurian areas, where the postsilurian erosion has only slightly attacked this subcambrian landsurface, the Archean makes by its eveness a very striking contrast to the ordinary surface forms of the Swedish archean districts. The flat archean surroundings of the silurian table mountains Halleberg and Hunneberg, east of the Göta river, compared with the dissected and hilly Archean west of the same river (for instance west of Trollhättan) offer good examples of this conspicuous contrast. Further illustrations to this feature can be obtained from the map accompanying the paper by S. De Geer on the topography of middle Sweden [4].

That this now existing plane surface really represents the allmost unaltered subcambrian plateau is proved by an interesting discovery, quite recently made by A. Gavelin at the south-western shore of the lake Wänern [5]. In the well developed gneiss plateau there small dikes occur, filling out fissures in the gneiss, and in these dikes cambrian brachiopods were found. The dikes consequently must represent the sand which was washed out from the weathered landsurface by the cambrian transgression. Alltough this locality is many miles distant from the nearest cambrian areas now existing, the superficial features of the subcambrian plateau have not been more defaced by the postsilurian denudation than that these small and undoubtedly quite superficial sandstone fissures have been preserved. This fact can hardly be interpreted otherwise than by the hypothesis that the area was buried underneath a silurian covering until late geological time.

In the same manner as in Westgothland the denudation has laid bare the subcambrian surface in the surroundings of the other silurian areas of Sweden, where these areas are not limited by faults [4].

The archean areas which are uplifted by faults are, as already said, hilly and traversed by valleys, carved out by the postsilurian erosion. As the hilltops generally rise to the same average height over wide areas,

even when the rocks are of much varying composition and structures, it is probable that a plain laid trough the hill-summits should not fall much below the subcambrian surface. The correctness of this supposition is substantiated by the fact that sandstone-dikes, petrographically of the same kind as the dikes already mentioned, have also been found at some hilly and by valleys dissected tracts of the Archean, viz. in the vicinity of Loftahammar at the Baltic coast.

As a consequence of these considerations it follows that the displacements, by which the now existing silurian areas haves unken in relation to their surroundings, cannot be much greater than the difference in height between the top levels of the latter and the still preserved subcambrian surface of the sunken areas. In middle Sweden these differences seldom reach more than 50 to 100 meters. Some isolated horsts, however, rise to greater heights, for instance the mountains Omberg and Hökensås on both sides of the lake Wättern. Besides, the insignificant throw of the postsilurian displacements in middle Sweden is proved by the fact, that the Silurian of the sunken areas generally is represented only by its lower divisions, the thickness of which mostly does not exceed some ten meters. In the southernmost part of Sweden, in Scania, the postsilurian displacements, on the contrary, are comparatively great and there the Silurian occurs with a much greater thickness.

Regarding the displacements of middle Sweden, it is worthy of notice that the sunken areas generally are tilted, while the adjacent higher plateaus mostly are horizontal or incline in directions which are independent of the faults. This feature could be interpreted as an argument for the opinion that the movements in question have been going downwards in relation to the general earth crust level, that consequently the areas really were »sunken». But as there is no doubt that the Fennoscandian area, because of the predominant denudation, to which it was exposed, in past geological æras has been a rising area, the uplift of which depended on the discharching by denudation, it seems probable that the displacements, on the whole, have been movements of uplift, by which some smaller areas have stayed behind. This mode of viewing can be corroborated by the fact that the postglacial landrising in Sweden also has been smaller in these same areas of displacement which in relation to their surroundings appear as sunken areas.

Whether the subcambrian plateau is a product of continental degradation or of marine erosion or of both these factors cannot at our present stage of knowledge be decided. Considering the extraordinary levelling of the plateau, the hypothesis of a marine formation of the plateau could seem preferable; but, on the other side, the deep precambrian weathering and the still remaining weathering products indicate a subaëral formation.

That a vast time, however, was required to produce the subcambrian platform is obvious. From the following exposition, and also from the diagram p. 2, it will appear that at least two precambrian complexes,

the *Jotnian* and the *Jatulian*, which were separated from each other by a great unconformability, must have been removed by denudation, before this subcambrian plateau could be worked out in the Archean.

On the distribution of land and sea at the beginning of the cambrian transgression over this plateau our knowledge is very insufficient. Thus, it is not known in what direction the cambrian transgression proceeded or where the land areas were situated from which the cambrian sediments were coming. That land areas existed at cambrian time in the actual highlands of Sweden, which already at this time were carved into hills and deep valleys, is proved by the occurrence of silurian strata in the bottom of these old valleys, but wheter the cambrian sediments of middle and southern Sweden derive from this tract or from other land-areas is undecided.

Upper and Middle Præcambrian.

Jotnian.

This name is introduced by SEDERHOLM as signifying the sandstone formations which in Fennoscandia have somewath the same position in relation to the Archean and the Cambrian as the Torridon-sandstone of Scotland and Keeweenawan in North America.

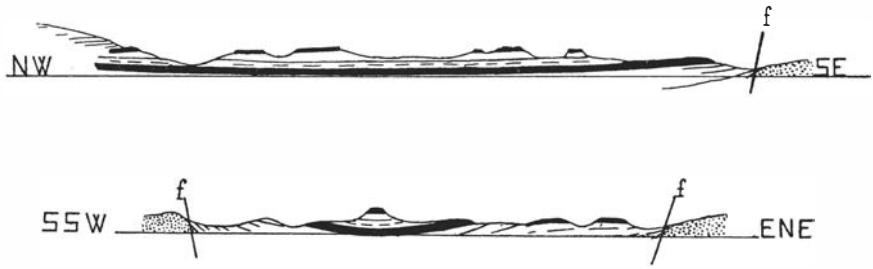

Fig. 1 and 2. Sections trough the Dala-sandstone with its diabase-beds. On the outside of the faults (f) the Dala-porphyries.

The mode of occurence of the Jotnian in Sweden bears in many ways strong resemblance to the mode of occurence of the Silurian in the same country. Thus it occurs as several small isolated areas, scattered over nearly the whole of Sweden, preserved from denudation by displacements and by covering diabase beds.

The greatest jotnian area lies in the province Dalecarlia, west of the lake Siljan, and embraces about 7500 km^2. The underlying rocks belong to the renowned »Dala-porphyries» which also form the surrounding mountains (cf the map). The southern part of this sandstone-area is bounded by faults and is sunken in relation to the porphyries of the

environs. In the NW the sandstone is overlaid by the highland formations (the »sparagmites»). The stratigraphy is illustrated by the figs. 1 and 2, which, as well as the petrographical description, mainly are taken from the treatises by TÖRNEBOHM [6].

The sandstone-formation (without considering the intercalated diabase beds) reaches a maximum thickness of 800 meters in the South and thins out towards the North. In the same direction the material also becomes less coarse. From these circumstances TÖRNEBOHM concludes that the material was afforded from a land area lying in the South. The main bulk of the formation consists of a reddish-brown sandstone, but yellowish and white varieties also occur. Thin intercalations of chocolate-coloured shales are frequently met with in the upper horizons, and conglomerates are constantly present as bottom-layers. Their pebbles are mainly porphyries and quartzites, the latter of a characteristic orange colour. Felspar, fresh or kaolinized, is a prominent constituent, particularly in the lower horizons. Calcareous layers have been found only occasionally, at some localities in the northern part of the area.

False bedding and ripple-marks are very common in the sandstone. No organic remains of any kind have been found. It has been suggested that some yellowish patches in the red rock, which may have been produced by the reduction of a ferrugineous cement, could possibly indicate the presence of organismes. On the surfaces of the layers these patches commonly appear as circular spots of varying size. Petrographically they can only be distinguished from the surrounding sandstone by their colour.

The diabase-beds which are intercalated in this formation are of different ages and petrographical characters. One type is a rather coarse ophitic olivine-diabase (»Åsby-diabase», TÖRNEB.) and forms an intrusive sheet in the sandstone. An other olivine-diabase (»Särna-diabase» TÖRNEB.) is fine grained and is also intrusive. Occasionally these both diabases do not contain olivine but quartz, because of the resorbtion of silica from the sandstone. A third type (»Öje-diabase», TÖRNEB.) is porphyritic and often amygdaloid; it forms an effusive bed of 15—90 meters in thickness and 80 kilometers in length. Nearly connected with this bed is a conglomerate with small pebbles of jasper, which may derive from the amygdules of the underlying diabase. The building up of the sandstone-formation thus must have been interrupted by a time during which the vesicules of the diabase were first filled with jasper, and subsequently the amygdules, by the weathering of the rock, loosened and gave material to the conglomerate.

Some smaller areas of jotnian sandstones, scattered over the Archean of middle Sweden, do not offer any special interest. They are mainly composed of the same rocks as the area above described and are always preserved owing to faults along which they are sunken. A short enumeration of these areas can serve to demonstrate the once wide extent

Fig. 3. Jotnian sandstone, Gäfle-Bay, with suncracks. 1/2 natural size.

of the Jotnian. The occurence at the river Svartelfven, south of the great area of Dalecarlia, can be considered as a continuation of this area. In the province Gästrikland another area of sandstone with two diabase beds occurs. Nearly attached to this area are some small occurences at the bottom of some firths in the province Upland. In the lake Mälaren also small relicts of the Jotnian with accompanying diabase are met with. All these occurences belong to areas which are bounded by faults. Petrographically they are all of the same kind. Noteworthy is the occurence in some of these areas of windworn pebbles (»Dreikanter»), a peculiarity which they have in common with the Torridon-sandstone of Assynth.

In the southernmost part of Sweden one jotnian area only occurs, the so called »Almesåkra-group», SE from the southern end of the lake Wättern. This group is composed of white and red quartzites, felspar bearing sandstones and arkoses, chocolate-brown shales and, more subordinately, conglomeratic layers and red calcareous sandstones. Dikes and beds of diabases are very abundant. They are remarkable by the intense contact influence exercised on the quartz-rocks, many times resulting in micrographic quartz-diabases and other rock-varieties of abnorm composition, as is described by HEDSTRÖM [7]. Fragments of the intruded rocks have also been more or less affected by the diabase-magma.

In connection with these rocks the curious *pebble-diabases* deserve also to be observed. The pebble-diabases occur as considerable dikes in the archean surroundings of the Almesåkra-area. This diabase is characterized by its richness in well rounded pebbles of quartzite and, more subordinately, of other rocks, especially archean porphyries and vein-quartz. Often the pebbles are so numerous that the diabase only appears as a cement between them; and the rock then acquires the aspect of a puddingstone. As the pebbles petrographically are identical with the pebbles of the Almesåkra-conglomerate, it is probable that they derive from this rock, which at the time of the eruption of the diabase probably had not hardened, but existed as gravels. The gravels should then have slided down in the opened dike-fissures and thereby have been included in the diabase. The occurence of these pebble-diabase dikes in the Archean at a great distance from the Almesåkra area consequently indicate that this rock-group originally extended far beyond its present boundaries [8].

The Almesåkra-group is cut by faults which, in a similar manner as in the other jotnian areas, have preserved its rocks from denudation. Besides, also gentle foldings and traces of a regional metamorphism are to be seen in the same area. In this respect it differs from the other jotnian areas. Because of this difference SEDERHOLM has referred the Almesåkra-group to his *jatulian* division of the Precambrian, a hypothesis which I cannot find to be satisfactory grounded. Even when there is a possibility that this group can be somewath older than the other jotnian sandstone-areas, it may howewer most conveniently be put into this

division, to which it with regard to its petrographical characters is nearer connected than to the Jatulian.

The last, and in some respects, the most interesting jotnian area, here to be treated, lies at the Bottnian Gulf and embraces the outhermost islands and promontories of the beautiful Ångermanland coast. The sandstone rests here on gabbros and granites of subjotnian age and is covered by an extended bed of olivine-diabase which also sends intrusive sheets between the strata of the sandstone. For further information on the interesting igneous rocks of this area reference may be made to the congress-guide A 2 b and to the monograph published by LUNDBOHM [9]. The sandstone-formation itself has an insignificant thickness, seldom exceding 60 meters and often sinking down to some few meters, but it has a considerable extent, always forming a terrace at the foot of the diabase table-mountains. Alltough locally displaced by faults, which probably are contemporaneous with the diabase intrusions, the sandstone shows, on the whole, a very regular dip of 5° to 10° to SE (cf. fig. 4, p. 12).

The sandstone is generally rather quartzitic and of a yellowish or white colour; it alternates with layers of chocolate-brown shales and contains small bands of conglomerates, the pebbles of which mostly consist of vein-quarz. Downwards, the rock grades into a schistose arkose, formed by the weathering products of the underlying gabbros and granites. Indisputable organic remains have not been found here, as little as in the other jotnian areas, but some »*Eophyton*»-like tracks, resembling the cambrian *Eophyton*-forms of Westgothland have been annotated by LUNDBOHM [9].

It is worthy of note that this sandstone-formation, with regard to its peculiar relation to diabase-beds and to subjotnian igneous gabbros and granites or rapakivis, is wholly analogous to some jotnian sandstone areas in southern Finland. Besides, consanguined igneous rocks are also known in near connection to the sandstone-area of Gästrikland already mentioned. These igneous rocks, however, occur to the greatest part on the bottom of the Bottnian Gulf, a little to the East from the sandstone-area, They are known mainly as boulders in the glacial deposits of the adjacent part of the province Upland.

On the geographical and geological relations of the Jotnian to the Cambrian.

From the preceding descriptions, as well as from the geological sketch-map, it appears that the Jotnian and the Cambrian do not generally come into immediate contacts. Only at some points in the highlands and possibly also in the Bay of Gäfle the Cambrian or Silurian rests directly on jotnian rocks. Since the latter originally must have covered very extended areas in Sweden, their absence underneath the

Cambrian indicates that their denudation was performed to a great extent already before the cambrian transgression. This conclusion, besides, is confirmed by what is said in the preceding about the small effects exercised by the postsilurian denudation on the subcambrian landsurface (p. 4). The denudation of the Jotnian thus must represent a very great hiatus between this formation and the Cambrian. In this respect, as in many others, there exists a striking resemblance to the western Highlands of Scotland, with their great discordance between the Torridonian and the Cambrian. The distribution of these formations in Scotland, especially in the Assynt-district, also indicates that the Torridonian there was already in precambrian time reduced by the denudation allmost to its present areas.

As a consequence of this opinion about the Jotnian in Sweden one might also suppose that the faults which bound the jotnian areas and the displacements by which these areas have been preserved from denudation are of precambrian age and do not belong to the same epochs as the faults above described by which the Paleozoic of Sweden was displaced.

As there can arise some doubt about the precambrian age of the sandstone-areas now described, inasmuch as they — as it will appear from the map — generally exclude each other and do not come in immediate contacts by which their relative age can be proved, this question may be touched upon a little.

It is known that MURCHISON considered the jotnian sandstone of Dalacarlia as *Old Red* and equivalent to the red sandstone which in Orsa (Dalacarlia) and in southern Norway is superimposed upon the upper Silurian [1]. The same opinion was also formerly maintained by some Swedish geologists. Later investigations, however, have shown that this interpretation was erroneous; the Silurian in the highlands of Sweden occurs in precambrian valleys which are excavated in the so called Sparagmite-formation, and this formation in its turn lies in undisturbed position upon the jotnian sandstone in question. Another argument for the precambrian age of the jotnian sandstone-areas is afforded by the Åsby-diabase which has intruded allmost all these sandstones, but nowhere in Sweden has been proved to have penetrated the Silurian, in the bottom-conglomerates of which it, on the contrary, has occasionally been found as pebbles.

The subjotnian landsurface.

That a long period of subaërial denudation preceded the Jotnian is indicated already by the petrographical characters of this formation. The immense quantities of quartz and also the not insignificant part that fel-

[1] See MURCHISON, »On the Silurian and associated rocks in Dalecarlia» etc. Quarterly journ. of the Geol. Soc. 1847.

spars play in the composition of some varieties of the sandstone bear evidence of a deep going weathering and desintegration of older rocks. At many localities the immediate substratum for the jotnian bottom-layers has also been found to consist of arkoses and other weathering products.

About the topography of the subjotnian landsurface only few direct observations can be made. In the Almesåkra-area some exposures are known, but the greatest among them do not reach more than some hundred meters in length. From the pebbles of the jotnian bottomconglomerate still adherent on this surface it can be concluded that the present surface really represents the almost unaltered subjotnian land-surface and that the same there was well levelled. By faults and displacements it has later on been tilted and has a steep dip towards the West.

In Ångermanland the subjotnian surface can be followed in a much larger scale along the sandstone-terraces below the escarpements of the diabase table-mountains. Except some irregularities which have been caused by faults, the boundary-line between the sandstone and its substratum indicates that the latter forms a well levelled plateau with a gentle dip of some few degrees from WNW to ESE. The mountainous landscape which is formed by the granites and gabbros on the west side of the sandstone-belt has aquired its present topography by postjotnian erosion. Originally the subjotnian plateau must have extended westwards over this igneous area (Cf the congress-guide A 2 b).

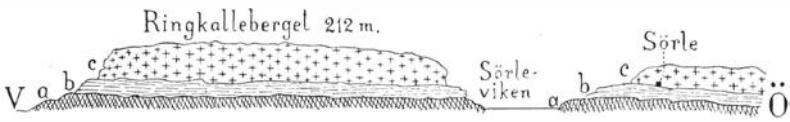

Fig. 4. Section trough the mountain Ringkalleberget, Ångermanland, showing the sandstone (b) lying on the subjotnian platform (a) and covered by a bed of diabase. (c).

Regarding the other jotnian areas there are no direct observations made on the topography of the subjotnian landsurface, but it is not probable that there should appear any great differences in comparaison to the already described areas, except in the western highlands, where a mountainous topography existed in prejotnian time.

Compared to the denudation which levelled the subcambrian landsurface, the forming of the subjotnian surface ought to represent a much greater destruction of the Archean. The rigthness of this opinion is proved already by a comparaison of the amount of weathering products which build up the cambrian and the jotnian sandstone formations. While the former generally reaches only an insignifiant thickness the jotnian sandstones are often many hundred meters in thickness.

From the geographical distribution of the present jotnian and cambrian areas, as well as from the topography of the archean surroundings of some jotnian areas (for exemple the sandstone in Gästrikland), it also seems to be allowed to conclude that the subcambrian denudation has not been going to a considerable depth underneath the subjotnian landsurface which may have been dismantled the covering Jotnian, without being itself much exposed for destruction.

Practically both these old landsurfaces seem fairly to coincide in some tracts of Sweden (for exemple in northern Upland). Also in this respect it exists an analogy with the precambrian geography of Scotland, where the (subtorridonian) Lewisian platform has been exposed by denudation, but not more destroyed than that the same, on the whole, can be still recognized.

In the foregoing it has been alluded that the denudation which preceded the Jotnian was much more deep going than the denudation of the subsequent periods. The same conclusion can be drawn from what is to be said in the following about the Jatulian and the denudation of this precambrian complex.

Subjotnian igneous rocks.

In the immediate vicinity of many jotnian areas, and partly forming the substr atum for them, some igneous rocks of peculiar types occur which can conveniently be signified as *subjotnian*, inasmuch as they are older than the Jotnian, but younger than the preceding precambrian complex of sediments, the Jatulian, and also younger than the folding of this complex. They are separated from the Jotnian by a period of denudation, which is well accentuated, and from the Jatulian by a period of terrestrial movements.

In Ångermanland this relation to the Jotnian is most evident, in southern Finland the relations to the Jatulian are best illustrated. As already stated (p. 10), the Ångermanland sandstone rests directly on weathered granites and gabbro-rocks, which by the denudation have been levelled to the subjotnian landsurface, before the sandstone was formed. These igneous rocks, as is shown by the structures and the mode of occurrence, must be interpreted as plutonic and consequently have consolidated at some depth underneath the landsurface which existed when these rocks were intruded. A not insignificant denudation thus must have taken place before the subjotnian landsurface was formed in these rocks. The covering rocks which must have been removed probably reached a thickness of at least some hundred meters. In Ragunda, where similar igneous rocks occur, it can be proved that their covering was of this size, and as the plutonic characters of the rocks in Ångermanland are more

pronounced than in Ragunda, the removal by denudation was rather more than some hundred meters in Ångermanland.

In Sweden the subjotnian igneous rocks can nowhere be directly connected with the postjatulian folding, but in eastern Finland it is possible to determine their relation to these crustal movements. As is known by the investigations of the geologists of this country the jatulian folding lines there generally run NNW—SSE and point towards the rapakivi-area at the northern coast of Ladoga. The rocks of this area, however, do not show any traces of having been affected by regional metamorphism. Therefore, as especially SEDERHOLM has shown, it is beyond doubt that the rapakivi and the associated igneous rocks are younger than the folding of the Jatulian. But the rapakivi-rocks of Finland are over the Åland archipelago so nearly connected with the petrographically analogous areas of Gäfle-Bay, Rödö, Ångermanland and Ragunda that the geological age of these areas can be considered as thereby fixed.

For the geologists on both sides of the Bottnian Gulf it is manifest since about twenty years, that these rocks are to be separated from the Archean. Together with some other igneous rocks, which are younger than the Archean, but the age of which has not been fixed closer, they have been comprised under the name »*postarchean*». Regarding especially their position to the jotnian sandstone of Ångermanland it seems appropriate to fix even their upper age-limit, and in this respect the term »*subjotnian*» may be available. This term is preferable to »*jotnian*» because of the rocks in question being essentially older than the sedimentary complex which has been signified with this name. A special new term for this group of igneous rocks seems to be superfluous, inasmuch as no contemporaneous sedimentary rocks are known in Fennoscandia.

Petographically the Swedish subjotnian rocks, as well as the analogous rocks of Finland, are treated rather detailed in monographs by LUNDBOHM [9], HÖGBOM [10] and HOLMQVIST [12, 13]. Referring for further information to these monographs and to the congress-guide A 2 b [11] I can restrict the present description to a summing up of the most prominent features of these igneous areas.

The subjotnian rocks are principally granites, which often grade into syenitic rocks, and further gabbros of various structures and composition. Also intermediate rocks, vacillating between the salic and ferric members, are not uncommon. Porphyric rocks of various kinds occur as dikes which penetrate the former and their archean surroundings.

The *granites* are true alkali-granites, their felspar being mainly a perthitic ortoclase. In some varieties the albite as well forms independent crystals or occurs as a border to the perthitic ortoclase. Because of the copious inclusions of ferric oxide (Fe_2O_3) the felspar and the whole rock is commonly flesh-coloured or deep reddish-brown. In some varieties this ferric pigment is wanting, and the rock gets a dirty green colour which may be caused by the presence of the iron in the form of dilute FeO.

The felspars partly form porphyric individuals, partly they are intergrown with the quartz to a micrographic groundmass, which can be either predominant over the porphyric crystals or play a more subordinate part in the rock. The quartz also is often present as porphyric grains.

The graphic or eutèctic structure is very characteristic for these subjotnian rocks, but is developed with much varying distinctness. Not seldom this structure turns into a sort of poicilitic structure, by which round grains of quartz lie without orientation enclosed in the perthite. The typical rapakivi-structure is not so common and not so well developed in the Swedish occurrences as in the contemporaneous rocks of Finland. Generally also the former are not so coarse grained as the latter. The Rödö-area, in the neighbourhood of Sundsvall has among the Swedish occurrences the rapakivi-structure best developed.

The ferro-magnesian constituents occur in very varying amounts. Mica and hornblende are commonly found together, and generally they have crystallized after the quartz and the felspar, filling the interstices between these components. Pyroxene, a pale green diopside, is also often present as irregular small grains. Magnetite and zirkone are characteristic subordinate minerals. The former shows in relation to the salic minerals the same boundary-forms as the mica and the hornblende; it thus belongs to the last crystallized minerals. In miarolitic cavities flusspar is often present.

The granites often turn into *syenites*, which commonly are quartziferous. The ferric minerals are in these syenites represented, beside by mica and hornblende, by pyroxene, which in the more basic varieties is not the above mentioned green diopside but a reddish diallage. Noteworthy is the occurrence of a fayalitic olivine together with quartz, in some of the more basic varieties of the syenite. The colour of these rocks is brown or greenish, according to the colour of the perthitic felspar. The syenites are often extraordinary much disposed for weathering. Especially on the southern slopes of the mountains this desintegration of the rocks is often to be seen in a scale which is uncommon in our climate.

The *gabbro-rocks* are of varying composition and structure. Quartz and orthoclase are often present, olivine, on the contrary, is wanting. Together with the diallage also mica and hornblende occur in considerable amounts. In Ragunda the rock is fine-grained and the structure approaches the rock to the diabases (»Ragunda-diabase»). In Ångermanland coarse anorthosites are wide-spread modifications of the gabbro.

These basic rocks are consolidated before the granites, and curious phenomena of contact-metamorphism and resorbtion are, as a rule, to be seen in the boundary zones between both these rock groups. By the influence of the granitic magma on the basic rocks intermediate, partly monzonitic rock types have arisen which, however, are very varying as to their structures and composition. In Ragunda the gabbro is through its whole mass splintered by the granitic intrusion to a breccia, the fragments

of which show all stages of resorbtion. In the anorthosites of Ångermanland the granite-magma has eaten it's way between the felspars of the coarse grained anorthosite, thus giving rise to a peculiar rock, consisting of porphyric anorthite crystals lying in a micrographic cement of quartz and orthoclase.

For further particularities about the petrography of the subjotnian igneous rocks of Ragunda, Ångermanland, and Rödö may be referred to the above mentioned monographs and to the congress-guide A 2 b. About the cognated rocks of the Gäfle-Bay, which have not been described in any monograph, some remarks may be made here.

As already is said (p. 10), these rocks are known mainly as loose boulders, spread out in the glacial deposists of the adjacent land-area. Only at Strömsbro, to the North from Gäfle, some small cliffs of the fix rock have been found. This rock is a flesh-red rapakivi-granite in which the quartz is partly substituted by calcite. It is probable that this »calcite-granite» was originally a somewhat porous felspar-rock, and that the calcite has later on filled the pores. Generally dark minerals occur scarcely in this rock. They are either a chloritic biotite or amphibole.

Among the boulders from this area one finds almost all the rock varieties which are known from the areas of Ragunda, Ångermanland, and Rödö. Especially the porphyric dike-rocks are richly represented. They show the greatest resemblance to the dike-rocks from Rödö, but some varieties which are not known from this locality are found here. As little as in the other subjotnian areas of Sweden supracrustal igneous rocks are present in the area of Gäfle-Bay.

That the rocks in question really are older than the jotnian sandstone in the vicinity is proved by their occurrence as pebbles in the bottom conglomerates of the sandstone.

Remarks on some igneous rocks of undecided age.

Beside the rocks already described, which by their relations to the Jotnian can be placed in the geological time scheme, some igneous rocks occur which are younger than the Archean and thus have been considered as belonging to the rapakivi group or to other postarchean groups. I will at this occasion not take any regard to the igneous rocks which by their relations to the Silurian indicate their postcambrian age, for instance the diabase-beds of the silurian table-mountains of Westgothland, but I will only give some remarks on the occurrences which with any probability can be supposed to be presilurian.

The greatest group among these rocks is formed by the »*Dala-porphyries*», which extend over a wide area west of the lake Siljan, there forming the substratum for the great jotnian area of Dalecarlia, and also

extending over the surroundings.[1] Some of these porphyries turn into granites (»Siljan-granites») which have a great resemblance to the subjotnian rapakivi-rocks. On the other hand, they are closely connected to some sandstone-like tuff-beds (»Digerberg-sandstone»), with which they form alternating beds. TÖRNEBOHM considered this igneous group as archean, an opinion embraced also by some other Swedish geologists. I have formerly, although with some reservation, placed them among the postarchean rocks, and SEDERHOLM has more decidedly asserted their postarchean age. I shall not here repeat the arguments for and against, I may only call attention to some facts referring to this subject. The porphyries are undisputed younger than the latest epochs of archean folding in this district, as is proved by their unaltered primary characters and by the horizontality of their tuff-beds. In this respect they agree with the subjotnian rocks and differ from the archean porphyries of Småland and in the middle of Sweden; but in other respects they seem to be closer allied to some igneous areas in Lappland, which have been intruded by the latest archean granites, the »serarchean» granites (see below). The predominance of supracrustal rocks is a characteristic feature for the area of Dalecarlia, as well as for the area of northern Sweden alluded to, this feature, on the contrary, being unfamiliar to the subjotnian areas. From the »serarchean» granites they also differ petrographically to much to be classified in this group. The age of these rocks therefore ought to be an open question. The petrography of the Dala-porphyries is known principally by the descriptions by TÖRNEBOHM, and can be summed up as follows.

The oldest rocks of this group are flesh-red and brick-coloured felspar-porphyries with micrographic or microgranitic groundmass. The former (the »Garberg-porphyry») reminds one of the rapakivi-rocks, the latter is a well defined type which, with its brick-red coloured groundmass and its scattered small phenocrysts of the same colour, can easly be separated from other porphyric rocks and thus in the glacial geology has been much used for the determination of the directions of the ice movement. Younger than these two types are some basic porphyries. Among them some are olivine-bearing melaphyries, other have a quartziferous, grained groundmass with phenocrysts of mica, augite, bronzite, and plagioclase (the »Wenjan-porphyrite»). The basic porphyries are often amygdaloid and are accompanied by tuff-beds.

The youngest porphyries of this group (the »hornstone-porphyries» TÖRNEBOHM), form a number of isolated hills rising abruptly over the surroundings. They are characterized by a dense felsitic groundmass of black, brown or chocolate-like colour, and by small phenocrysts of light coloured ortoclase or plagioclase. The groundmass often shows a beautiful crypto-

[1] The porphyries and the with them associated granites which northwards from this area have a great extension in the highlands and there form the substratum of the sparagmites and the Silurian also may be considered as belonging to the Dala-porphyries.

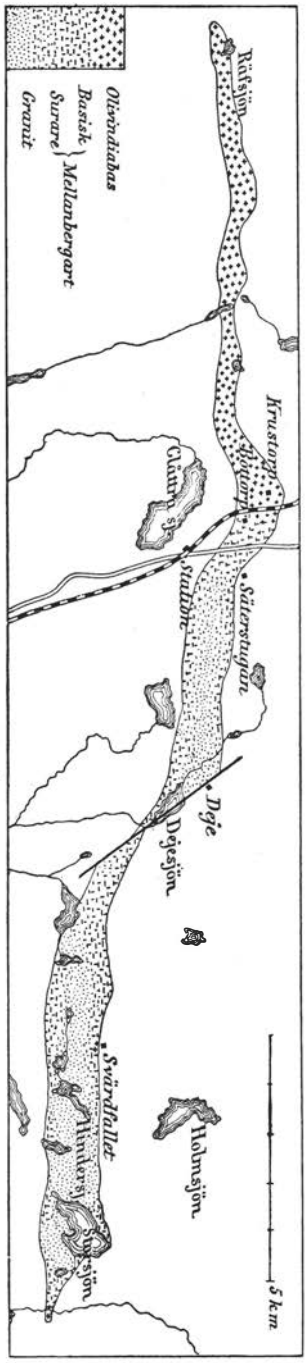

Fig. 5. The Brefven dike (after WINGE).

poicilitic or rather cryptographic structure; fluidal structure is also very often well developed.

In the area of the Dala-porphyries another porphyric rock occurs which may be mentioned in this connection, altohugh it perhaps is essentially younger, viz. the »*Särnaite*» or the *cancrinite-syenite-porphyry* of Särna, well known by the descriptions by TÖRNEBOHM.[1] The rock which also occurs in modifications of a granitoid structure has cut the Dala-porphyries; its relation to the adjacent jotnian sandstone is not made clear.

The *nepheline-rocks* of Alnö, which have been described in a monograph by the author, and the *catapleite-syenite*-rocks on the east side of the lake Wettern, recently described by TÖRNEBOHM, are also of an undecided age. The former ought to be somewath younger than the rocks of the rapakivi-group, inasmuch as the dike-rocks of Alnö have been found in the rapakivi-granite of Rödö. The catapleite-rocks have been considered as mesozoic by TÖRNEBOHM, an opinion which is founded on the supposition that the so called »Wisingsö-formation» of the Wetter-bassin should be of triassic age.

The *diabase-dikes* which occur in the Swedish Archean belong to many different geological epochs. Some of them, for instance the uralite-diabase-porphyries of Småland and the hyperites of western Sweden, are of archean age and will be taken regard to later on in connection with the surrounding archean rocks. The greatest part of the diabase-dikes are postarchean, but in most cases their age cannot be more exactly fixed. Often they are associated to groups and run in parallel directions over wide areas, and sometimes these directions coincide with the directions of the faults by which the Jotnian and the Silurian have been displaced. As a specimen of these dikes the great *Brefven-dike*, south of the lake Hjälmaren, may be mentioned. Petrographically this dike is interesting because of the variability of the rock, which in the middle and eastern

[1] Papers of purely petrographical contents have generally not been quoted in the bibliography it the end of this treatise, inasmuch as they are referred to in the great handbooks of petrography (for instance in ROSENBUSCH, Mikroskopische Physiographie der Eruptivgesteine).

parts grades from a typical olivine-diabase (»Åsby-type») to a micrographic granite, with very small amounts of femic constituents. Another great dike is the *Hellefors-dike*, a little to the SE from the former. The rock is there also quite varying, but can be signified as a coarse olivine-diabase which differs from the Åsby-diabases mainly by the abundance of secondary minerals (chlorite, uralite). Both these dikes, and many other in the same district, run in the direction E—W. In the South of Småland, other directions are prevailing, and the rocks differ also petrographically from the now described diabases. Beside the already described *pebble-diabases* (p. 9) many dikes occur, which are characterized by interesting contactphenomenas and included exogene felspars, as described by BÄCKSTRÖM, MOBERG, and HEDSTRÖM.

With regard to the distribution of the diabase-dikes over the archean areas of middle and southern Sweden there is a curious fact which deserves to be noted. While dikes of diabase are very common in the eastern Sweden, there forming many different groups, dikes of diabases do not occur in western Sweden. Their absence, for instance in the province Westgothland, in the surroundings of the silurian table-mountains of this province, is as much more striking as these mountains always are covered by extended beds of diabases, which once must have broken up through the Archean. At the western boundary of the gneiss-district of western Sweden, in the later on to be treated boundary-belt which is of so great a significance for the interpretation of the Swedish Archean, dikes of diabase again appear. Beside the archean hyperites, which will be discussed in another connection, a number of dikes runs along the eastern border of this boundary-belt, the rocks of which form a special type of *bronzite-diabase* (TÖRNEBOHM). This diabase is to be considered as postarchean, inasmuch as it has not been metamorphosed by the archean foldings, which have put their marks on all older rocks of this boundary-zone.

In northern Sweden various diabases occur. Some of them are probably archean, but mostly they are yuonger. They form not only dikes, but also irregular intrusive bodies and massives which have been intruded in the archean rocks or in the jotnian sandstones. The latter mode of occurrence has been illustrated already in connection with the description of the jotnian areas of Dalecarlia and Ångermanland. On the age of these diabases no closer determinations are possible than that they are postjotnian. On the whole, the petrographical characters of the diabases ought to be used with great reservation for stratigraphical purposes, as is illustrated by the fact that the archean hyperites often are very similar to some postarchean diabases, or by the fact that quartz-bearing micrographic diabases can be geologically equivalant to olivine-diabases of the Åsby-type.

On the Jatulian and the epijatulian folding.

By the admirable investigations of our colleagues in Finland it is proved that rock complexes of significant thickness and extent occur in

the eastern parts of their country, which are separated by great periods of denudation from the Jotnian on the one side and from the Archean on the other. These *jatulian* complexes are, contrary to the jotnian sandstones, more or less folded, and often they have been overlapped by the eastern Archean by thrust movements.

In Sweden only one area of similar rocks and tectonical relations is known, viz. the »*Dal-formation*» on the western side of the lake Wenern [14]. The composition and the order of succession of this complex appears from the subjoined tabular statement.

1. *Bottom-quartzite.* Reddish quartzitic sandstones, with bottomlayers of *conglomerate* and *arkose.* Total thickness about 200 meters.
2. *Dark slates*, with intercalated impure and sometimes *bituminous limestone*, and subordinate beds of *reddish sandstones.* Two or three sheets of metamorphic *basic igneous rocks* are often met with in this division. They are partly tuffaceous, partly amygdaloid, but generally their original structures have been destroyed by metamorphism, and the rocks have been transformed into schistose greenstones, mainly composed of chlorite, epidote, albite, quartz, titanite, and magnetite. The total thickness of this division reaches 800 meters.
3. *White quartzite*, with subordinate layers of *red slates* and impure limestone. Thickness 470 meters.
4. *Gritty schists,* grading into light coloured mica schists. Sometimes they are less metamorphic, and then they could be signified as impure felspar-bearing sandstones (»sparagmites»). Small layers of *conglomerates* and *slates* are interstratified in this division. This division seems to be separated from the former by an unconformity. The total thickness is taxed to 400 meters.
5. *Breccia*, composed of the rocks of the former divisions and of archean rocks, and lying unconformably over them. This peculiar rock is, at least to its greater part, a product of the thrust movements which have taken place in this complex.

No undoubted organic remains have been found in this complex, but TÖRNEBOHM has described some curious structures, occurring in a limestone, which resemble organic forms [15].

The »Dal-formation» is folded, and the folding axes generally run in the direction N—S. The folds are often overturned, and at the western boundary considerable overthrusts occur, by which the archean gneisses have been driven eastwards over the younger formation, as has been pointed out by TÖRNEBOHM in a paper published already 1883 [15]. It is probable that the overthrusts reach much greater amounts than TÖRNEBOHM has supposed, but no detailed revision of the geology of this area has been undertaken since the formation was first mapped by the Geological Survey in the sixties of the last century. In the fig. 6 I have given an interpretation of the architecture by which the overthrusts become of a consi-

derable size in comparaison with the overthrusts as they have been demonstrated by TÖRNEBOHM.

The tectonical movements have caused more or less prominent metamorphic features in which the mecanical effects generally are prevailing over the chemical transformations. The archean rocks which have taken part in the movements have got this metamorphism impressed on their older metamorphic characters. Beside the cataclastic structures the development of epidote and sericite are characteristic for the archean gneisses of this area; these gneisses have in the older geological litterature, because of their difference from the normal archean gneiss-rocks of Sweden (which generally have the structures and composition of lower or more deap-seated metamorphic zones), been signified with special names, for instance »Kroppefjälls-gneis», »Järbo-gneis». These archean rocks occur not only in the overthrust masses, but also extend over the surroundings of the Dal-formation, there often enclosing small remnants of the synclinals of this complex, which have escaped being removed by denudation.

On the time in which this folding has taken place no direct evidences are available. When the parallelisation of the complex with the Jatulian in Finland is right, the folding must have preceded the great subjotnian denudation, and thus can conveniently be signified as *epijatulian*. This parallelisation has not been accepted by all Swedish geologists. TÖRNEBOHM has suggested that, on the contrary, the Dal-formation is equivalent to the jotnian Dala-sandstone. Really, and no regards taken to the tectonical features and to the petrographical differences which arise from the metamorphism, both areas show some quite obvious resemblances. The predominance of quartz-rocks and the intercalations of basic igneous beds are common for both these complexes. The sparagmites of the highlands, which are superimposed the Dala-sandstone unconformably, remind one of the »gritty schists» of the Dal-formation, which seem also to be separated from the lower divisions of this complex by an unconformity. However, all facts considered, the probability might be greater for the equivalence of the Dal-formation to the Finnish Jatulian, an opinion which especially SEDERHOLM has vindicated. The probability of this opinion is supported by the »Thelemark-quartzites» in Norway and their associated rocks which, as pointed out by SEDERHOLM, much remind one of the Jatulian of Finland. The Thelemark-complex is folded, and the folds run, as in the Dal-formation, in the direction N—S. But a little to he North from this Thelemark-area the

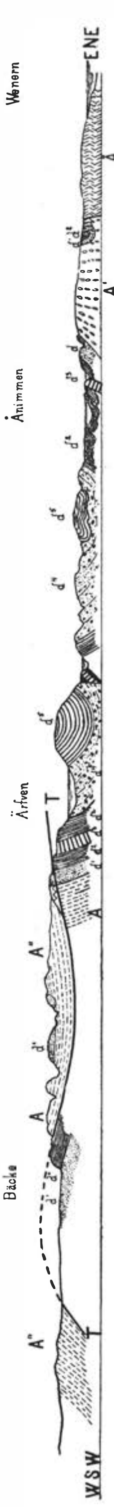

Fig. 6. Section across the folding axes of the Dal-formation. A, A′, A″ Archean gneisses; Å Åmålcomplex; d, d^1—d^5 Dal formation; T—T Thrust.

precambrian sparagmites occur, corresponding to the sparagmites which in Dalecarlia succeed the Dala-sandstone; and these sparagmites bear no signs of having taken part in the folding which has seized the Thelemark-quartzites. From this circumstance it may be alloved to conclude that the folding-systems of the Thelemark-quartzites and the Dal-formation are older than the sparagmites and the with them connected jotnian sandstones.

The Dal-formation is dissected by a number of faults, running in the direction NW—SE, thus obliquely crossing the folding lines. These displacements are distinctly marked in the topography and in the distribution of the rocks, as is especially well illustrated by the geological map, section »Baldersnäs». Topographically the Dal-formation can be characterized as a hilly district with many lakes, with the ridges and the lakes extending in the same direction as the folding lines. Between this area and the lake Wenern an exceedingly well levelled plateau of archean rocks extends, rising not more than some twenty meters over the level of the lake. This plateau is best developed in the neighbourhood of Mellerud (section »Rådanefors»). As already has been described (p. 4) this platform represents the almost unaltered subcambrian land-surface. The western boundary of the platform, which runs along the foot of the mountain-ridges Kroppefjäll and Kappebofjäll, seems to coincide tolerably well with a fault. The mountains and valleys on the western side of this fault have been carved out in the subcambrian land-surface which originally may have extended further to the West.

That the Dal-formation already in precambrian time was reduced by the denudation almost to its present extension may also be indicated by the fact that only small remnants of its synclinals occur in the Archean of the unaltered subcambrian landsurface which is still preserved on the eastern side of the Dal-formation (cf the sections »Rådanefors», »Upperud» and »Wingershamn»).

The subjatulian landsurface.

Although somewhat obliterated by tectonical disturbances and metamorphic forces the unconformity between the Dal-formation and the Archean is generally well visible. The bottom-conglomerates of the former are deposited on very different archean rocks, on gneisses, on the rocks of the Åmål-complex, later on described, and on granites which have penetrated this complex. Pebbles of all these rocks are also met with in the bottom-conglomerates, and at many localities the latter turn into an arkose and into the only a little or not at all deranged weathering products of the substratum. Considering the varying development of the bottom-conglomerates TÖRNEBOHM has suggested that the subjatulian land-surface was not a levelled one, but, on the contrary, a very mountainous surface. This opinion is also based on his views on the mecanics of the overthrusts

[15]. However, I think that TÖRNEBOHM has much exaggerated the height of these prejatulian mountains. It seems probable that this landsurface may have been less well levelled than the subjotnian and subcambrian landsurfaces, but that the prominences, on the whole, did not rise much over the valleys.

If I am right in my opinion already above expressed that the subcambrian land-surface is not worked out to any considerable depth underneath the subjotnian landsurface, it can be concluded from the geological features east of the Dal-formation, above referred to, that the subjotnian land-surface, on the contrary, was formed by a denudation, which reached to a great depth underneath the subjatulian land-surface. The small remnants of the synclinals of the Dal-formation in the Archean, above mentioned, prove that a great denudation must have taken place in the Archean after the folding of the Dal-formation, and that consequently the subjatulian land-surface there has been situated far above the subjotnian and subcambrian surfaces, which — broadly speaking — in this district fairly coincide with the present land-plateau. Measured with the amount of the denudation, the interval between the Jatulian and the Jotnian thus may be much greater than the interval between the Jotnian and the Cambrian, and also greater than the long aera of denudation which in Fennoscandia has occupied nearly the whole postsilurian time. With this mode of viewing, one can imagine why the jatulian complexes which, with regard taken to their great thicknesses, must be supposed to have originally extended far outside their present areas, already in prejotnian time were in such an extent removed by denudation, that they only exceptionally are known as substratum for the jotnian sandstones.

Lower Precambrian or Archean.

Upper limit of the Archean.

The formations above treated have in Sweden unanimously been regarded as essentially younger than the Archean. By the geologists of the older generation they generally were signified as Cambrian or Lower Cambrian, or they were regarded as facies of the Silurian. Later on, when there began to be payed more attention to the great unconformity between these formations and the fossiliferous Cambrian, they were grouped together under the provisoric term »*Precambrian*» (NATHORST, 1894), a term which after the proposition of SEDERHOLM is nowadays generally exchanged for »*Algonkian*», with the two subdivisions *Jotnian* and *Jatulian*. Above, I have avoided the use of »Algonkian» as possibly causing some misapprehension among foreign geologists, who may incline to a wider extension of this term as comprising also some complexes which in Sweden

generally have been signified as archean. The term »*Proterozoic*» cannot either seem appropriate to signify these formations, inasmuch as the presence or absence of animal life is unsuitable as ground of division for geological formations in which undisputed organic remains have not at all been found. Besides, the problematic organic traces which occur in these formations are not more evincible than the indications of organic life which occur in some archean complexes. It could be proposed to follow the example of American geologists and entirely give up the term »Archean», but regarding the Archean of Sweden, and of Fennoscandia on the whole, it is perhaps most in conformity with nature to hold the Archean separated from the younger precambrian formations by its old name. At all events, there is not sufficient reasons to introduce a new nomenclature in this treatise, the purpose of which is essentially limited to give an orientation in the precambrian geology of Sweden, as it is apprehended in present time. Some in this paper inserted terms, as for example »subjotnian», »subjatulian», »epijatulian», »serarchean», have been chosen with the special view to change the hitherto used terminology as little as possible. The significance of these terms ought to be understood, without much explanation, from the connection in which they are used.

The upper limit of the Archean of Fennoscandia is indicated by the subjatulian denudation and the immense time which it must represent. This great break in the sequence of formations — probably the greatest in the history of the earth — separates the Archean from the younger complexes which above have been signified as jatulian. One can form an idea of the minimum amount of the subjatulian denudation from the fact that the metamorphic prejatulian or archean rocks which form the substratum for the Jatulian generally show structures, characteristic for the deep-seated rock-flowage zone. At least some thousand meters of the Archean thus must have been removed by denudation, before the jatulian sediments were laid down.

The youngest prejatulian granites, the »serarchean» granites, which will be described in the following, were also laid bare from their covering by the same denudation. It could be proposed to introduce an especial term between the Archean and the Jatulian for the vast time during which the just named denudation was performed. But, inasmuch as no sedimentary complexes occur in our country which could be referred to this time, it may be most convenient to signify this time by the term »subjatulian», which thus is formed in analogy with the term »subjotnian». The great terrestrial movements which have seized the archean rocks of Sweden and which are previous to te subjatulian denudation are conveniently referred to the Archean. Moreover, the wide spread granites which have intruded the Archean after its folding and which have been exposed by the subjatulian denudation generally have been regarded as archean. It could be proposed to exclude these granites from the Archean, inasmuch as they are younger than the great foldings and displacements

which have given to the main mass of the Archean its most striking features, and signify them as subjatulian, for example, in analogy with the signification »subjotnian», used for the igneous rocks of the rapakivi-group (p. 13). But such a change of the nomenclature hitherto used seems to be of little value and should to much break with the principles which have been followed by all Feanoscandian geologists in the mapping of our archean and other precambrian rocks.

Serarchean granites.[1]

The granites belonging to this group occur as smaller and greater massives, scattered over the archean area of Sweden, from Blekinge and Bohuslän in the South to Lappland in the North. Compared to the older granites they are not generally much deformed by metamorphic forces. Secondary gneiss-structures thus are, as a rule, wanting, but less prominent cataclastic features are seldom wholly absent. Regarding their mineralogical and structural characters these granites can be classified in a few types. *One type*, occurring over wide areas in middle Norrland, and more scarcely in other provinces, is a coarse grained gray or reddish porphyric granite with great (3—6 cm.) Carlsbader-twins of orthoclase or microcline. The femic minerals are commonly represented by black mica and, in some less acidic varieties, by hornblende. *Another type*, either forming independent massives or nearly connected with and grading into the porphyric granites just described, is a fine or middle grained gray or light reddish biotite-granite. As a good example of this type the granite in the surroundings of Stockholm, the »Stockholm-granite», may be mentioned. *A third type*, a true muscovite-granite, occurs very abundantly as small massives in Ångermanland. To these types can be added as a *fourth type* the coarse pegmatitic granites which generally form a dike facies in the boundary zones and in the surroundings of the massives, but also can extend over greater areas as massives (for instance in the province Närike, NW from the lake Hjälmaren). Some of these pegmatites are rich in pneumatolytic minerals, for instance the renowned occurrences of Ytterby, Finnbo, Broddbo, Kårarfvet, and Utö.

Characteristic for these serarchean granites with regard to their geological appearance is that they never are connected with effusive rocks

[1] The granites of this group generally in the litterature have been signified as »youngest» or »younger archean granites». On the survey map by Törnebohm [1] they have got a separate colour and have been called »archean granites of the third group», Holmqvist in his monograph on the Swedish granites [13] uses the term »durchbrechende archaeische Granite». The term, here proposed, derives from the latin »*sero*» = late, and is thus equal to »late-archean», »spätarchäish», »senarkeisk». It could have been preferable to use the term »eparchean», but this term has already been used in another sense in the American litterature.

and never turn into porphyric or micrographic boundary-facies, but that they generally are accompanied by a multitude of coarse pegmatites, originating from the massives or cutting them and their surroundings, Basic, dioritic and gabbroid rocks are generally not present in these granites in other wise than as distincly enclosed, fragments, but micaceous segregations occur occasionally which give to the rock a mottled aspect (f. ex. the Skellefteå-granite). As a peculiar facies of the Stockholm-granite the orbicular granite from Vasastaden is to be mentioned. The most

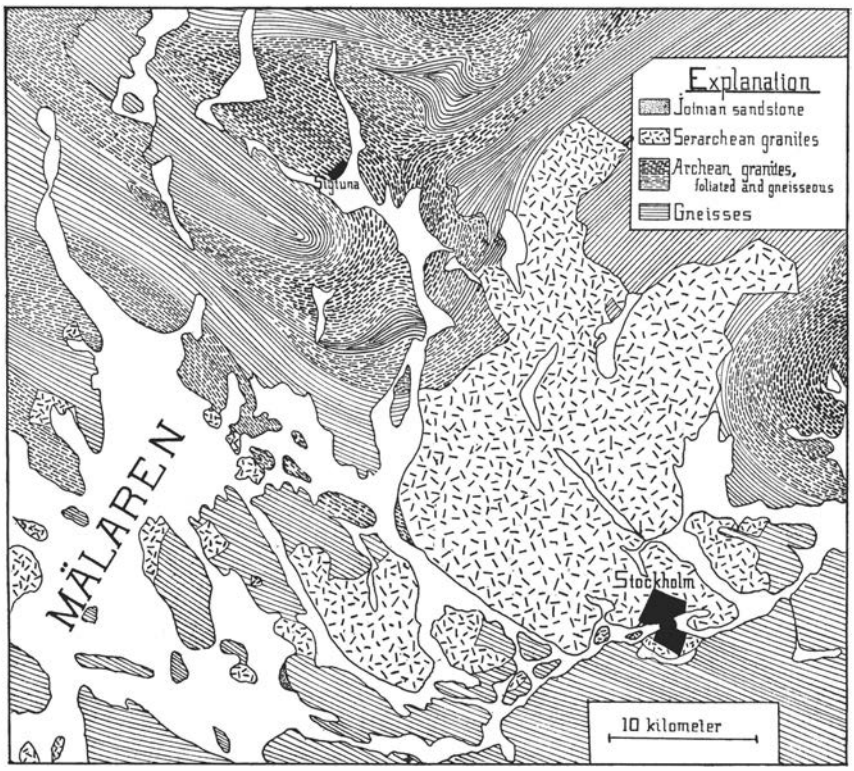

Fig. 7. Sketch-map of the Archean in the surroundings of Stockholm.

striking contrast to the other archean granites this group shows in its behaviour to the surrounding rocks, as is best illustrated by the sketch-map fig. 7 and the map plate I. The boundaries of the serarchean granite-massives run wholly independent of the strike of the surrounding gneisses and schists which are in all directions cut by dikes and veins originating from the massive, and in the granite itself small and great bodies of the gneiss-rocks have been enclosed, which often have their fragmental characters well preserved, inasmuch as they are only little affected by resorption. On the other hand these fragments have been often transformed into »veined gneisses» by pegmatitic injections and segregations.

In some cases the metamorphic influence of the granite on the schists is as insignificant that the older metamorphic characters of the latter are still easly recognizable.

Although some granite massives can not without hesitation be classified as serarchean and be separated from the older, generally more or less gneisseous granites, and although also some doubt can arise with regard to the discrimination of some occurrences from the subjotnian granites, already described, it seems as if the group in the restriction here given represents, on the whole, a tolerably distinct chronological unity. This group is on the one side younger than the dynomometamorphism of the main mass of the Archean, on the other it is older than the subjatulian denudation. It is a peculiarity of the Archean of Fennoscandia that the great granitic intrusions have not continued in the sedimentary complexes which above have been described as jatulian and jotnian. The serarchean granites thus mark the upper limit of the Archean, as especially SEDERHOLM has laid stress on in his chronological dividing up of the Precambrian. From a formalistic point of view one could think that it was unlogical to take these granitic intrusions as a criterion for the limiting of the Archean from the younger Precambrian, but the geological relations of the latter in other respects corroborate, with regard to the great Precambrian area of Sweden and Finland, the validity of this mode of viewing.

Stratigraphical principles for the Archean.

Among the Swedish geologists of the older generations neptunistic ideas were predominating. Really the Wernerian School has gathered the principles of its system from Swedish naturalists of the eighteenth century, especially from LINNÉ and THORBERN BERGMAN. Still in the latter part of the last century neptunistic ideas were embraced by our leading geologists of which fact the maps and the interpretations of the Archean bear witness. Almost all schistose, foliated and gneisseous rock-structures were regarded as sedimentary, and much labour was from this point of view spent on the establishing of a stratigraphical succession in the Archean. This mode of viewing was also to a certain extent adopted by TÖRNEBOHM in his fundamental researches in the seventies and eighties, but thereby he supported his chronological scheme by the geological relations of the supposed sedimentary rocks to the granite massives which have such a great extention and occur in such a great number of petrographical types in the Swedish Archean. TÖRNEBOHM distinguished three chronological granite groups to which the sedimentary and schistose rocks could be correlated by their contact features. Starting from similar prin, ciples SEDERHOLM has later on tried to get a chronological scheme, applicable for the whole Fennoscandian archean area. Some uncertainity

however, is necessarly attached to this metod, as well as to other chronological divisions which are not based on paleontological evidences. Granites of different petrographical types can be synchronous, and the same petrographical type can recur in massives of different age. Even the degree of metamorphism of the granites ought not to be considered as a criterion of the age, inasmuch as the metamorphic forces can have been stronger and have continued longer in one district than in another.[1] Only when minutely following the geological and petrographical features from tract to tract the metod may be applicable. At present the Fennoscandian area is not surveyed and mapped in this manner to its whole extension. Thus each chronological succession applied on this extended area has, at our present stage of knowledge, its value mainly as a working hypothesis. But as founded essentially on the correlations of petrographically defined groups, the subdivisions have a significance apart from the chronological value, since they give a general view on the petrography and the architecture of the Archean.

For the purpose of this treatise it may be sufficient to divide the Archean into two great groups or facies, when the serarchean granites are leaved out of consideration. One group then is characterized by the predominance of gneisseous rocks; the other group is less strongly metamorphic and is composed, partly of still recognisible supracrustal igneous and sedimentary rocks, partly of granites and associated intrusive rocks. Generally speaking, these two groups have been regarded as representing two great chronological divisions, but it often happens that the younger rocks can be so strongly performed by the metamorphic forces that they have got the characters of the first group or, on the contrary, that older rocks have preserved their primary characters just as well as the rocks of the latter division. Furthermore, the gneiss rocks of the supposed older group can really sometimes be younger than the overlying upper group, may the palingenetic ideas of Sederholm [2] be right.

No unconformity of more than local value is known in the Archean, which could be used as separating line between older and younger divisions. But there are many limited areas on which it is possible to accomplish a subdivision.

For the following general view on the Archean of Sweden it is most practical to divide this extended and variegated area in different districts, each of them characterized by a peculiar development of its predominant rock complexes. The boundaries of these districts will appear from the sketch-map, Pl. I. The districts will be described in a geographical order, beginning with the southern and proceeding to the northern districts. In connection with these descriptions some remarks will be made on the correlations in which the districts stand to each other.

[1] Moreover, if the ideas recently developed by SEDERHOLM on the importance of *palingenetic* processes in the Archean of Fennoscandia [2] prove to be true, the granites become still much more unthrustworty for chronological divisions.

The great gneiss-district of Southwestern Sweden.

This area is composed of strongly metamorphic rocks among which *red granulated gneisses,* in the older litterature signified as *iron-gneiss (»jern-gneis»)*, are the most common. They have their name from the presence of magnetite as a conspicuous constituent. Other femic minerals are generally very scarcely present. By the increasing of these minerals (mica, pyroxene, hornblende) this gneiss turns into grayish, often more or less distinctly banded gneiss. The structure is generally middle grained and typically granular. When seen in small pieces the rock has a granitic aspect, but in the field a more or less distinct banking and parallel structure is to be seen. The chemical composition of these gneisses is a true granitic one, and often they turn into foliated and massive granites, with partly preserved primary structures. Such granites often form lense-shaped bodies in the gneiss-area, and then they can be regarded as relics which have escaped being performed to gneiss. These granites are often porphyric, and their great felspars have become more or less lenticular, thus giving rise to eyed granites or gneisses. TÖRNEBOHM has pointed out that these granitic nuclei, as a rule, show a slower transition upwards than downwards to the surrounding gneiss. There ought to be separated from these eyed granites and gneisses some rocks in this district, the »eyes» of which have been formed by crystallisation during the metamorphic process. These »eyes» often grade into stripes and bands, composed of coarse grained segregations of felspar (and quartz), thus giving rise to a kind of banded gneiss. In the surroundings of Trollhättan these rock-varieties and gradations can be easly studied.

As intercalations in the red iron-gneiss, and in some parts of the district prevailing over them, another gneiss occurs which is characterized by a grayish colour and a well developed banded structure. The banding is partly caused by the distribution of the mica, partly by the varying size and amount of the other components. This gneiss has also a granitic composition. Hornblende can be present in the gneiss, which often grades into amphibolites, forming either intercalated thin bands or thicker belts or even lense shaped bodies. These amphibolites, as well as similar ones occurring as belts in the iron-gneiss, may often be metamorphic basic dikes which run parallel with the strike of the surrounding gneiss, In the archipelago of Koster, in Kattegatt, one can very well follow the transition of these amphibolitic belts into still recognizable dikes.

In the greater amphibolitic masses, gradations into gabbros or diorites are not seldom to be seen, which are analogous to the transitions from gneiss to granite, already described.

A peculiar basic variety of the gneiss occurs south of Gothenburg, in the neighbourhood of Warberg. This rock, the so called »Warberg granite» or »Warberg-gneiss» is granulated, with relic structures occas-

sionally preserved. Mineralogically the rock differs from the normal gneiss by the presence of a pale green diallage as main femic constituent, by the perthitic felspar, and by the small amount of quartz. Chemically the rock is nearly related to the syenites. The pink green rock is well exposed in the quarries south of Warberg, where also its relations to the ordinary iron-gneiss and the granitic gneiss, to which it shows transitions, is well perceivable.

Among the basic rocks of this district the *hyperites* offer the greatest interest. They are limited mainly to a zone of some twenty kilometers breadth, running along the eastern boundary of the district [Pl. I]. Generally this rock forms extended hills and ridges of some kilometers length, rising over the surrounding gneiss in which they are conformly enclosed. At their boundaries the hyperites turn into garnetiferous amphibolites, with a generally well developed schistosity. In the interior they have their primary igneous structure well preserved, and the minerals are quite fresh. The original structure is rather ophitic, and the plagioclase sometimes forms flatened phenocrysts with a trachytoidal arrangement. The relative amount of the different minerals is very varying. Of the two pyroxenes, the diallage and the hyperstene, the latter is commonly the more abundant in such varieties which are poor in olivine. Titanomagnetite is sometimes concentrated in such amounts as to form an iron-ore. The famous mountain *Taberg*, south of the lake Wettern, is to its main part composed of a variety of the hyperite which contains as essential components olivine and titanomagnetite.

From the correlation between the amphibolitic boundary-forms of the hyperites and the adjacent gneiss it is evident that the hyperites have taken part in the tectonical revolutions by which this gneiss-district has obtained its metamorphic character. It is, however, somewhat unexspected to find the primary structures of these hyperites preserved in such a great extent, when they have been exposed for tectonical forces of such violence.

Regarding the age of the hyperites there can be gained some evidences from their relations to a quartzite-complex occurring in northern Wärmland in the neighbourhood of the among mineralogists renowned mountain *Horrsjöberget*. This complex, which will be described later on in connection with some other analogous areas, is cut by a hyperitic dike belonging to the great boundary belt of the gneiss-district already alluded to. In the same manner the hyperites in the neighbourhood of Kragerö in Norway have intruded similar quartzite-complexes. These complexes have taken part in the tectonical movements by which the gneiss-district of western Sweden and adjacent parts of Norway has gathered its metamorphic features, and the hyperites themselves have also been metamorphosed in their boundary-zones by the same movements. Pegmatitic dikes and veins, which may be interpreted as archean, occasionally are met with in the hyperites (f. ex. at Taberg). From these circumstances

it is obvious that the hyperites ought to be considered as archean rocks, but that they must be essentially younger than the iron-gneiss in which they apparently occur as beds or intercalations. Their close connection with the iron-gneiss is a consequence of their being exposed for the same metamorphic forces. It may in this connection also be remembered that the dikes of bronzite-diabase already mentioned (p. 19), are younger than the with them geographically connected hyperites, as is proved by the fact that they show no signs of having been metamorphosed and that they cut the hyperites.

The architecture of the gneiss-district is characterized by a predominant N-S strike, especially marked in the eastern and western boundary-zones of the district. In the middle parts of the great gneiss-area the strike is less decided, as will appear from the map, Pl. 1. Contrary to the general rule in the Archean of Sweden, the structure planes often have over wide areas only a gentle dip, or they lie tolerably horizontal. From these features it may be concluded that the tectonical movements by which the rocks of this district have been metamorphosed chiefly have been thrusts and intense overfoldings; and from the petrography and the structural characters of this area it may be allowed to suggest that the movements to the greatest part have taken place in the zone of plastic deformation or of rock-flowage.

The region on the whole can thus be regarded as the root or base of a deeply denuded archean moutain-range in which thrusts or horizontal displacements have, as in many younger mountain-ranges, predominated over the forming of more vertically erected folds.

Later on in this treatise I will return to the different opinions about the geology and the age of the gneiss rocks of this district and to the question about its relation to the Archean of eastern Sweden. Before leaving the district, a few remarks may, however, be added about some areas of comparatively less metamorphic rocks and rock complexes occurring here.

In its westernmost part, close to the coast of Kattegatt, the gneiss is intruded by a granite massive, the »Bohus»- or »Strömstad-granite», which is to be considered as serarchean.

In the surroundings of the Dal-formation some granites occur which may partly be only relic-granites, belonging to the great gneiss-area, partly some younger granites, more or less metamorphosed by the epijatulian folding (cf p. 21). The archean rocks in this tract generally bear evidence of this folding and are characterized especially by cataclastic structures, development of sericite, epidote, and chlorite, thus differing from the ordinary gneiss rocks of the district which have got their metamorphic character by the older displacements already described.

In the neighbourhood of the Dal-formation another rock complex also occurs which is of a special interest. This complex is known as the *Åmål-formation* or *Åmål-complex.*

Situated at the west-coast of the lake Wenern, and bounded to the West by the Dal-formation, this complex was mapped already forty years ago, at the same occasion as the Dal-formation. According to the descriptions by TÖRNEBOHM (14) the complex is composed of porphyric rocks, conglomerates, quartzites, and greenish metamorphic tuffs (»eurites»), and is by an unconformity separated from the overlying Dal-formation.

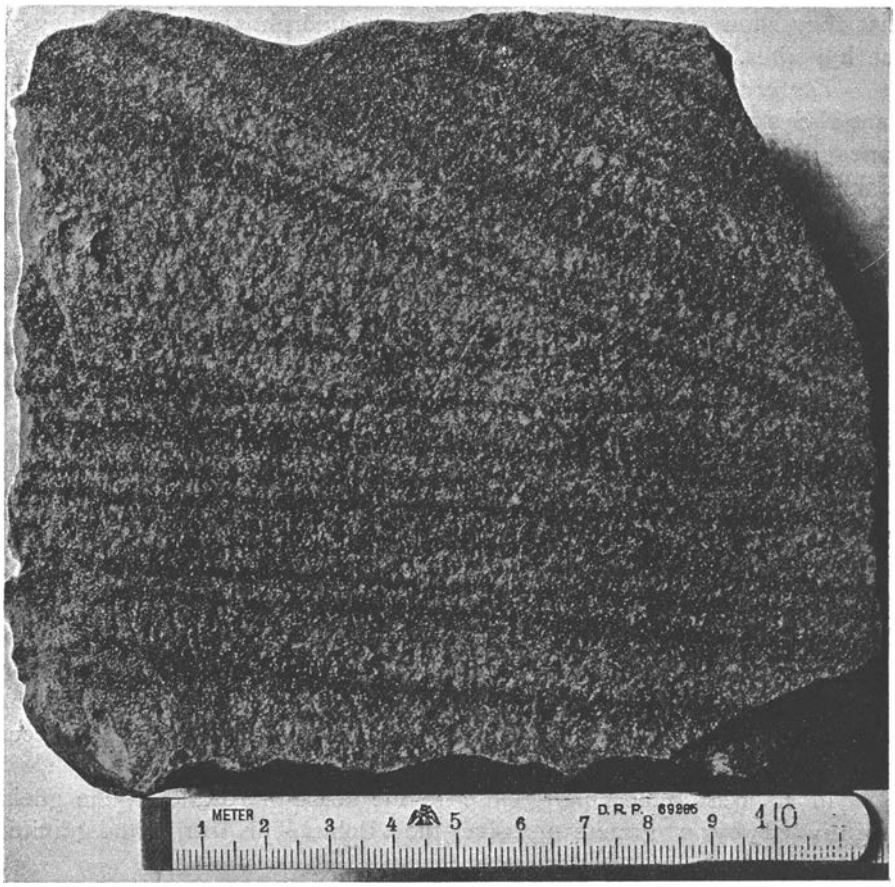

Fig. 8. Archean quartzite from the Åmål-complex, showing current bedding.

The conglomerates, which probably are the first described of the Archean, occur at different horizons and are generally easly recognizable as true conglomerates. The quartzites show occasionally current bedding (fig. 8), well marked by small layers of hämatite. Ripple-marks have also been noted in this rock. The green tuffaceous rocks alternate with the quartzite and are by transition rocks allied to it. The Åmål-complex was folded and metamorphosed already in prejatulian time, and it forms a part of the subjatulian land-surface upon which the Dal-formation was

laid down (p. 20). The complex is intruded by granites which, owing to their relations to the Dal-formation and to the subjatulian denudation, must be regarded as archean or serarchean. The granites have exercised an intense contact influence on the Åmål-quartzite, much resembling the contact phenomena of the Westerwik-quartzite which will later on be described.

The Åmål-complex can be followed several miles northwards from Åmål. In this direction the metamorphism increases, and the complex is covered by gneiss rocks which may be interpreted as overthruded. These overthrusts may probably be referred to the great tectonical revolutions by which the Archean of western Sweden was metamorphosed. Consequently the gneiss-structure of the great western gneiss-district is to be considered as younger than the Åmål-complex.

Another and not less interesting quartzite formation occurs within this great gneiss-region, close to its eastern border, viz. the *Westanå-complex*, first described by G. DE GEER [16] and later on treated in a monograph by H. BÄCKSTRÖM [17]. Referring to the latter treatise for further information, I will here only give a short summary of this interesting complex.

The Westanå-complex is composed of quartzitic rocks, amphibolites, and dense fine-grained gneiss, which are pressed down in the ordinary gneiss-formation (iron-gneiss) of western Sweden. The quartzitic rocks form the uppermost member and are partly pure quartzites and partly muscovite-quartzites, with a more or less strong schistosity. The latter often contain cyanite, andalusite, and otrellite. Occasionally tourmaline, rutile, and hämatite are present in the quartzite, the hämatite forming thin layers, as in the Åmål-quartzite. Conglomerate layers with well rounded, but deformed quartzitic pebbles are interstratified in the muscovite-quartzite. Underneath the quartzite bed there lies a bed of amphibolite, with a maximum thickness of about 100 meters. This rock is interpreted by BÄCKSTRÖM as a metamorphosed diabase or diabase-tuff. The dense fine-grained gneiss which forms the lowest member of the complex represents, according to the same author, metamorphic quartz-porphyrite-tuffs (dacite-tuffs). These rocks occur also as intercalations or alternating with the quartzite.

BÄCKSTRÖM, considers the complex as being metamorphosed partly by tectonical forces, partly by granitic intrusions. The latter should be of greater importance and older. However, it may be suggested that at least a part of the granite massives in this neighbourhood are serarchean and younger than the great folding epoch of the Archean.

The *Horrsjöberg-complex* in northern Wärmland, described by A. SJÖGREN already 1876 [18], shows striking analogies with the Åmål- and Westanå-complexes. The predominant rocks are quartzites and porphyries, both more or less metamorphic and with varieties which are quite similar to the rocks of the two other areas. That the complex is inter-

sected by hyperite is already above mentioned (p. 30). It is very probable that these three areas represent small remnants of a formerly more extended division of the Archean, younger than the iron-gneiss formation in which they have been pressed down, and that they have taken part in the displacements by which the great gneiss region of western Sweden got its metamorphic character.

Finally, a few words may be added about a rock of the gneiss-district which often has been mentioned as indicating organic life in remote archean time. This rock is the bituminous gneiss of *Nullaberg*, which in the older literature has been interpreted as a layer in the great iron-gneiss formation. With our present knowledge about the metamorphic processes by which gneisses are formed, it is evident that an eventually bituminous rock cannot have escaped being transformed to a graphitic one, when exposed to metamorphic forces of a strength sufficient to produce a true gneiss rock. A bituminous gneiss, hence, can hardly prove the existence of organic life in archean time. A graphite-gneiss should be more convincing. It seems probable, after the microscopic examination made by TÖRNEBOHM [19], that the rock of Nullaberg has been a porous microcline rock, which secondarily has been penetrated by a bituminous liquid which later on by oxidation has been transformed to the present pitch-like substance. Besides, the microcline rock does not belong to the iron gneiss, but may rather be interpreted as a sort of pegmatite in which the quartz is wanting and substituted by small holes or pores. Similar rocks, occasionally containing bitumen or calcite, have been found also in other parts of the Swedish Archean. And some of these founds are undoubtedly of igneous origin, f. ex. the so-called »calcite-granites» of Upland.

The great granite-district of South-eastern Sweden (Småland).

The archean district now to be treated, with its generally well preserved igneous rocks, presents a striking contrast to the thorough metamorphic area of western Sweden. Predominating here are *granites* of very varying composition and structures and also of different ages. In the southern part, and in some localities at the northeastern boundary, scattered granite massives occur which may be classified as serarchean, but the main bulk of granites ought to be regarded as older, although they, because of their insignificant metamorphism, often look like younger granites. Basic rocks, diorite and gabbro, and even syenites occur frequently in close connection with some granite types. Manytimes the granites also turn to monzonitic and adamellitic rocks. As the petrography of this granite district is treated at some length by HOLMQVIST in his monograph on the Swedish granites [13], I can here desist from a detailed description. In the following there will be opportunity to lay stress upon some occurrences and types which are of special geological interest.

Beside the granites and the other plutonic rocks, *supracrustal igneous rocks* have quite a large extension in this district, forming lengthened areas with predominant east-western strike, and being enclosed by the granites (cf the map, Pl. I).

The greatest part of these volcanic rocks consists of acid porphyries and associated tuffs. O. NORDENSKJÖLD, in a noticeable monograph [20],

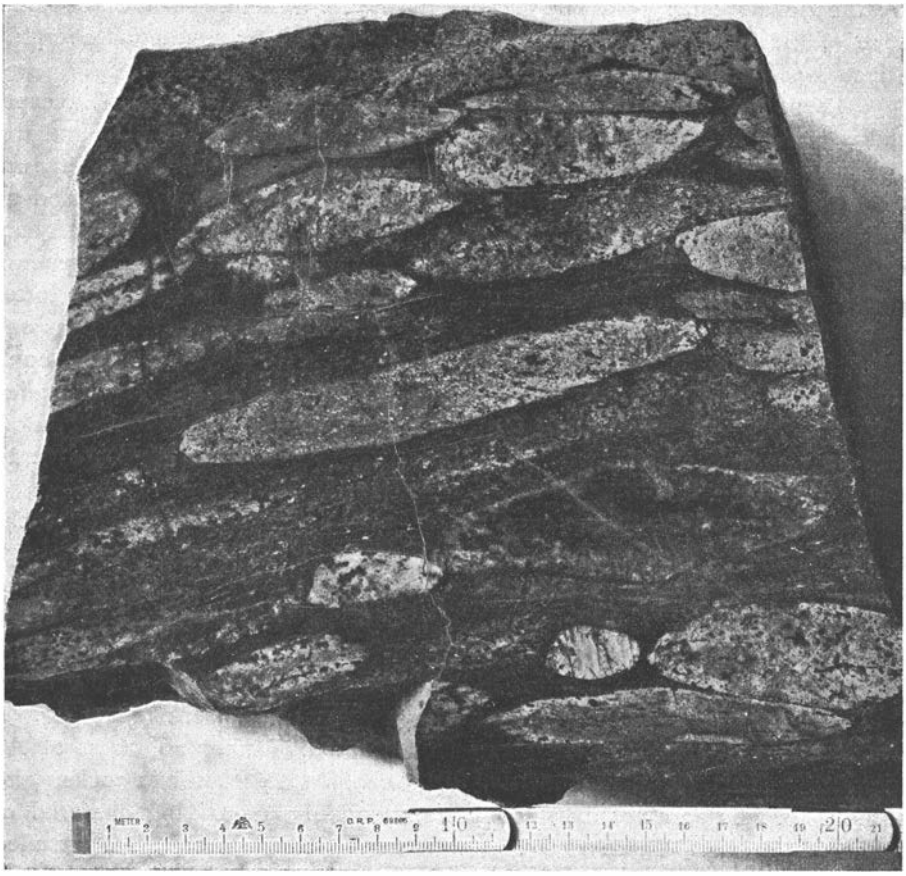

Fig. 9. A pressed archean conglomerate, with pebbles of porphyries, granite, vein-quartz. Malmbäck-complex.

has described the petrography of these interesting rocks and shown that they occasionally have many well preserved primary features, as for instance: fluidal structures, sphärolithes, perlitic cracks, lithophysæ, ash-structures. The primary features, however, are mostly obliterated by metamorphism, and the rocks have often acquired a more or less distinct schistosity, thus grading into the generally more metamorphic rocks, which have been signified as hälleflintas, granulites, leptites.

The relations of these supracrustal rocks to the surrounding granites offer much of interest, but they are not yet wholly cleared up. Although it is substantiated that these granites generally are younger than the adjacent volcanic rocks, it often happens that there cannot be drawn any distinct boundary, inasmuch as the rocks apparently grade into each other quite imperceptibly. This transition may be caused partly by the contact-metamorphic influence of the granite on the volcanic rocks, partly by the development of a fine-grained porphyric structure in the boundary zone of the granite itself, and partly also by later dynamometamorphic effects on both rocks.

Porphyric dikes of great petrographical interest are frequent, especially in the neighbourhood of the contacts between the granites and the volcanic rocks, and they cut them often in a great number, often running tolerably parallel to each other. These rocks can be classified as quartz-porphyries and porphyritic uralite-diabases. The former hold generally great idiomorph phenocrysts of felspar and rounded quartz-phenocrysts, lying in a micrographic or microgranitic groundmass; the latter often contain phenocrysts of plagioclase, which can reach as much as one decimeter in length. Both rocks frequently occur together, forming »composed dikes» or »mixed dikes» in which the basic rock generally occupies the exterior, the acidic rock the interior of the dike. For further information about the petrography of these dikes reference may be made to the papers by NORDENSKJÖLD [20] and HEDSTRÖM [21].

In connection with the supracrustal igneous rocks, metamorphic rocks of sedimentary origin occur in some localities, especially in the surroundings of the Almesåkra-complex. Phyllites and slaty rocks, sometimes alternating with or grading into tuff-rocks, play the greatest part among these sediments; quartzites and calcareous rocks occur more subordinately. Conglomerates have also been found in these archean complexes. A very beautiful conglomerate, with well rounded pebbles of different rocks (fig. 9), lies in the »*Malmbäck-complex*» (southeast of Taberg and west of Almesåkra). This complex consists, further, of dense felsitoidic rocks, with a more or less distinct band-structure, probably containing material of tuffaceous origin. These rocks, as well as the conglomerate, are intruded by an archean granite, and they were already metamorphosed before the intrusion. Thus their referring to the Archean cannot be disputed.

The *western boundary* of this granite-district is not distinct, there is a tolerably broad belt of intermediate character which joins the district to the western gneiss-area. On the whole, the gneiss rocks of this area look more granitic in this belt, and the eastern granites, in their turn, often show gneiss structures, which, however, by some cataclastic features and by the development of sericite and epidote often differ from the typical gneiss structures of the western area. Two distinct cataclastic zones of this kind run in north-southern direction close to Jönköping, one following the eastern, the other following the western shore of the lake

Wettern [22], It is possible that these zones may be referred to displacements which are essentially younger than the terrestrial movements that have metamorphosed the archean rocks of western Sweden.

It is noticeable that the general strike of the rocks in the two great districts is very different, being N—S in the western district, as has already been said, and in the eastern district prevailingly E—W. In the transition-belt, just described, one can sometimes see indications of a gradual change from the latter to the former direction, but, as a rule, it is not possible to decide which of them is the older and which the younger.

At the *southern* end of the granite-district fine-grained, commonly grayish gneisses form a belt which has the strike in E—W and separates the granite area from the southern Baltic coast (see the map). These gneiss rocks, both structurally and tectonically, resemble the rocks of the iron-gneiss area. In the surroundings of the Westanå-complex they join also with this area of which they can be regarded as a ramification to the East. The dip of the gneiss here is generally quite gentle (10—40°) to the North. Approaching to the western gneiss area, one will find that the strike changes to NW—SE, but wether it passes continually into the N—S strike of this area is undecided. Unfortunately the rock is much covered by glacial deposits and swamps, just in the tract where the relation between the two strike directions should be stated. This boundary belt is described and mapped by HEDSTRÖM [23].

The boundary between the granite district and this southern gneiss zone is not distinctly marked, inasmuch as the granites generally become foliated when approaching the gneiss. There exists consequently some analogy in the behaviour of the granite district towards the southern and western districts. The foliation of these granites is previous to the serarchean granites which form some isolated massives in the neighbourhood of the Westanå-complex.

At the *north-eastern boundary* of this granite-district the granites come into contact with an interesting sedimentary formation which is composed essentially of quartzite, quartzitic mica-schists and with them nearly connected felspar-bearing rocks (»leptites»), and also with amphibolites. This formation is known under the name of the »*Westerwik-complex*». The quartzite of Westerwik often shows current bedding and reminds one more of some postarchean quartzites than of archean rocks. Its archean age, however, is proved by the fact that it is intruded by granites which unanimously have been regarded as archean, and must be interpreted as such, with the limiting of the Archean, that is in common use in our country. The intruding granites (especially the coarse, porphyric »Loftahammar-granite») have exercised strong contact influence on the quartzite, and have given rise to interesting contact-rocks which are exceptionally well exposed on the bare rock surfaces of the Westerwik-archipelago [24]. Beside these contact features, a network of granitic veins also often bear evidence of the geological relations between the granite and the sedimentary rocks.

This complex shows much resemblance to the Westanå-formation, above described. Conglomerates are wanting, but andalusite- and sillimanite-quartzites, muscovite-schists, and quartzites with bands of hämatite occur here, as well as in the Westanå-complex. Amphibolites play in the vicinity of Åtwidaberg an important part in a rock series which is a north-western continuation of the Westerwik-formation, and these amphibolites probably correspond to the amphibolites of Westanå. The Westerwik-complex, with its intruded granites, has been strongly pressed and has a more or less pronounced schistosity or foliation, running in the direction NW – SE, tolerably well following the north-eastern boundary of the great granite-district. The pressure has here, as well as on the western side of the granite-district, been especially strong in some thin belts and has performed the granites to dense mylonites. These pressure-zones have hade a great influence on the modelling of the land surface in this tract.

The granite-district now described is destitute of greater *ore-deposits*. Although a number of ore-occurrences are known, only a few have been worked with profit. Except the nickel-ore of Klefva which has the character of segregations in a dioritic rock, the ores of this district are epigenetic and are mostly confined to quartz-veins and crush-zones. Among these the gold-mines of Ädelfors, the copper-ores of Sunnerskog and Fredriksberg, and the mangan-ores of Spexeryd and Hohult may be mentioned. The copper-ores of Solstad, Skrikerum (which also contain selene-minerals), Gladhammar (also with cobolt-minerals), and Åtwidaberg are situated at the boundaries of the great granitic area and ought rather to be referred to the outside of it and to the adjacent gneiss-districts.

The eastern gneiss-district, south of the lake Mälaren.

A considerable district of predominant gneiss-rocks extends from the lake Mälaren in the North to the above treated granite-district in the Southwest, and reaches the Baltic coast in the East, hence forming a triangular area with the corners in the neighbourhood of Stockholm, Wästerwik and near the north eastern end of the lake Wenern.

The most conspicuous rock of this district is a gray *garnet-cordierite-gneiss* with a chemical composition indicating its derivation from a clay-sediment. Sillimanite, graphite, and pyrite are also characteristic components in this gneiss. The femic minerals are generally represented by mica, but amphibole is also sometimes present and is then often concentrated as to form bands or lenses of amphibolite. The structure of this gneiss is commonly banded, the banding being marked mostly by coarse-grained and somewath pegmatitic segregations of felspar and quartz, which alternate with the more fine-grained dark gneiss. The arrangement of the components gives often the rock the appearence of having a rough fluidal structure. Fine-grained, round or elliptic patches of the gneiss

then lie enclosed in a coarser, pegmatitic mass. These patches are often bordered by a thin zone of different composition which, because of its behaviour to the weathering, stands out and forms peculiar scrolls on the exposed rock-surfaces.

Reddish and grayish gneisses of a granitic composition also play an essential part in this district. These gneisses sometimes look like the iron-gneiss of the western Sweden, sometimes they are eyed gneisses with relic granite characters. Some of the gray gneisses are distinctly banded and then they are not always easly distinguished from the garnet-gneiss with which they seem to be nearly connected. The geological relations of the different gneisses of this district, however, are not quite clear, the mapping of them being made before the modern views about the metamorphism.

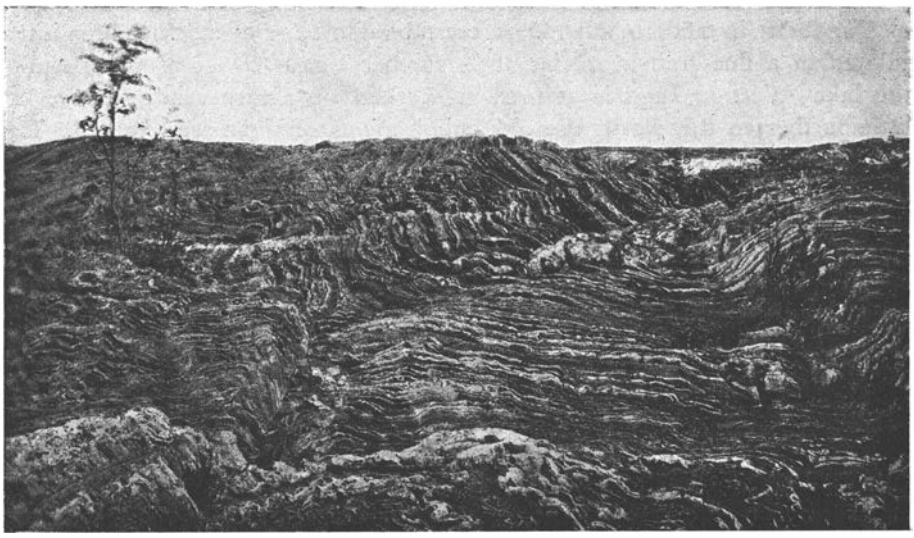

Fig. 10. Weathered surface of a folded limestone, containing layers of fine grained gneiss. Persö, Södermanland.

TÖRNEBOHM, in his older investigations interpreting the greatest part of these rocks from a neptunistic point of view, has endeavoured to establish a stratigraphical succession, which however — as also held forth by TÖRNEBOHM himself — cannot be regarded as thrustworthy. The rocks here have really gone through such violent and sweeping revolutions that the interpretation of their geology offers immense difficulties. It can be suggested that some of the granitic gneisses have as granites intruded the metasedimentary gneisses before or simultaneously to the great tectonical movements which have befallen them.

Limestones are often intercalated in the gneisses, above described, especially in the garnet-gneiss. They are commonly coarse or middle grained marbles and form lengthened bodies or layers which can have an extension of some kilometers. Often they are dolomitic and turn into

true dolomites. Olivine, serpentine, and talc occur abundantly in some varieties, for instance in the renowned Kolmård-marble, in which they give rise to a beautiful *Eozoon*-structure. Other occurrences are characterized by contact-minerals, as spinel, chondrodite, humite, wollastonite, vesuvian, garnet. The limestones, especially the smaller occurrences, are generally rich in silica minerals, and often they alternate with thin layers of fine grained gneisseous rocks (fig. 10). The latter are often broken as to form a breccia of a more or less conglomeratic appearance.

Among the *ore-deposits* occurring in the gneiss-district only a few may be noted in this treatise. Magnetite-ores form lense-shaped bodies in some fine-grained varieties of the gneiss. They for the most part are of the same kind and mode of occurrence as the magnetites of the next district. Copper- and cobolt-ores have been broken since long ago in the limestone of Tunaberg in Södermanland. A considerable band of zincblende is intercalated in a fine-grained gneiss at Åmmeberg, near to the northern end of the lake Wettern, and is at present worked on a rather large scale. A little further to the North the old cobolt-mines of Vena are situated. The ore is in these mines confined to quartz-veins which cross a fine-grained gneiss.

An intermediate position between the limestones and the iron-ores can be assigned to the *eulysite* of Tunaberg and Gillinge. The main component of this rock is a mangan-olivine, and the rock certainly is formed by a metasomatic transformation of a band of limestone, comparable with the transformation in other localities of this rock to magnesian-silicates or to iron-ores, more or less mixed with ferromagnesian silicates. Really the eulysite also turns into a manganiferous iron-ore, rich in mangan-olivine.

The general strike is in this gneiss-district E—W, in the southern part turning to NW—SE, and in the northeastern part to SW—NE. The dip is, contrary to the dip in the western gneiss-district, mostly steep or nearly vertical. In the eastern part of the gneiss area (Södertörn and the archipelago) the dip is, as a rule, to the SE, from which fact it has been concluded that the garnet-gneiss of the mainland is older than the fine-grained and leptitic rocks which form a belt running along the great islands of the archipelago (Utö, Runmarö, Nämdö, Ornö). The immense thickness which must be assumed from this point of view, however, makes it more probable that a system of isoclinal folds and secundary structure planes occur in the gneiss, a suggestion which to some degree is substantiated by the tectonics of the above named islands, where the stratigraphy is less obliterated by the metamorphism than it is on the mainland.

Younger granites, probably for the most part of serarchean age, have intruded the rocks of the gneiss-district and form a number of massives which are often accompanied by pegmatitic dikes. These massives occur principally in the vicinity of the southwestern and northern boundaries of the gneiss area; but also in its interior, for instance in the neighbourhood of Trosa and Norrköping, some small massives are met with. Whether

the splendid »Grafversfors-granite» is a serarchean granite or not, can be disputed. At its boundaries this massive partly looks like the older granites, but on the whole it seems, because of its contact features, to be nearer connected with the serarchean granites.

The relations of the district now in question to the adjacent districts will, for the rest, be discussed later on. In this connection only some remarks about the relations to the southwestern granite district and to the iron-gneiss district in the West may be made.

It has already been remarked (p. 37) that a stripe of quartzites and associated rocks, the Westerwik-complex, extends along the boundary between the gneiss-district and the great granite area. Leaving out of consideration this stripe which, besides, does not continuously separate the two districts, one can say that these districts are connected with each other by intermediate rocks, inasmuch as the granites of the southern district become more or less strongly foliated when approaching the gneiss district, and the gneisses of the latter, in their turn, become more granitic when approaching the great granite area. These features are well illustrated by the surroundings of Åtvidaberg [25] and the archipelago of Loftahammar. Thus it looks that in this wise a real transition exists and that the rocks of the gneiss area are, at least partly, to be interpreted as only a metamorphic facies of the granite area.

In the tract north of the lake Wettern this gneiss-district and the iron-gneiss-district of western Sweden come in relation to each other. Notwithstanding that even here no distinct line of demarcation can be drawn between the two districts, they are to a certain degree separated by a belt in which the rocks mostly have a more granitic structure. These granitic gneisses or foliated granites partly form lense shaped areas or nuclei which towards the exterior gradually become more gneisseous and without distinct boundary grade into the surrounding gneisses. The E—W strike of the gneisses of the eastern district becomes in the vicinity of these gneiss-granites more varying and gradually steals along the direction of their foliation. In a similar manner the iron-gneiss becomes more granitic, and its strike turns in the same direction as the foliation of the same granitic areas. There are in this tract no facts which indicate that these two great gneiss-districts represent different divisions of the Archean. One might rather from the now shortly mentioned correlations conclude that they represent strongly metamorphic facies of the same archean igneous rocks and sediments which in adjacent parts of Sweden have better preserved their primary characters.

The ore-bearing leptite-granite-district of middle Sweden.

As it will appear from the sketch-map Pl. I, this great district can naturally be limited: to the *South*, by the lakes Hjälmaren and Mälaren,

by which it is, on the whole, separated from the last described gneiss-district; to the *West*, by the river Klarelfven and the iron-gneiss-district coming in there; to the *North*, between the Norwegian boundary and the lake Siljan, by the Dala-porphyries, and between Siljan and the Bottnian Gulf, by the great gneiss-area of Southern Norrland. To the *East* the district reaches the sea and embraces the archipelago between Gäfle and Stockholm. South of Stockholm a stripe of leptitic rocks runs through the outermost islands (cf p. 40); this stripe can be regarded as a branching off from the district here under consideration. This district can in some respects be compared with the granite-district of southeastern Sweden. Here, as well as there, granites of different kinds play the greatest part, while supracrustal igneous rocks, sometimes together with metamorphic sediments, occur as belts and stripes between the granitic areas. But in other respects this district has prominent features which are not at all or in a very subordinate degree to be seen in the other district. Notorious characteristics of this kind are, for instance, the richness in this district in limestones and various ores, the generally more metamorphic character of the rocks, among which leptites and gneisseous or foliated granites have a great extent, whereas such rocks occur only scarcely in the other district.

The term »leptite». Before entering upon an examination of the geology of this district it is necessary to make some remarks about the term «*leptite*».

This term was forty years ago introduced by HUMMEL to signify some dense or very fine-grained gneissoid rocks which form a prominent member in the Archean of middle Sweden. However, the term was not accepted by other Swedish geologists. It was exchanged, first for the term »eurite», later on for two other terms, »hälleflintgneiss» and »granulite», the former used in the publications of the Geological Survey, the latter especially by TÖRNEBOHM, in his fundamental works on the Swedish Archean.

These terms, which have caused some confusion among our foreign colleagues, have in the last years, by agreement of the now working geologists in Sweden, been changed for the first proposed term »leptite». [26]. The suitability of a collective term for the rocks in question can be disputed from an absolutely theoretical point of view, inasmuch as this name includes many genetically and structurally different rocks, but at our present stage of knowledge it may be considered as appropriate, especially for field geology and for survey maps, to group these rocks under a common term. The *typical leptites* are dense, fine grained metamorphic rocks which in their chemical and mineralogical composition agree with the gneisses. Micas are generally present, though mostly very subordinately; garnet occurs in some varieties, but is seldom a prominent ingredient. A chemical peculiarity to which was first called attention by

H. JOHANSSON [27] is the predominance in many leptites of soda felspar over the potash-felspars.

Microscopically, the leptites show various structures, but granular and contactmetamorphic structures are by far the most common. In some cases mylonitic rocks acquire a leptitic appearance and have been signified as leptites.

Schistosity and layer-structure are more or less distinctly developed. Salic and femic bands often alternate, thus giving rise to a pronounced banded structure. Seen as hand specimens, the rocks sometimes look like very fine-grained granites and cannot always be distinguished from aplites. The colour of the leptites is varying; grayish and light reddish colours are the most common.

The typical leptites are generally nearly connected with granite massives, bordering them and having the strike parallel with their boundaries. When the granites have a strongly developed gneisseous structure, the leptites also become more gneisseous, and then the boundary between the rocks can be obliterated and is often not perceivable.

The original material of the leptites is very various. Often they are derivates of porphyries and their tuffs, in other cases they derive from sediments, as for instance, from felspar-bearing qvartzites. Aplites and other boundary forms of granites may also in some cases have been transformed into leptites by metamorphism.

To distinguish all these genetically different rocks is in the field work very difficult. Even in the best exposures, as in the coast-tracts, where the rock surfaces generally offer excellent opportunities to study the details, all efforts are manytimes fruitless, because of the metamorphism having obliterated the original features.

Theoretically considered, the leptites, however, may be either metaigneous or metasedimentary, and they may have got their present characters either by contact metamorphism, or by pressure metamorphism, or by the influence of these two forces together. It looks as if the pressure metamorphism had taken place under conditions which were not much differing from the conditions prevailing by contact metamorphism at great depth.

Together with the leptites, and often alternating with them, fine grained amphibolites and syenitic derivates are often met with which can be signified as *amphibolitic* and *syenitic leptites*, just as one speaks of amphibolitic and syenitic gneisses. It may, on the whole, be accommodate to bound the term »leptite» in accordance with the extent of the term gneiss. This analogy, however, ought not to be brought to far, for some gneisses have hardly any equivalents among the leptites. Thus no »veined leptites» and »eyed leptites» which are wholly corresponding with the veined and eyed gneisses are found.

»Eyes», as well relict as grown by metamorphic processes, certainly occur in several leptite varieties, but they are commonly more scattered

and occasional than in the eyed gneisses, in which they have more the character of essential constituents.

A peculiarity with regard to the mode of occurrence of the leptites which is noteworthy is that they, as a rule, occupy continuous areas and not form subordinate layers in rocks of structurally much differing character. Chemically and mineralogically different varieties of the leptites, on the other hand, often alternate with each other, and they include sometimes layers of limestone, quartzite and mica-schist, but a complex of this kind is commonly characterized by its dense, fine-grained structure. At their boundaries the leptites often grade into rocks of other structural character, as well into true gneisses as into non-metamorphic or only little metamorphosed porphyric rocks and tuffs, as will in the following be illustrated by several examples.

From what is now said it appears that the leptites have a regional extent, and do not occur as occasional modifications of other rocks, or — in other words — that they are regional rocks representing definite stages of metamorphism. Because of these features they deserve to be signified with an especial term and mapped with an especial colour on the petrographical maps of our Archean. The circumstance that here and there rocks have been regarded as leptites, which rightly ought to have been signified, for instance, as mylonites or as aplites, cannot be adduced against the usefulness of the term. Mistakes have often been made in the signifying of many other rocks, too, but this circumstance has not been regarded as proving the unfitness of the terminology. Generally speaking, the term in question may be of equal teoretical value as the term gneiss. It has been proposed to include the leptitic rocks in the gneiss term, but then this term should get an extension which could not be desirable, as ought to be understood from the above made remarks on the geology and petrography of the leptites.

The granite-leptite-district of middle Sweden can conveniently be subdivided into three subdistricts: an eastern, a middle, and a western, each of them characterized by its special features.

The eastern subdistrict.

The centre of this district can be placed north of Upsala, and its middle part is represented on the fig. 11. Granites play the greatest part, forming a number of massives, separated from each other by leptites and porphyric rocks. Many of these granites are rich in hornblende and enclose diorite and gabbro massives of a more subordinate extent. In some of the granite areas the rocks are altogether strongly foliated and gneisseous (fig. 12), in other areas the granites are foliated only at the boundaries, as will appear from the sketch map, fig. 11. In some cases the parallel-structure is not secondary, but a primary fluidal or proto-

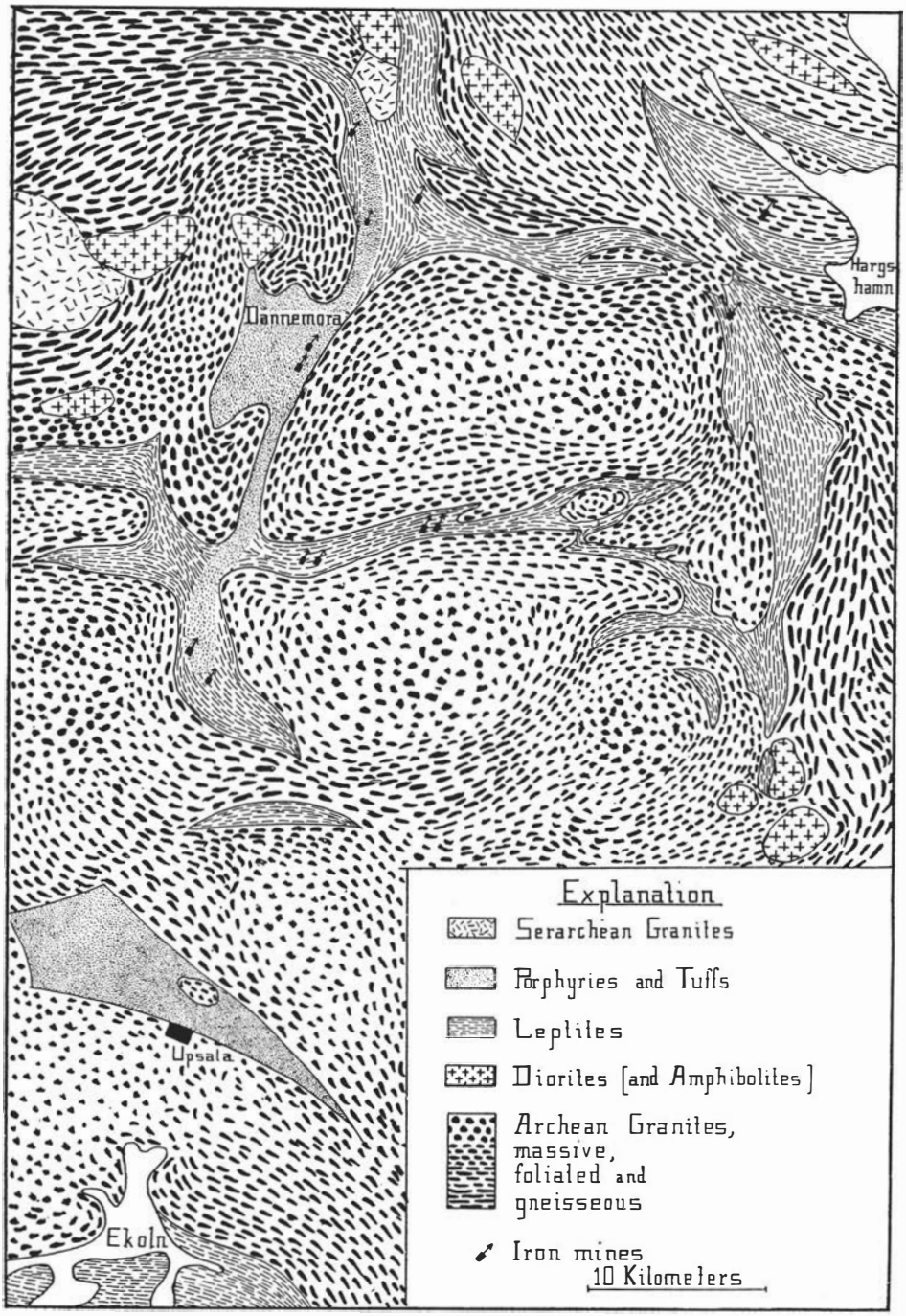

Fig. 11. Sketch-map of the Archean of a part of Upland.

clastic one. Serarchean granite massives, further on, occur, generally accompanied by numerous pegmatitic dikes. The greatest area of this kind is formed by the fine-grained gray biotite-granite of Stockholm (fig. 7).

Contrary to these granites which, as has already in a foregoing chapter been described, represent essentially younger intrusions, with their boundaries running wholly independent of the structure planes of the older rocks, the former granite massives apparently are conformably enclosed by the surrounding leptites, and the strike of the leptites follows the foliation of the granites concordantly. At well exposed localities, where the pressure metamorphism has not been to strong, one can occa-

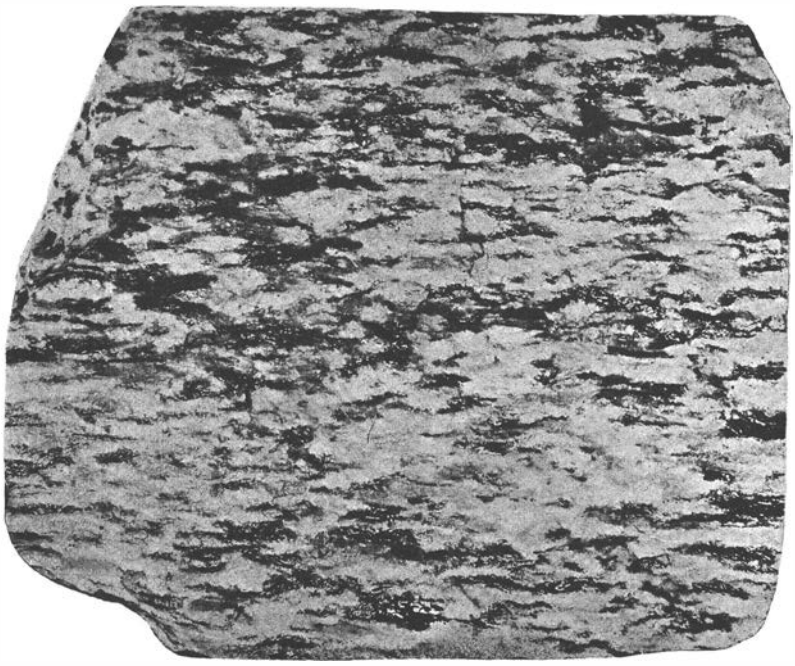

Fig. 12. Strongly foliated granite, Sigtuna. Natural size.

sionally prove that these granites have intruded the leptites and sent »layer-dikes» along their structure planes, but, as a rule, the intrusive character of these massives is obliterated and hardly recognizable.

Close to Upsala a small area of porphyric rocks with associated volcanic breccias occurs which, with regard to its petrographical characters and its connection with the surrounding granites, shows great analogy with the above described porphyric areas in Småland (p. 35). Although the granites are younger than the supracrustal rocks, a transition apparently finds place, the granites becoming fine granular or micrographic near the contacts, and the porphyries on their side, probably by contact influence from the granite, becoming somewath granular or leptitic

in the vicinity of the granite. Furthermore pressure-metamorphism has in some degree contributed to obliterate the original structures of the contact rocks.

There is a further analogy to the Småland-porphyries in the occurrence of dike-rocks in the neighbourhood of the contact, crossing as well the porphyries and their tuffs as the granite. These dikes consist generally of uralite-porphyrite, but mixed dikes also occur which consist of red quartz-porphyries, grading towards the boundary into dark porphyrites which contain uralite as phenocrysts.

In the neighbourhood of Dannemora, north of Upsala, another area of supracrustal rocks extends between the granite-massives (cf fig. 11).

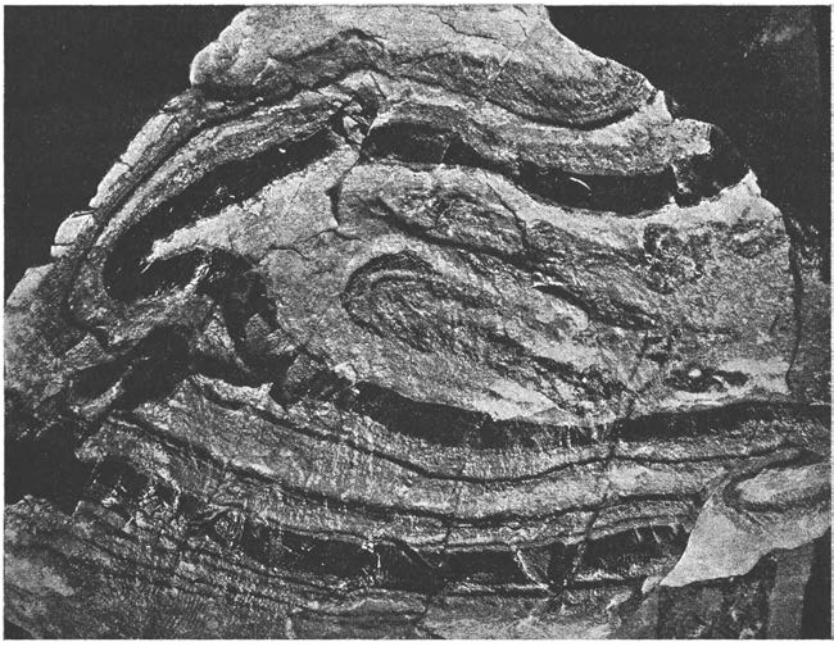

Fig. 13. Banded tuff (»hälleflinta»), strongly crumpled. Dannemora. 1/2 natural size.

This area is composed of leptites, porphyries and tuffs, and in them interstratified limestones and ores. As a rule, the leptites occupy the exterior, the other rocks the interior of the areas. The former ought to be regarded as metamorphic derivates of the porphyries and their tuffs.

In the surroundings of the Dannemora iron-mines the last named rocks have partly their primary structures well preserved. The tuffs are dense, distinctly banded »hälleflintas» which often are strongly crumpled (fig. 13). These banded tuffs alternate with the limestone and are themselves often calcareous.

The magnetite-ores of this area generally form lengthened irregular

bodies with a maximum length of some hundred meters and a thickness of up to seventy meters. The ores are intermixed with, and also enclosed in mixtures of ferromagnesian silicates (»skarn») which are often strongly manganiferous. The iron-ores of Dannemora with their »skarn» lie in a limestone or near the contact between this rock and the porphyries and tuffs (»hälleflintas»). Some of the other ore occurrences, for instance the mines of Ramhäll and Brunna, lie, without intervening limestone, enclosed in the leptites or »hälleflintas».

When the ores are accompanied by »skarn» or connected with limestone, they may be interpreted as metasomatic bodies. Whether the metasomatism may be caused by the influence of the granite-massives in the vicinity, is an open question, but some facts seem to indicate that the ores really could derive from the granitic magma. On this subject the congres-guide C,4 will probably give further information.

The Dannemora rocks are dissected by a number of basic and quartz-porphyric dikes which stand in the same relation to the dominant granites and porphyries as the dike-rocks of the Upsala area, already described. At Brunna the leptite turns, in the vicinity of the ore, to a quartzitic rock (»leptite-quartzite»), and even conglomeratic layers are met with there. The pebbles are petrographically of the same kind as their cement, thus they are best discernible on weathered rocksurfaces, on which they stand out from their matrix by a somewath different colour. It is possible that this conglomerate and some other similar ones, occurring in the leptites, are metamorphic volcanic breccias or pressure breccias (autoclastic conglomerates).

Turning to the East from Dannemora, one can follow the leptitic belts to the coast and to the archipelago of the Åland sea. The rocks are in these belts almost thoroughly metamorphosed, and the porphyries, which at Upsala and Dannemora have preserved much of their primary structures, are here transformed into leptites. The granites are also, on the whole, more gneisseous here than in the tracts just described. Occasionally, however, one can recognize some primary features. A beautiful example thereupon is to be seen in the leptitic belt close to Hargshamn. In a quarry which is situated between the railway station and the harbour, a black, tolerably coarse mica-schist is broken. On the weathered surface of this rock small elliptical spots appear which bring forth, as plainly as one could wish, an amygdaloid structure. Microscopically these spots are found to consist mainly of a granular quartz, and they are not sharply limited from the quartz-grains and mica-flakes of the surrounding rock. On the structure planes of the fresh rock surfaces the amygdaloid spots are either indiscernible or they appear only as indistinct mica-covered knots. Transversely to the schistosity they are generally quite inappreciable on the fresh surfaces. Besides quartz and mica, the rock also contains grains of amphibole. That the rock is a metamorphosed

lava can hardly be disputed, when its amygdaloid structure is seen in its fullest development.

This mica-schist is nearly connected with reddish leptites which partly (west of the railway station) are banded, partly are more massive and occur as ramifying dikes, cutting the schists. These leptites were originally tuffs and quartzporphyries.

In another respect the neighbourhood of Hargshamn is also interesting. It can there be seen how the granite really has intruded the schists and leptites, and enclosed fragments of them. This feature is, as has already been alluded to, quite uncommon, inasmuch as the pressure metamorphism generally has obliterated the original contact relations of the granite massives to the adjacent leptite belts.

In the coast region, south of Hargshamn, foliated and gneisseous granites are predominant, while the leptites and the to them attached rocks are subordinate. Diorite- and gabbro-massives, among which the renowned massive of Rådmansö is the greatest, frequently occur in these granites. They are often transformed into amphibolites where they are enclosed by strongly gneisseous granites, and then they have, as well as the granite-massives themselves, acquired the form of lengthened, lense shaped bodies.

Basic, amphibolitic dikes are very frequent in this tract. Generally they run tolerably parallel with the schistosity of the surrounding rock. Relic porphyric structures are occasionally to be seen in these dikes. The best opportunity to study this dike-formation one finds in the coast cliffs north of Grisslehamn. There also dikes of an acidic character occur which together with the basic rocks form composed dikes.

Turning back to the central part of the subdistrict now in consideration, and going westwards from Upsala or Dannemora, one passes over wide granitic areas, composed of several petrographically different granite-types (»Upsala-granite», »Wänge-granite», »Sala-granite» a. o.) which cannot here be described. On the whole, their geological relations to the subordinately occurring leptitic formations are the same as in the eastern parts of the subdistrict. These granites continue towards the old mining town Sala which can be regarded as a western boundary point of this subdistrict. The porphyries and limestones which come in west of Sala may be referred to the area which will now be described.

The middle subdistrict.

This district forms a nearly circular area with the four mining towns Sala (in the East), Fahlun (in the North) Filipstad (in the West) and Nora (in the South) lying in the periphery. Here leptites and with them associated supracrustal rocks play a greater part than the granites.

Among the *granites* some may be regarded as serarchean, their boundaries being independent of the strike of the leptites which they

have intruded with numerous dikes and of which they have enclosed small and great fragments. It has already in another connection been said that some of these granite-massives are pegmatitic. Other granites of the serarchean group are coarse-grained and porphyric. Partly they become foliated and then they cannot always be separated from the older granites. TÖRNEBOHM holds them for older than the granite-group which I have signified in this treatise as serarchean, but younger than the archean granites of the eastern subdistrict, just described. Really they occupy, with regard to their geological appearence and their stage of metamorphism, a somewath intermediate position between the typical serarchean granites and the older archean granites. The granites of the latter group have mostly in this district a strongly gneisseous structure and occur as lengthened lenses, apparently conformably intercalated between the leptitic areas.

Small *diorite*-massives set up in a great number, especially in the western parts of this district. Although they often are metamorphosed to amphibolites at their boundaries, these massives have still recognizable intrusive contacts with the surrounding leptites and porphyries. Other amphibolites, on the older maps partly signified as diorites, are supra-crustal basic rocks, occurring as intercalated beds in the uppermost members of the leptite-formations.

The *leptite-area* of this district is built up chiefly of *leptites*. These rocks turn into mica-bearing dark *quartzites* and sometimes also grade into or enclose true *mica-schists*. Conglomeratic beds have also been noticed. In the peripheric parts of the district the leptites turn into true gneisses; in the interior, on the contrary, they are less metamorphic and stand in near connection with *porphyries* and *porphyric tuffs*.

Intercalations of *limestone* and *dolomite*, sometimes forming extended belts, are not uncommon. These carbonate-rocks are more frequent in the porphyries and tuffs than in the leptites. The greatest occurrence of limestone, and probably the greatest continuous bed of this rock in the Swedish Archean, has a length of about 40 kilometers, with a maximum breadth of nearly 3 kilometers. It is situated close to the town Nora and runs in the direction SW—NE. Another great occurrence is situated near the eastern boundary of the district and encloses the lead- and silver-ore of Sala. The ore there is an epigenetic concentration of galena (and zinkblende) following a fault which crosses the limestone. Several other limestones of this district are ore-bearing, as will be illustrated below by some examples. The limestone which is represented by the fig. 14 is interstratified in the leptite of Persberg.

One of the most characteristic features of this district is its richness in *ore-deposits*. The most important of them are the iron-ores, but copper-, lead-, and silver-ores have also in past centuries been broken here in considerable quantities. Other ores, as mangan-, zink-, and cobolt-ores, have been of a more subordinate economical significance.

Here only some summary remarks can be made on the geology of the ores; for a more detailed account of them and of the literature there may be referred to the congress-guide C 4.

The *iron-ores* are partly magnetite-ores, partly hämatite-ores, the former being of a much greater importance. They have generally a more or less layer-like mode of occurrence, apparently intercalated in the lep-

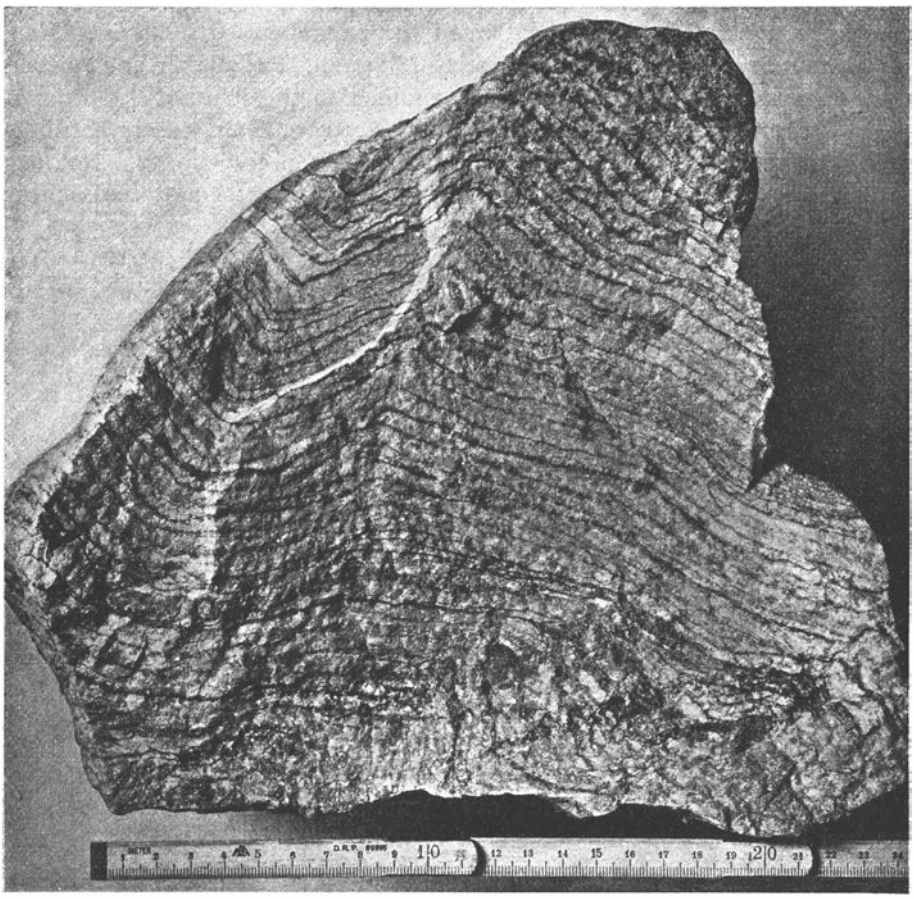

Fig. 14. Limestone, banded and folded. Persberg.

tites, the porphyric rocks, and the limestones, or confined to the contact belt between the last named rock and the silica rocks. As pointed out, especially by HJ. SJÖGREN [28] these ores generally might be of a metasomatic nature. Their nature of epigenetic concentrations is especially clear, when they lie in limestones and at the contacts of these rocks. Of this kind are, for instance, the mines of Persberg, Nordmarken, Klackberget and some other mines in the mining fields of Norberg, Pajsberg, and Långban. In the two last named mines the iron-ore (hämatite) is

partly substituted by mangan-ores. The ore-bodies of the just named mines are generally of a very irregular shape and are often accompanied and enclosed by amphibole- and pyroxene-mixtures (»skarn»). At Långban and Pajsberg these »skarn»-minerals are represented by a number of mangan-silicates (rhodonite, richterite, astochite a. o.). Joints (»skölar») often cross the ores or separate them from their wall-rock. They may, in many cases, have played an important part for the metasomatic processes, in facilitating the circulation of the metal-bearing solutions. Many of the minerals through which the mines Långban, Nordmarken and Pajsberg have been world-wide renowned are confined to the joints.

The quartz-bearing hämatite-ores of Norberg, Grängesberg, Striberg, and some other mines have more the character of true layers. Not only when taken as a whole these ores form belts of great length and uniform

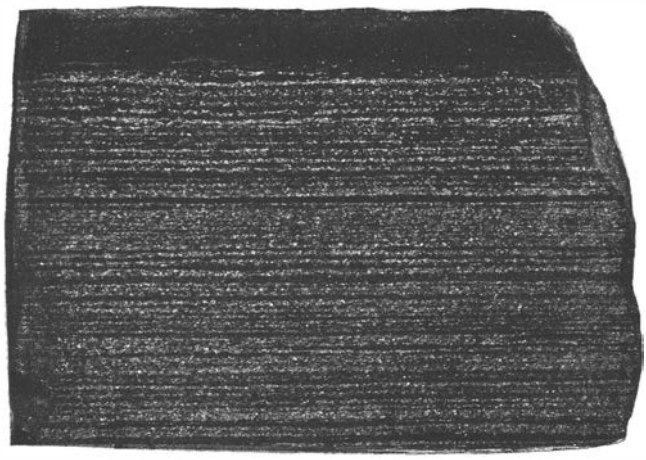

Fig. 15. Fine-banded hämatite. The dark bands are quartz, the light bands are hämatite. Norberg. Natural size.

thickness, but a subordinate layer structure is also often to be seen, marked by alternating thin layers of hämatite and quartz (fig. 15). These ores are not accompanied by »skarn», but are directly intercalated in the leptites, which then, contrary to the gray magnetite-ore bearing leptites, generally are of a reddish colour.

Some hämatite-ores are not granular, but are composed of a thin laminated hämatite (f. i. the Åsboberg-mine near Striberg). The wall-rock is then often a mica-schist. Such an agreement between the structure of the ore and the wall-rock is a quite common phenomenon, which seems to signify that both have got their metamorphic characters by the same processes. Consequently, one might suppose that the ores existed already in late archean time and that they stand in no relation to the present surface or to processes which are connected with the same. From a practical point of view this statement has a certain interest as proving

that the amount of ores — the area taken as a whole — seems to be about the same at deeper levels as in the occasional sections formed by the present surface.

The most important iron-mines of this district are, from an economic point of view, the mining fields of Grängesberg, Norberg, Persberg, and Nora.

Among *the sulfidic ores* of this subdistrict the *copper-ores* are mostly confined to quartzitic varieties of the leptites and to mica-schists. The greatest of these ore deposits, the Fahlun mines, lie in a gneisseous variety of the leptite which in the nearest vicinity of the ore is quartzitic. The epigenetic nature of the Fahlun ores, as well as of the other sulfide-ores, is still more evident than is the case with the iron-ores. It seems probable that the quartzitic wall-rock of the copper-ores is a product of metasomatic processes which have destroyed the felspar of the leptite in substituting it by quartz.

Beside the concentration along joints, by which the richest ore is formed, the sulfides (pyrite and chalcopyrite) have also been deposited as impregnations in the quartzitic wall-rock itself.

Some other copper-mines lie in limestone, f. i. the Håkansboda mines which also contain cobolt-minerals, thus resembling the ore-occurrence of Tunaberg (p. 40). Beside the mines of Sala, already mentioned, there are also some other silver-mines in this district, but they are all of little value.

The question, above (p. 48) touched upon, whether the ore deposits of the leptitic areas in middle Sweden could stand in some connection with the granite-massives, the boundaries of which they often seem to follow, cannot be nearer discussed at this occasion. Although such a connection is very probable for some of the ore occurrences, conclusive facts still seem to be wanting. A great number of ore deposits which in no essential parts differ from the others occur many miles from any granite contact, and these deposits have hardly been formed by solutions which have come from magmatic bodies. The opinions among the now working Swedish geologists about the ore deposits of the Archean are very various and it is delicate to prognosticate which teory there will prevail in the future.

The Saxå-Grythyttan-complex. In the western part of the subdistrict here under consideration, the leptitic rocks are covered by an upper rock-complex, which forms two synclinal areas, separated from each other by an intervening belt of the older rocks. This complex differs petrographically from the leptitic rocks, partly in being less metamorphosed, partly by the composition of the original material. When approaching to this rock-complex, one finds that the leptites (*b*) grade into

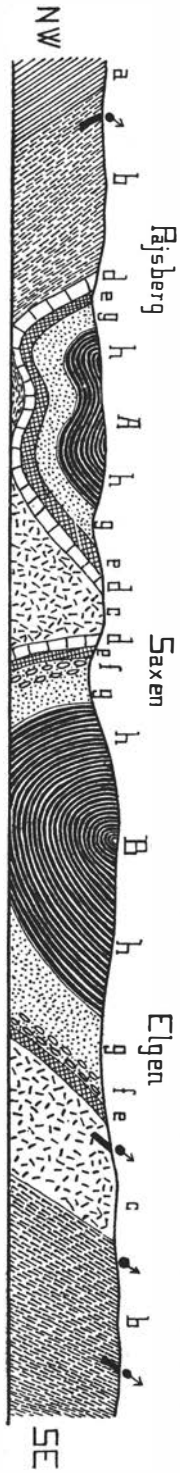

Fig. 16. Cross-section of the two synclines of the Saxå—Grythyttan complex.

slightly metamorphosed porphyries and tuffs (»hälleflintas») which form the immediate substratum (*c*) for this complex. On the western side, however, the leptites continue in typical development close to the complex (cf fig. 16). The undermost horizon of the complex is represented by limestones and dolomites (*d*) and in their bottom contact the mines of Nordmarken, Långban, and Pajsberg are situated. The carbonate rocks do not form a continuous bed, but are partly substituted by the basic igneous beds and tuffs which generally form the next member of the complex (*e*). At some localities the limestone is larded with small fragments of these basic rocks which, in spite of their metamorphism, can by microscopical examination be recognized as scorious lapilli. The eruptions thus must have been partly contemporaneous with the sedimentation of the limestone. Over these rocks there are beds of dark porphyries and tuffs (»hälleflintas») containing near to the bottom small conglomeratic intercalations (*g* and *f*). These rocks sometimes come directly, without intervening beds of the limestone and the basic rocks, just mentioned, over the older porphyries and tuffs which belong to the underlying leptite-complex, and then the boundary between them is hardly discernible.

The dark porphyries and tuffs are in their turn covered by phyllites and mica-schists (*h*) with which they are also connected by intercalations. The uppermost member of the complex is a conglomerate containing various and well preserved pebbles (fig. 17). This conglomerate is wanting in the section represented by the fig. 16.

The Saxå-Grythyttan-complex seems to represent an upper division of the Archean in this district, lying unconformly on the leptites and the porphyries associated with them. With regard to the comparatively insignificant metamorphism that some of the rocks in the complex have undergone, one could incline to separate it from the Archean, but it is not only intruded by serarchean and also by older granites, but it was also folded and metamorphosed before these intrusions took place; their referring to the Archean thus cannot be disputed. It can be suggested that this complex does not represent a division younger than all the leptites and the with them associated rocks of this district, but that it rather could be a less metamorphosed facies, equivalent

to some parts of the leptite-area, where the metamorphism has been stronger, but such a hypothesis is not supported by the general distribution and petrographical characters of the rocks.

Besides, some complexes much reminding one of the Saxå-Grythyttan rocks will be described from other parts of Sweden, and from their geological relations it will appear that the interpretation of these complexes as representing the uppermost supracrustal rocks which are known in the Swedish Archean has the greatest probability.

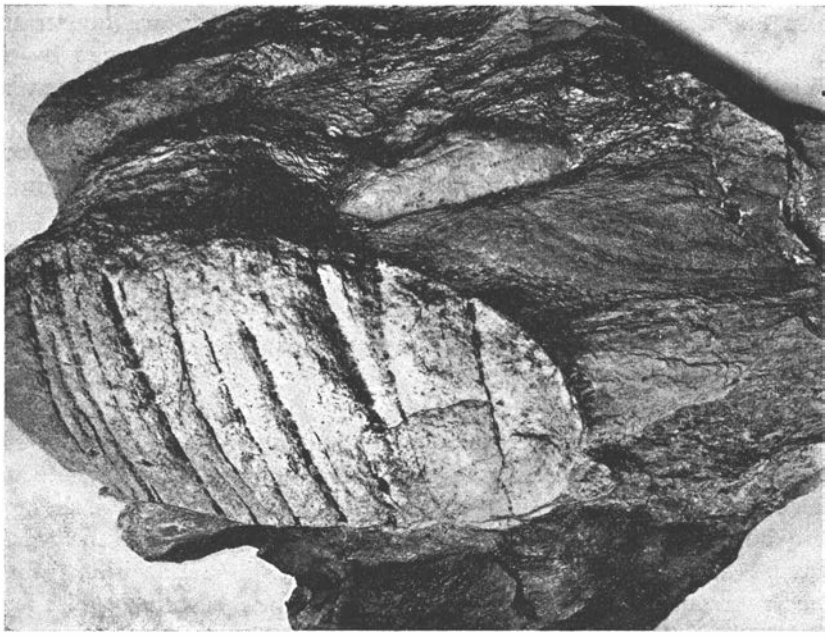

Fig. 17. A pressed conglomerate with a crushed pebble of quartzite. Elfvestorp. 1/2 natural size.

The western subdistrict.

This subdistrict forms a triangular area which is bounded, in the East by the area just described, in the West by the iron-gneiss area and the river Klarelfven, in the North by the Dala-porphyries and the jotnian Dala-sandstone.

This subdistrict differs from the adjacent eastern subdistrict chiefly by the predominance of granites over the leptites and by the scarceness or absence of ores and limestones. Only a few leptitic areas, which, however, reach considerable extension, occur in this country. In some of them slightly metamorphosed porphyric rocks are prevailing over the leptites, and there also varieties which petrographically much resemble the Dala-porphyries are met with. TÖRNEBOHM has really considered

them as a continuation of these porphyries; but as they are intruded by some archean or serarchean granites, a consequence of the opinion of TÖRNEBOHM must be that the Dala-porphyries belong to the Archean (cf p. 17). SEDERHOLM, on the other hand, disputes the suggestions of TÖRNEBOHM and holds the Dala-porphyries for younger than the porphyries of this district.

Quartzitic rocks which are nearly connected with the leptites occur in some tracts of the district. The greatest quartzite area is situated south of Siljan. The rock is commonly dark, and often banded, sometimes it looks like a sandstone. Small layers of conglomerate are interstratified in the quartzite. The archean age of these rocks is proved by their transition to the archean leptites in the neighbourhood and by their relation to the serarchean granites which have intruded into them.

Furthermore, the leptites are close connected with areas of strongly gneisseous granites or granite-gneisses occupying great areas in the interior of the district. The boundaries between these two rock groups seem to be hardly recognizable, because of their obliteration by metamorphic forces. These tracts are, however, only summarily reviewed and little known. Not only the older granites now mentioned are gneisseous, but also the younger, probably to a great part serarchean granites which have intruded the former and the leptites, since these rocks already had acquired their metamorphic characters, are often strongly foliated, especially in the vicinity of the western great gneiss-district. The strike of this foliation runs conformly to the strike of this adjacent gneiss district. Because of the gneisses also often being somewath granitic along the eastern boundary, no distinct limit between the two districts can be drawn, but there is rather a quite broad belt in which a transition from the thorough metamorphic western iron-gneiss to the eastern granite-leptite district takes place. The dip of the structure planes is generally to the East in this boundary belt and in the vicinity. Interpreting the structure as generally a layer-structure, TÖRNEBOHM in his monograph of the leptite-granite district of middle Sweden [29] came to the conclusion that the western iron-gneiss represented an older division than the »leptite-formation». But as there for the modern petrography is no doubt that the structure of the rocks here under consideration is a secondary pressure structure, the conclusion from the features referred to might rather be that the western district represents a more metamorphic stage of the same or similar rock-complexes which further to the East have their primary characters still remaining to a certain extent. It will be opportunity to recur to this question in a following chapter, where the relationship of the different archean districts of eastern Sweden to the great western iron-gneiss district will be discussed.

Relations of the granite-leptite-district of middle Sweden to the adjacent northern and southern gneiss-districts.

As will be seen from the map Pl. 1, the district which has been described above has one great gneiss area to the South, which is already treated (p. 29), and another great gneiss area in the North, later on to be described. The relations of these gneiss areas to the granite-leptite district deserve to be dwelled upon a little, because of their significance for the theoretical views about the Archean of Sweden. As the structure planes of the gneisses, generally speaking, dip inwards to the leptite-granite area, TÖRNEBOHM was even here supported in his opinion that the gneisses of these areas represented an older division of the Archean than the leptites with their associated rocks. However, the secondary character of the structures recognized, the dip cannot be a stratigraphical criterion. And an examination of the limits of these areas under the guidance of the admirable map which TÖRNEBOHM himself has established [29] seems to contradict such an interpretation, and rather suggest that the gneiss areas ought to be regarded as strongly metamorphic facies of the same complexes which are represented in a less metamorphic stage by the rocks of the leptite-granite district. Some facts and features supporting such a manner of viewing may be called attention to.

There are nowhere, whether at the northern nor at the southern limits of the leptite-granite district, any circumstances known, which could be adduced as signs of an unconformity between these rocks and the supposed older gneisses of the adjacent areas. On the contrary, the latter are, in a very noticeable manner, generally connected by intermediate rocks with the leptites and the to them attached granites. Thus a transition belt of greater or smaller breadth exists between the supposed lower and upper divisions of the Archean. Some examples of the manner in which the transition takes place may be adduced.

Going from the central parts of a granite area belonging to the leptite district (not an area of serarchean granite), one finds, in approaching to the great gneiss district, that the granite becomes more and more gneisseous and finally, having lost all remnants of primary structures, becomes transformed into a granular gneiss. The gneiss, which at first is homogeneous, becomes in its turn, when followed further, inhomogeneous, with segregations of salic minerals along the structure-planes, and as final stage the banded or veined gneiss arises which occupies great parts of the southern as well as of the northern gneiss districts.

It is not only the granitic rocks of this district which by intermediate forms are connected with the gneiss areas, but the same is the case with the leptites. Selecting a leptite area which is not separated by an intervening

granite massive separated from the great gneiss areas in the South or in the North, one finds, in approaching the gneiss, how the leptite gradually loses its dense structure and becomes a fine-grained gneiss (»gneisseous leptite» or »leptitic gneiss» = »gneisig granulit» and »granulitisk gneiss» on the maps of TÖRNEBOHM). By the appearance of strips or bands of salic segregations these transition rocks often join with the adjacent banded gneiss. In some cases they seem to be transformed into mica schists.

Generally the transition forms between the leptites and the banded gneisses occupy only small belts, but occasionally they can extend over wide areas, as is illustrated by several occurrences on the map of TÖRNEBOHM [6]. From a study of this map it, moreover, appears that the leptitic gneisses or gneisseous leptites occur not only in the boundary belt between the gneiss districts and the granite-leptite district, but that they also, and especially in the southern gneiss district, occur here an there in the interior. This fact is just in accordance with the apprehension suggested here on the gneiss district as a metamorphic facies of rocks which have been originially of about the same kind as the rocks of the granite-leptite district. The areas of leptitic gneiss should then be interpreted as areas which have not wholly lost all their leptitic characteristics. As a hint of the rightness of this opinion, there also can be called attention thereupon that these leptitic gneisses of the southern gneiss district often are accompanied by granite-gneisses which may be regarded as relics of the granites to which the leptites, as has already been said (p. 43), generally are nearly attached. Another peculiarity which seems to support the interpretation of the veined gneiss as — at least in many cases — a metamorphosed leptite is to be seen in the gneiss itself. In the contorted veined gneisses it is a common feature that the rounded fragments and patches which occur in some varieties of this gneiss have a very leptitic appearance and look as if they were remnants of the rock from which the veined and contorted gneiss has originated.

There has in a foregoing chapter been mentioned a leptitic belt running along the great islands of the archipelago south of Stockholm, which belt can be considered as a ramification from the great leptite-granite area. This belt and its relations to the gneisses which enclose it give also good illustrations of the intimate geological connection between the leptites and the gneisses. For details about the geology and petrography of this tract reference may be made to the papers which will be published soon by HOLMQVIST and myself on the Archean of Utö and Ornö.

Relations of the great western iron-gneiss district to the three above described eastern districts of southern and middle Sweden.

In the previous treatement of the three eastern districts, which towards the West reach to the great iron-gneiss area, their correlation to this area has been summarily described. It has been proved that the characteristic features are obliterated in a broader or smaller boundary zone and that an apparent or real transition finds place, by which the strongly metamorphic rocks of the western gneiss district gradually are substituted towards the East by less metamorphosed rocks. It has, furthermore, been shown that the dominant strike in this boundary zone runs in the length direction of the same, and that east of this zone the strike becomes more undecided and gradually turns to the east-west direction prevailing in the eastern districts.

Nowhere in the 600 kilometers long boundary zone, or in the vicinity of the same, anything has been observed which could suggest an unconformity between the Archean of the western district and the Archean of the eastern parts. On the contrary, all evidences speak for the interpretation of the boundary as a line or a belt where the terrestrial movements which have impressed on the western area its strong metamorphism have been lessened and stopped, thus leaving the rocks of the eastern areas in a more primary condition.

One finds here, in a greater scale, the same features which have above been described as regarding the boundaries of the two eastern gneiss districts to the leptite-granite district. The general conclusion which is to be drawn from these facts seems to be: *the Archean, as it is developed in the southeastern granite district and in the granite-leptite-district of middle Sweden, represents the oldest known archean rocks of this country, and the great gneiss areas in western and eastern Sweden are strongly metamorphosed facies of rock complexes which may originally have been of about the same kind as the granites, leptites, and the with them associated rocks.*

Two restrictions, however, ought to be made. It is not proved, and can hardly be proved, that older rocks are entirely wanting in the gneiss areas; and it is not excluded that in these areas some rocks and rock complexes have existed which have no equivalents among the rocks of the other districts, The above formulated statement, hence, may have its validity only regarding the great leading features of the Archean of this part of Sweden.

Really some differences as to the original composition of the different areas can be suspected by a comparison of the present chemical characteristics of them. There are, for instance, in the leptite-granite district

no rocks of considerable extension which chemically correspond with the wide extended garnet-cordierite-gneiss of the adjacent eastern gneiss area. The last named rock, with its often associated graphite and sulfides, indicates a bituminous clay as original material; but rocks of this character seem to play an insignificant part among the leptitic rocks. Another difference occurs with regard to the ores, which are more frequent in the leptite district than in the gneiss area.

A comparison of the western gneiss district with the eastern districts shows also that some chemical differences exist there which indicate differences in the original composition. The most striking feature in this respect is the absence or scarceness of ores and limestones in the first named district, compared with the richness in some parts of the eastern districts. This contrast, however, is not so significant as it appears at a first glance. By a nearer examination of the western parts of the eastern district, one finds that ores and limestones even there are wanting or sparely present. The general petrographical characters of these parts really prove that they on the whole would acquire the appearance of the western gneiss district, when exposed for metamorphic forces of the same kind and strongness as the forces which have metamorphosed the western district. In this respect there is a noticeable analogy with the relations of the granite-leptite district to the southern and northern gneiss districts, above treated (p. 57). Even there one finds, generally speaking, that the chemical characters of the rocks of adjacent areas show the greatest agreement in the vicinity of the boundaries. This peculiarity, which seems to be a general feature, is easly explained from the point of view which has here been set forth, but the same peculiarity must be considered as an unlikely change, when the districts, as generally has been supposed, represent divisions of the Archean which are of very different age.

The here expressed ideas about the geological relations of the different archean districts to each other differ in fundamental points from the interpretations which TÖRNEBOHM has given in his important maps and treatises on the Swedish Archean, and they may at present be regarded only as a working hypothesis which ought to be proved by a reviewing of some convenient tracts of the boundary belts.

The maps and papers of TÖRNEBOHM were published about thirty years ago, at a time when the knowledge of the metamorphism was still very small. Thus the most important resource for a dechifering of the Archean was at that time still wanting. But one must be imposed by the acute perception and the intuitive power af combination which find

expression in these maps. I do not know any modern map of a great archean area so full of matter as the map of TÖRNEBOHM over »Mellersta Sveriges bergslag» [29]. It is because of my confidence in the correctness of the great lines of this map, with regard to the petrographical features, that I have ventured to put forward the above developed ideas, although I have only an insufficient personal knowledge of the boundary belts, where the key to the interpretation of the geology is to be looked for.

This interpretation, besides, is already some years ago set forth by G. DE GEER in a much disputed paper dealing with a supposed folding of the Archean in algonkian time [30]. DE GEER suggested that the gneisses of western Sweden were recrystallized from an original Archean of about the same kind as the granitic area of south-eastern Sweden. These gneisses were therefore signified as *deuterogeneous*, the other Archean as *protogeneous*. The opinion from which DE GEER started, viz. that the metamorphism of the gneiss area was caused by the same folding epoch which had set its marks on the Dal-formation, was certainly erraneous, but the hypothesis buried a nucleus of truth concealed in his ingenious suggestion. However, the leading geologists in Sweden and Finland which had been especially engaged with the Archean were to much fettered by their theoretical views about the succession of the rocks as chiefly indicated by their grade of metamorphism, as to be immediately influenced by the revolutionary ideas of DE GEER. Really, in the lively discussion which followed the publishing of the hypothesis, DE GEER met a rather unanimous opposition [30]. But it is noticeable that among the speakers at this occasion, HEDSTRÖM, who had recently mapped a part of the boundary between the iron-gneiss district and the eastern granite district, expressed his agreement with the views of DE GEER. Besides, it may be noted that HOLMQVIST later on in his suggestive theoretical papers on the Swedish Archean [31, 32] has at different occasions put forward ideas going in the same direction. As to the time for the folding and metamorphosis of the western gneiss district, however, DE GEER has not gained adherents. —

Beside the theories here referred to, two other attempts to interpret the contrast between the eastern and western Archean of the Southern Sweden may be mentioned. NATHORST, in a paper published already 1886 [33], called attention to the straight running boundary between the two districts, and suggested that there was a great fault. The hyperites, which in a very striking manner are attached to the western side of the boundary (cf p. 30), should then have been intruded in connection with the forming of the fault, and the western area should have been sunken in relation to the eastern area. As a consequence of this hypothesis, the western gneisses should be younger than the granites and porphyries of the eastern district and should once have covered them, but later on have been removed by the denudation. This hypothesis, which placed the thorough metamorphic gneisses in an upper division of the Archean and

the porphyries of Småland in a lower division found no sympathy among the petrographs. BÄCKSTRÖM on the other hand, in his monograph of the Westanå region [17], published 1897, suggested that the great hypothetical dislocation of NATHORST rather might have taken place in an opposite sense and that, hence, the eastern area was the sunken area, and that the great granite massives of this area were intruded in the supracrustal rocks just in connection with this displacement. The absence of supracrustal rocks on the western side of the supposed fault should then find its explanation by their removal by denudation, and the iron-gneiss area should represent an older division of the Archean, exposed because of the same denudation.

Against the fault hypothesis, however, the geological features of the boundary speak, inasmuch as the boundary has not at all the character of a fault, but is, as has already been demonstrated in preceding chapters, a broad transition belt between the two districts. It is principally because of this feature which always distinguishes the boundaries between the metamorphic gneiss district and the less metamorphosed granite-leptite districts, that the views developed in this paper on the different districts as different metamorphic facies of the Archean, not as different chronological divisions, seem to be preferable to the fault hypothesis.

The Bottnian gneiss district.

The predominant rocks in the coast provinces of Norrland, from the above described granite-leptite-district in the South to the Skellefteå river in the North, are gneisses of different kinds. In the southern part, and especially in the interior of the province Hälsingland, reddish eyed gneisses with transitions on the one side into foliated granites, on the other into even-granular gneisses have a wide extension. Hyperites are also present in this area which in some respects remind one of the hyperites of the gneiss district of western Sweden. It can also be mentioned that rock varieties of the gneiss itself occur which may be compared with the Warberg-gneiss (p. 29). Such a pyroxene-gneiss or gneiss-granite has been found, for instance, in Järfsö. Garnet-gneiss occupies considerable areas between Umeå and Skellefteå and between Gäfle and Sundsvall. The banded gneisses in the southernmost part of the district (cf p. 57) are also sometimes garnetiferous. Limestones and iron-ores are confined mainly to some smaller areas of fine-grained leptitic gneisses in the same part.

Between Sundsvall and Örnsköldsvik, the middle part of the district, the rocks differ considerably from the gneisses of the southern and northern parts. They have also on the survey maps been distinguished with especial colours and have been regarded as younger than the gneisses above mentioned [34, 35, 36, 37]. Partly, they have been compared with

the leptites of middle Sweden, with which they, however, cannot be paralleled. In their least metamorphic forms they are generally fine grained dark schists, varying between mica-schist and amphibolite. Varieties consisting essentially of quartz, with the biotite very subordinately present, also occur. Transversely to the schistosity they look like a dark quartzite. Andalusite and disthene are occasionally present in these schists. Iron-sulfides often occur abundantly and give the rock surfaces a rusty covering. Interesting concretionary bodies which might be compared with the concretions in recent calcareous clays and marls (»marlekor») have been found in a dark fine-grained mica-schist in the vicinity of Sollefteå and at some other localities. A conglomerate, or possibly a metamorphic tuff breccia, occurs near the lake Locknesjön, together with leptitic and amphibolitic schists which might be referred to the complex in question.

The schists now described represent a comparatively slight stage of metamorphism. When they have been intruded by the serarchean granites which have a wide extent in their surroundings, they have often been so intricately mingled with granitic matter so that they have been transformed into veined gneisses, or they can have been in such a degree resorbed by the granite magma that they only appear as inhomogenities, strips and contorted patches in the granite. These rocks have on the survey maps been signified as »granite and gneiss mixed», a signification which is so far somewath misleading, as the enclosed rock is not gneiss, but one of the above described schists.

In the westernmost part of the province Hälsingland, there is a small area of supracrustal rocks, the *Loos-complex*, bounded partly by the gneiss above described, partly by a younger granite (the »Rätan-granite»). The complex is composed chiefly by metamorphic schistose tuffs and porphyries, and of basic amphibolites, with still perceptible amygdaloid structure. Conglomerates and tuff-breccias are subordinately intercalated. On the whole, the complex reminds one of the Grythyttan-complex. It is folded in the same direction (NW—SE) as the strike of the older gneiss. In the amphibolites of Loos the old *cobolt-mines* are located, where the element *Nickel* first was discovered (by CRONSTEDT 1751).

A little to the South from the Loos-complex, on the boundary between the gneiss and the Dala-porphyries, there are some very small areas of quartzite and sandstone, nearly connected with some porphyric rocks of undecided age. It may be suggested that these areas belong to the Loos-complex, but it is also possible that they are associated with the Dala-porphyries. Their relations to the serarchean granites are not known.

The serarchean granites of middle Norrland.

The greatest continuous granitic areas of Sweden are situated in the interior of Norrland, between the Bottnian gneiss district in the East and

the Silurian in the West. Smaller granite massives of the same petrographical characters, moreover, occur in the surroundings of this great granite area.

The most extended granite of this group is the coarse-grained, porphyric, gray or reddish granite which after the lake Refsunden in eastern Jämtland often has been named the »Refsund-granite». This granite is commonly a biotite-granite, especially characterized by its great porphyric Carlsbader twins of microcline, reaching 3 to 6 centimeters in length. Hornblende is present in some varieties which, by their subordinate quartz, turn into syenitic rocks. Often the porphyric microclines become more scattered and at the same time smaller, and the rock suddenly turns into an even-grained granite of about the same kind as the independently occurring massives of fine-grained granites which in some tracts of Norrland represent the serarchean group. South of Bräcke (Dysjö), in the vicinity of Örnsköldsvik, and at many other localities this connection between the two types is to be seen. The fine-grained granite occurs, besides, as dikes which cut the porphyric granite and the schists. To the serarchean granites also the muscovite-granites of Ångermanland are to be referred. They form a number of small massives cutting the schists already described. It is probable that this granite represents a magma which has contained much pneumatolytic matter, and that just because of this, the metamorphic influence on the schists often has been unusually strong.

The southernmost part of the great granite district consists of a red, porphyric, titanite-bearing granite, »Rätan-granite», which generally differs distinctly from the northern Refsund-granite. The Rätan-granite differs from all the described serarchean granites by some characters which, on the other side, approach this type to the granites belonging to the Dala-porphyries. Miarolitic and micrographic boundary forms are such characters. It must be considered as dubious, whether the Rätan-granite is a serarchean granite, or whether it is nearer connected with the Dala-porphyries (cf p. 16). Possibly it will appear by a closer examination of this great area, that two or three granites of different ages have been comprised under this name.

The Archean of northern Norrland.

With northern Norrland is in this connection understood the whole part lying north of the Skellefteå river, which from a geological point of view forms a natural boundary. The southern gneiss and granite districts reach to the vicinity of this river, and northwards from the river the Archean appears with another, quite differing development. Some similarities can, however, be found with the granite districts of middle and southern Sweden. Thus granites also here play an important part, forming a number of considerable areas, and between them supracrustal rocks of different kinds occur which sometimes, with regard as well to

their petrographical characters as to their relations to the granites, remind one of the supracrustal rocks in Småland and middle Sweden. But, on the other hand, there are differences which give this country its peculiar character. Very striking is the often slight metamorphism of the rocks, which could suggest that they were not archean but much younger. Their referring to the Archean — in the sense used in this treatise for the term Archean — is founded, partly on their relation to the serarchean granites already described, partly on their relation to the upper precambrian formations of the highlands in the West.

Here and there, however, the rocks are more metamorphic and look like the ordinary Archean. At many localities the different stages of metamorphism can be followed from the not at all metamorphosed shales, sandstones, and conglomerates to the thorough recrystallized mica-schists and gneisses. It may, however, be remarked in this connection that there also occur gneiss areas which probably represent older divisions of the Archean, but their geological relations are for the most part not established.

Of this vast district, more than half of which, because of the desolateness of its nature and the nearly continuous covering with glacial deposits and peat-bogs, offers great difficulties for the surveyors, only some restricted areas have been explored more into details. Such areas are the surroundings of the great ore-deposits of Kiruna and Gellivara, and even some parts of the Skellefteå-complex. The former will be treated in especial monographs which, it is to be hoped, will be published in the immediate future. They can therefore be dismissed summarily att this occasion. As to the last named complex, which long ago has been studied, especially by the writer, there is still some field work left, before the prepared monograph can appear. For this reason I will here give a somewath fuller account of that area.

The Skellefteå-complex is located close to the northern boundary of the serarchean granite district of middle Norrland (cf the map, fig. 18). The Skellefteå-river flows through the southern parts of the area, the Byske-river through the northern part, both rivers near their mouths following the boundaries of the same. From the Bottnian Golf the area extends in northwestern direction far into Lappland, and sends ramifications to the North, by which a junction with the analogous complexes in the surroundings of Kiruna seems to be established. The eastern part is traversed by the railway, between the stations Kusfors and Långträsk. The station Jörn is a suitable starting point for excursions in the middle part, Skellefteå for the eastern, and Glommersträsk or Siksjö for the western parts. Långträsk and Myrheden are well situated for excursions in the north-eastern boundary tract.

Petrographically the complex is exceedingly various. Not only a great number of igneous and sedimentary rocks participate in the composition, but even the different stages of metamorphism contribute to the diversity. Generally speaking, this area can be subdivided in an *eastern*

or southeastern part, characterized by the predominance of schists, slates, and shales, and a *western or northwestern part,* composed chiefly of igneous rocks, as well plutonic as supracrustal, and with them alternating conglomerates and sandstones. Both these parts are nearly connected with each other, inasmuch as conglomerates and tuffs from the West alternate with the shales of the East, thus giving rise to a transition-zone, as is schematically illustrated by the map. The shales continue along the southern boundary of the complex further westwards than in the other parts, as is also to be seen from the map.

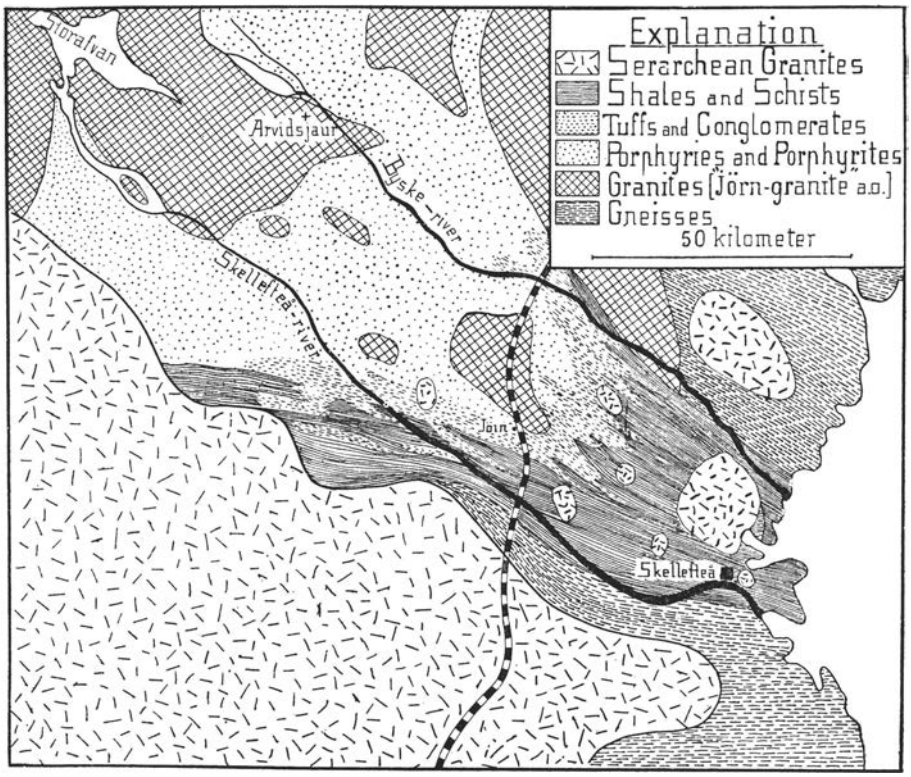

Fig. 18. Sketch-map of the Skellefteå-complex and its environs.

Serarchean granites of the Refsund- and Stockholm-types form a number of massives which have intruded the Skellefteå-complex. They can be regarded as outposts from the great granite district in the South, which also comes into contact with the complex on a long stretch, west of the railway. The boundaries of these granites run wholly independent of the strike of the schists, and numerous dikes and veins of the granites are met with in them. The contact influence is generally not very strong and does not reach far into the surrounding rocks. Enclosed fragments of the schists, which occasionally become very great, have often not lost their

previous schistosity, except close to the granite. Fragments of the carboniferous shales have been, partly or wholly, transformed into hornfels, and, at some localities, they have been absorbed by the granitic magma and have recrystallized as basic inclusions. In the porphyric coarse-grained granite, these inclusions appear as dark spots which often contain the same porphyric felspars as the granite itself.

The manner of occurrence of the serarchean granites is illustrated by the fig. 19. The granite there is regularly banked, and the banks lie nearly conform with the surface of the dome-shaped mountain, from which circumstance one possibly can suggest that the mountain represents a laccolithic mass which has been exposed by denudation.

Schists, slates, shales, and limestone. In the vicinity of Skellefteå, at the southern boundary of the complex, a reddish or gray, sometimes distinctly banded, coarse and middle-grained gneiss with amphibolitic intercalations forms the substratum of the complex. Immediately over this gneiss a crystallinic *limestone* occurs, forming the bottom layer of the complex. Although reaching a considerable thickness, the limestone does

Fig. 19. Section through the Skellefteå-complex near Skellefteå. *a* older gneiss, *b* limestone, *c* schists, *d* serarchean granite. Length of the section about 8 kilometers.

not form a continuous horizon, but is confined to some few kilometers length along the southern boundary. Another occurrence of this rock lies north of the Kåge-river, about 20 kilometers from its mouth, there always dipping outwards from a small circular area of a peculiar, strongly pressed granitic or monzonitic rock. The limestone lies either directly on this rock or is separated from it by a thin belt of a leptitic rock. The granite is close to the contact schistose and contains small strips of calcite. No trace of a bottom-conglomerate or weathering-breccia has been found, and the relation of the granite to the limestone is somewath dubious. However, there is the greatest probability that the granite here is older than the limestone. No other occurrences of limestone than the now mentioned are known from this complex, but some calcareous silicate rocks seem to represent the limestone at some other localities.

The *schists* are of various kinds. Quite coarse-grained black mica schists, alternating with amphibolitic ones, occur chiefly in the easternmost part, in the vicinity of Skellefteå, where they are intruded by the granite (fig. 19). The strike of the schists is there WNW—ESE, and the dip is vertical or steep. North of Skellefteå the schists become contorted and have partly the character of veined gneiss because of granitic intrusions.

Graphite and ferric sulfides are very frequent accessoric components in the schists, which originally may have been bituminous shales and marls.

Going to the West from Skellefteå, one finds that the schists become more slaty and phyllitic. Often they contain nodules of cordierite. Occasionally, for instance close to the river bridge of Krångfors, the schists contain concretionary bodies, which look like the pebbles of a conglomerate. They differ from their matrix, which is a black mica-schist, by their wants of cordierite and by the presence of great prisms of a pale-green hornblende. Some of the concretions have a concentric structure.

In the interior of the area (Waruträsk—Kågeträsk—Tarsnäs) the metamorphic characters vanish and the rocks can be signified as *shales*. They are often very rich in carbon, and then they look like the cambrian alum-shales. On weathered rock-surfaces there is sometimes to be seen a distinct band structure. They contain occasionally banks of a dark or black banded quartzite. Ferric sulfides and arsenic-kies are very common in these shales, as well as in their metamorphic equivalents, already described. When coming in contact with the serarchean granites, the shales turn into hornfels.

Going further to the West and approaching to Jörn, one finds that felsitoidic tuffs, dense amphibolites and conglomerate beds begin to be interstratified with and gradually displace the shales. Along the southern boundary of the complex, however, the shales reach further to the West (Norsjö and Malå), there also alternating with conglomerates and tuffs. East of Holmträsk (Norsjö) the shales contain a conglomerate with pebbles of a green amygdaloid rock, probably to be interpreted as volcanic bombs and lapilli of an andesitic lava. These rocks, at the locality just named, have been intruded and contactmetamorphosed by the great southern massive of serarchean granite.

Sometimes one can also find isolated pebbles of igneous rocks lying in the fine black shale. One porpyritic pebble of this kind was in a peculiar manner impregnated with a fine carbon powder which must be supposed to have penetrated the stone in the form of some sort of hydrocarbon originating from the bituminous shale.

Conglomerates and *sandstones* occur in the middle part of the area at many localities. They are extremely various with regard to their composition and to their degree of metamorphism. Often they are nearly associated with, grade into, or alternate with beds of tuffaceous origin. Probably some of them may be interpreted as hardened beds of volcanic mud. Conglomerates, formed by the weathering-breccias of an old land-surface, have been found only as boulders, but are not known as bottom-beds. The greatest part of the conglomerates of the complex can be regarded as intraformational, inasmuch as no unconformity of general significance is known in the same.

The conglomerates have their greatest development between Kusfors and Wargforsen, in the mountains north of the Skellefteå-river. They are there very polymict and vary from one bed to another. Pebbles of red porphyric and micrographic granites and of other granites are predominant in some beds. One granite type is characterized by rosa-coloured quartz-grains, but in other respects it agrees with the Jörn-granite, later on to be described. This peculiar colour seems to be secondary and caused by dynamometamorphic influence, since the same is not uncommon in quartz rocks which have been moderately pressed. Beside the granites, porphyric rocks play an important part in these conglomerates. Among them several varieties occur which agree with the western porphyries of the complex, while other varieties may be regarded as more superficial modifications of them. They look like trachytes, rhyolites, and andesites, and they may partly have been glassy, In a slice of ordinary size one can often distinguish many different types of these rocks among the fragments and small pebbles. The cementing matter of the conglomerates is very various. Grit, small porphyric fragments, quartz-sand, and small flakes of shales and schists form the groundmass, in which the greater pebbles of granite, porphyries, quartzite and other rocks lie embedded. Sometimes there are also met with great flat angular blocks of a reddish sandstone, scattered among the smaller pebbles. Possibly they represent thin beds of sandstone which have been intercalated in the conglomerate and later on have been fractured in pieces. Really such beds of a red or grayish sandstone occasionally occur in the conglomerate (for instance near Svansele, west of Kusfors). These sandstone beds, as well as the blocks just mentioned, are thorough clastic and often show distinctly current bedding.

Igneous beds, porphyries and porphyrites, also alternate with the conglomerate, for instance in the mountains NE of Wargforsen. In the mountain Dömansberget, a little further to the East, the conglomerate differs from the now described type by the predominance of basic rocks among the pebbles and likewise by a basic groundmass.

Another tract, interesting by its conglomerates, is situated east of Jörn, along the road between Bergnäs and Svanström. Some of these conglomerates are felsitoidic in their matrix as well as in their pebbles and nearly connected with porphyries and their tuffs, others are basic amphibolites and recrystallized so that nearly every trace of their original nature is removed. On the weathered rock surfaces, however, the pebbles usually stand out by differing colour, and the character of a conglomerate is in this case undisputable. This conglomerate alternates with slates, shales, and tuff beds. The last named can be, as handspecimens, mistaken for dark, hard shales, but microscopically, and on weathered surfaces their fragmental nature and igneous origin can be proved. Noteworthy is an occurrence (at Hvitberget, Nyholm) of a fragmentary rock which contains fragments of a greenstone, lying in a matrix of carbonate. Although more

metamorphic, the rock looks very like the peculiar tuff rock of Saxhyttan, described in a foregoing chapter (p. 54). The rocks now described, east of Jörn, are intruded by small massives of serarchean granite (for instance south of Kankberget, near Åskulla).

Among other occurrences of conglomerates in the Skellefteå complex there is a locality, north of Åsele (Byske-river), which deserves to be mentioned. The rock is metamorphosed to a gneiss in which the pebbles often appear only as indistinct strips or inhomogenities. On fresh surfaces the conglomeratic character can hardly be recognized, but on the weathered surfaces it can appear quite distinctly. Moreover, some quartzitic pebbles are met with, which have preserved their forms very well. The rock turns into, or is interstratified in a distinctly banded fine-grained or leptitic gneiss which is composed of quartz (very abundant), plagioclase, biotite, epidote, hornblende, and magnetite. The structure is characterized by the mosaic form of the quartz and felspar and by the development of the femic minerals as neadles or flakes which either cause by their arrangement a prominent schistosity or lie extended in all directions. The strong metamorphism may be caused by the pressing down of the rock in the older Archean with which it comes into contact at this locality.

Supracrustal igneous rocks have a great extension in the middle and western part of the complex, and they are there over wide areas the dominant rocks. Massives of plutonic rocks which, at least partly, are nearly connected with the supracrustal rocks occur here and there in this area (see below).

Among these rocks one finds a very representative series, from the most acidic quartz-porphyries to basic porphyrites, and each type is developed with various structures and accompanied by tuffs and breccias.

The *quartz-porphyries* are very various in colour (reddish, brown, dirty green, gray to black, yellowish), in the amount and size of their phenocrysts, in the groundmass (microgranitic, felsitic, micrographic, crypto-poikilitic), and in other structural features (fluidal, amygdaloid, a. o.).

Reddish gray *syenite-porphyries*, often strikingly similar to the porphyries of the Kiruna-complex, have also a wide extent and are by transition forms connected with the quartz-porphyries. A variety has been found which contains amygdaloid spots composed of hornblende and quartz. Another variety is rich in magnetite and has segregated a small band of iron-ore, a diminutive Kiruna.

Labradore- and *uralite-porphyrites* occur in a great number of varieties. Dense, sometimes amygdaloid greenstones, tuffs and breccias are associated with them. These femic rocks often alternate with the salic porphyries. A beautiful illustration thereupon is the mountain Hemberget (west of Myrheden), where a repeated alternation of different labradore- and uralite-porphyrites with fluidal felsitic quartz-porphyries is to be seen. In the vicinity of Wargforsen a similar alternation is met with, in which, however, also tuff rocks and conglomerates take part (cf p. 69). *Dike-facies* of the

above mentioned porphyric rocks also occur; they are commonly easily distinguished from the former by the size of their phenocrysts.

Generally the porphyric rocks are quite unaltered by metamorphic forces. But at the boundaries they are often pressed and sheared. Near

Fig. 20. Quartz-porphyry showing fluidal structure on the weathered surface. Hemberget. Nat. size.

to the Station Kusfors a quartz-porphyry, with great phenocrysts of a bluish quartz, has by the pressure got a pronounced gneissoid structure, but the original character of the rock is microscopically easily confirmed, because of the quartz having its corroded forms still preserved.

Plutonic or intrusive rocks form a number of massives in the western

part of the area. Only the greater among them have been marked on the sketch-map fig. 18. Prevailing are granites, the intermediate and basic rocks occurring chiefly as subordinate modifications of the granitic magma. A considerable massive of a middle to coarse-grained granite, generally of reddish colour, extends in the vicinity of Jörn. The quartz forms round bluish grains, the prevailing felspar is an ortoclase-pertite. Micrographic intergrowths of the quartz and the felspar is common, but not much developed. The femic minerals (mica and magnetite) are generally very subordinate and fill the interstices between the salic minerals. Miarolitic holes are occasionally to be seen. The rock reminds one very much of the subjotnian alcali-granites, but is a little more pressed than these rocks.

Some pebbles of the conglomerate west of Jörn (p. 69) derive from this granite which consequently is older than that conglomerate, and also older than the serarchean granites which have intruded the conglomerate complex.

The geological relations of this granite massive to the surrounding porphyries are hidden by the continuous covering with glacial deposits. Further to the West, in Arvidsjaur, granites of similar character have a wide extent, there nearly connected with red micrographic granites and granite-porphyries. Syenitic and monzonitic modifications are also met with in this extended granite area. Whether some light gray or reddish porphyric granites occurring in the same area may be allied with the types now described, is not decided, but it seems most probable that they belong to the same group.

In the vicinity of Hemberget and Siksjö a flesh-red, distinctly micrographic granite or granophyre forms a number of mountains. These small massives, which are nearly connected with the surrounding porphyries, have not been marked on the sketch-map. *Diorites* occur as modifications of the granite, especially in the environs of Myrheden. Both these rocks often show very complicated contact features, with mutual resorption-phenomenas, and often they are so intricately interwoven with each other, that their relative age hardly can be decided. Beside hornblende- and augite-diorites, also a quartz-mica diorite, with mica as the only femic mineral, has been found (Ålså-bridge, south of Myrheden).

Gabbros, and with them geologically equivalent diabases occupy some smaller areas east and west of Myrheden. These occurrences may be regarded as basic modifications of the diorites in the same tract. At Näsberget a *titaniferous magnetite* has segregated in the diabase, forming bands and banks which run conformly with the fluidal structure of the rock, thus resembling the iron-ore of Ulfö described in a previous paper (11). The diabase is poor in femic minerals close to these ore segregations, and the felspar, which has a fluidal arrangement, has the optical characters of microcline.

Concluding remarks on the stratigraphy of the Skellefteå-complex. There are great difficulties for a stratigraphical investigation of this complex. Over wide areas the rocks are covered by glacial deposits and peat-bogs. The extraordinary variability of facies and the recurrence of similar igneous rocks at different times also make it difficult to find leading principles. It will appear from the monographs which will be published on the analogous complexes of Kiruna and its surroundings how ambiguous the stratigraphy there is, although the investigations and the mapping there have gone much in details. Therefore it is not to be expected that the geology can be cleared up in the much more extended and insufficiently known Skellefteå-complex. Some general statements, however, have been gained. The underlying rocks have been found to be either gneiss and foliated granites (Skellefteå, Kåge) or fine-grained leptitic rocks (Kusfors, west of Tarsnäs, and some other localities). Directly upon these older rocks limestones have been found at some localities, as has already been described. These rocks which, however, are not always present as bottom-beds are succeeded by schists and shales which are chiefly confined to the eastern part of the area. To the West these sedimentary rocks alternate with beds of conglomerates, tuffs and porphyries. In the western part various plutonic rocks form massives which partly, because of the occurrence of the same rocks as pebbles in the conglomerates, are older than some of the conglomerates. But on the other hand some of the granites are closely connected with the supracrustal igneous rocks which at some localities alternate with the sedimentary rocks. It may be suggested that the granites and the plutonic rocks allied with them have intruded in the supracrustal complexes and that they have been, to some extent, exposed by denudation, thus giving material to the subsequent conglomerates. These, together with the volcanic agglomerates and sediments, must have been formed at different epochs, separated by intervening epochs of erosion; but no marked unconformity which could be followed over a wider area has been proved. The serarchean granites which occur in the area and at its southern boundary are not only younger than all the rocks of the complex, as far as is known, but they are posterior also to the folding and the pressure metamorphism to which the complex has, more or less, been exposed.

Among the already described archean areas in other parts of Sweden the Saxå-Grythyttan-complex (p. 53) shows the greatest resemblance with the Skellefteå-complex. The occurrence at the bottom of both these areas of a limestone and a peculiar fragmental igneous rock (cf p. 54 and p. 70) is a noteworthy analogy. Other analogies could also be enumerated. A difference with regard to the substratum is obvious, viz. that porphyries and leptites come immediately underneath the complex of middle Sweden, while gneisses generally form the substratum for the Skellefteå-complex.

With regard especially to the relations between the plutonic and supracrustal igneous rocks, this complex can in some respects be compared with the granite areas of Småland in their relations to the porphyries (cf p. 36), but, considered as a whole, the Skellefteå-complex, however, does not offer many analogies with these areas. The most striking feature is here the generally very insignificant metamorphism of the rocks, which for geologists who for the first time get to know them in the field or in a series of handspecimens could suggest that they ought not to be referred to the Archean, but to some younger aera.

The Kiruna-complex and associated areas. This signification may be used for a great area in northern Lappland, between the Luleå- and the Torneå-rivers. The area is especially interesting as enclosing the great iron-ore deposits of Kirunavara, Loussavara, Tuollovara, Svappavara, Ekströmsberg, Mertainen, Gellivara a. o.

Referring for a more detailed information to the monographs under preparation and to the previous litterature, cited in them, I will here only give a short summary of the geology of this complex. Generally the area shows a striking resemblance to the Skellefteå-area with regard to the petrography and geology of the dominant rocks. The most noteworthy difference lies in the great iron-ore deposits in the syenitic rocks of the former and the want — as far as is known — of such ores in the kindred rocks of the latter. As another difference there could be noted the scarceness in the former of such shales and schists which play a great part in the latter. This difference, however, has really only little significance, inasmuch as it dissappears, when the Kiruna-complex is extended to comprise some areas further to the East, which are composed of shales and schists and seem to stand in the same correlation to the Kiruna-complex as the eastern parts of the Skellefteå-complex to the western parts. Such occurrences are the Pajala-area and some areas near the mouths of the Torneå- and Råneå-rivers. The latter of them can really be regarded as an eastern facies of the Kiruna-complex with which it also geographically seems to stand in a continuous connection.

When these eastern areas are taken together with the Kiruna-complex, a striking analogy with the Skellefteå-complex is really established, inasmuch as the former, as well as the latter, has an eastern facies of schists and shales, and a western facies chiefly composed of igneous rocks. As in the former, granites, syenites, diorites, and gabbros occur, intruding or gradually connected with the supracrustal rocks, analogous relations between petrographically analogous rocks are also characteristic for the latter complex.

In some parts of the Kiruna-complex — taken in the wide sense as has here been given to it — the igneous rocks are metamorphosed to granular rocks with gneissic or granulitic structures. Thus the »syenite-granulites» and »syenite-gneisses» of the Gellivara region are metamorphic facies of syenites and syenitic porphyries which have been of the same

kind as the syenites and porphyries of Kiruna. And likewise the granular iron-ores of Gellivara represent a metamorphic form of the igneous ores of Kiruna and the other western ore-deposits of the same kind.

From the monograph on the Kiruna-region in preparation it will appear that the rocks there can be divided into a stratigraphical series with intercalated porphyric rocks which have erupted at different epochs. It will there be proved that, as has already been suggested about the Skellefteå-complex (p. 73), a long time, with a very varying geological history, is represented by the rocks in question. But it will also appear that the upper and the lower divisions of the complex are so nearly attached to each other, that hardly the upper boundary line of the Archean can be placed anywhere in the complex. In the Kiruna-complex no serarchean granites have been found which could throw light upon the geological age; but the geographical, geological, and petrographical connection of this complex with the Skellefteå-area, which has been intruded by the serarchean granites, makes it undoubted, that also the former area ought to be regarded as archean.

With regard to the limiting of the Kiruna-complex and its continuations eastwards from some gneiss- and granite-gneiss areas in the northernmost part of Sweden, there is some uncertainty, because of the still insufficient investigations. It is probable that there occur gneisses which are older than the rocks now considered, and which stand to them in the same correlation as the gneisses south of Skellefteå to the Skellefteå-complex. Other gneisses, on the contrary, seem to be strongly metamorphic granites, which belong to the intrusive masses of the Kiruna-complex.

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Besides, reference is made to the Congress-guides for the archean excursions in southern and middle Sweden, and for the excursions to Gellivara and Kiruna which will very soon be published.

Contents.

Illustrations in the text.

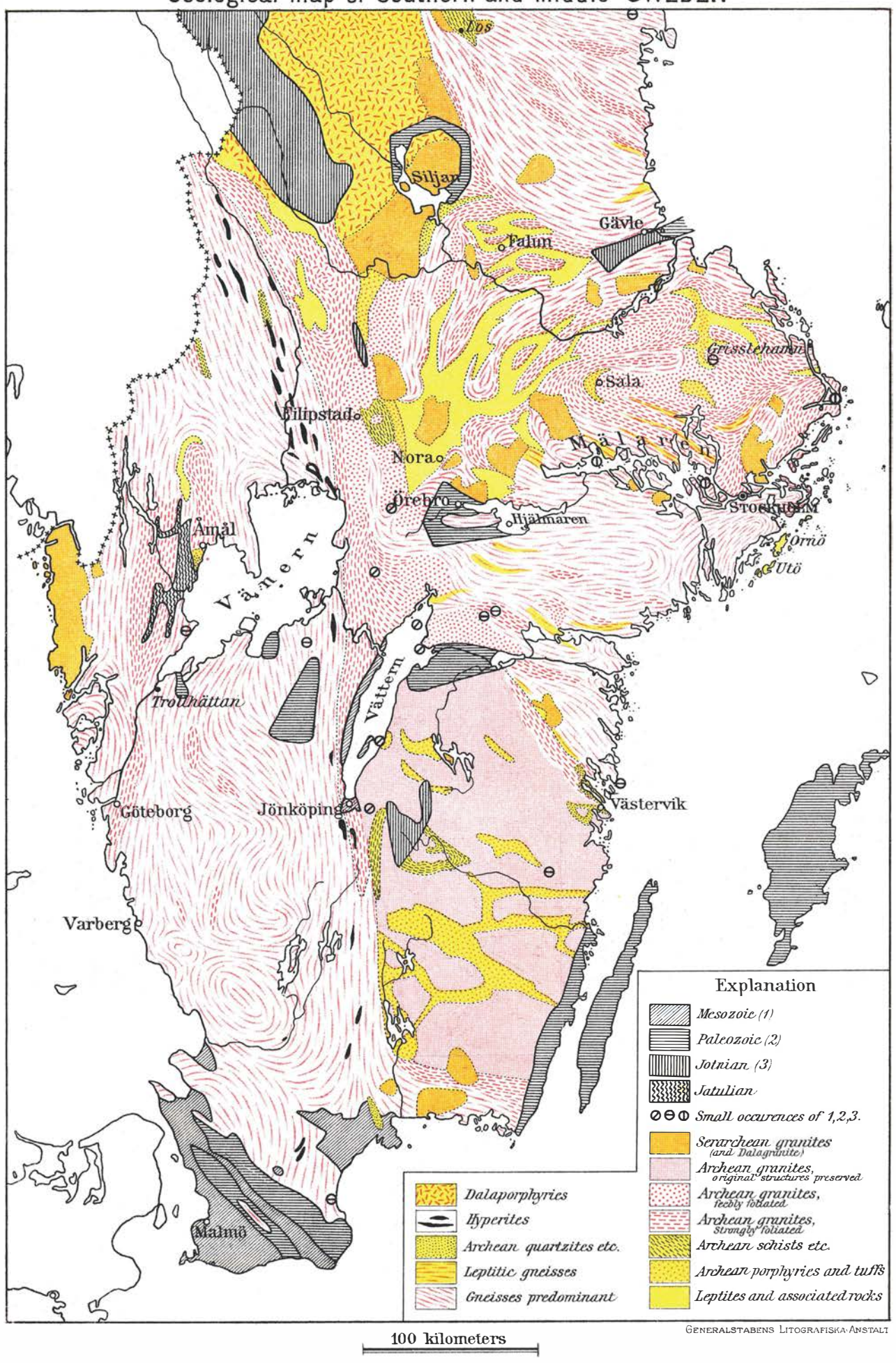
Plate I.

Geological map of southern and middle Sweden.

Addenda.

1. Since this treatise was written (jan. 1909) and partly printed, several papers have been published which deal with the Precambrian. Especially some of the American memoirs and the Text-book of Geology by RAMSAY contain suggestions which might have deserved to be taken into consideration. However, I can say that, on the whole, these papers have not altered in any essential point my above expressed opinions as to the Precambrian of Sweden.
2. In agreement with the common use among Swedish geologists I have comprised under the term »STRUCTURE» as well the term »TEXTURE» as the term »STRUCTURE» of the German and American petrographers. As a reason for that it may be sufficient to call attention to the confusion which arises from the opposite sense in which these terms are used by the German and American scientists (cf. f. i. GRUBENMANN, Krist. Schiefer I, p. 24—27, and PIRSSON, Rocks and Rock Minerals p. 154—160).
3. For incorrectnesses and inadvertencies in the language I have to make my excuses, hoping that they may not lead to any essential misapprehensions.

Geological map of southern and middle SWEDEN



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