SUOMEN GEOLOGINEN TOIMIKUNTA || GEOLOGISKA KOMMISSIONEN I FINLAND

BULLETIN
DE LA
COMMISSION GÉOLOGIQUE
DE FINLANDE

N:o 95

ON THE SUB-BOTHNIAN UNCONFORMITY AND ON ARCHÆAN ROCKS FORMED BY SECULAR WEATHERING

BY
J. J. SEDERHOLM

WITH ONE MAP AND 62 FIGURES IN THE TEXT

HELSINKI – HELSINGFORS
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PREFACE.

The study of the ancient rocks of southwestern Finland referred by the present writer to his Bothnian subdivision, was the first geological work of greater importance which he undertook. It was begun more than forty years ago, and he has often returned to the areas in question, not only because we are apt to come back, even in science, to our first love, but also because it has been necessary to defend his conclusions against attacks from different sides.

The main object of his first study was to prove the possibility of an explanation of the origin of the old supracrustal Archaean rocks of southwestern Finland through the action of actual causes, and also the possibility of a geological subdivision of this complex.

In a preface to his description of the rocks of the Tampere—Tammerfors area, he quoted the words of Charles Lapworth, spoken at the International Geological Congress in London 1888, in which he declared that he and many of his colleagues, adherents of Hutton, Lyell and Darwin »expected that future research would demonstrate the existence of many Archaean systems, but of the same general characters as those of the post-Archaean rocks, their original characters having been merely locally masked by subsequent metamorphism or alteration».

These words well express the idea which has guided the present writer's life-long study of pre-Cambrian rocks. He has tried to prove the truth of them by evidence gathered all over Fenno-Scandia.

As to the region now in question, most colleagues at home and abroad seem to agree with him concerning the last-mentioned conclusion. Only a small number of geologists, mainly in Sweden, have not been convinced by the evidence presented.

As to the existence of an unconformity separating the Bothnian rocks from their former basement in this and in other Bothnian areas, the opposition has been more general and persistent, and sometimes rather passionate. Most of the criticism has appeared in the Bulletin of the Geological Society of Stockholm, some of it also in periodicals in Finland. In one case, even a daily political newspaper contained an article on questions concerning the Bothnian rocks, trying to prove to its numerous readers that the opinions of the present writer were untenable.

Much of the controversy has been less tainted with personal feelings, and it has contributed very much to the elucidation of the subject. As the conclusions concerning the assumed unconformity were based, at first, on scanty evidence, and some errors could be detected in the argument, it is no wonder that more facts were demanded before accepting conclusions so widely applicable. The proofs now presented will probably convince even those geologists who like Thomas desire the most palpable material evidence before believing, but certainly not those ultra-sceptical men of science who refuse to believe even after they have seen the evidence, or who deliberately close their eyes to it.

A preliminary edition of the present bulletin was printed in July 1931, for the first international meeting of students of pre-Cambrian geology and mountain chains, in order to serve as a guide on the excursion to the area in question.

Only a hand-drawn map was distributed to these geologists, because the revisional survey of the southern contacts of the area of Bothnian schists had not yet been made. There was unfortunately no time for these contacts, to be visited by them.

The final revisional survey was made by the present writer in September and October, and after that the accompanying map was drawn and printed. It differs from the hand-drawn map based on the earlier survey by drawing a distinct boundary-line between the area of Bothnian schists and the rocks designated as amphibolitic schists on the former map. The reasons for this mapping will be given in this paper. The text of the bulletin has also been completed and revised since its first printing.

The present writer wishes cordially to thank his assistant, Mr. E. Mikkola, for the valuable work which he has done in this region. It was his discovery of new important outcrops that gave the impetus to the reiterated investigations of the present writer. Although Mr. Mikkolas working hypothesis was at the outset the reverse of that of the present writer, that circumstance did not hinder his working, with an objectiveness not common among young geologists, for the further elucidation of the subject. Much of the decisive evidence has been discovered through his energetic survey-work.

Dr. Eug. Wegmann has given his valuable aid in the elucidation of the tectonics of the region.

The present writer wishes to thank also all those who have taken part, scientifically, in the discussion of the subject, especially Dr. A. Gavelin, Director of the Geological Survey of Sweden who was the first geologist who gave him his wholehearted support in the question, and Professor P. J. Holmquist who in this as in other questions has pursued the discussion in such a way that every new polemic has only drawn the bonds of friendship closer.

The sincere thanks of the writer are further due to those colleagues who have kindly sent him photographs of rocks which have undergone weathering in modern times: to M. Y. Milon, Professor of Geology at the Faculty of Sciences in Rennes, Professor Kirtley F. Mathers, Chairman of the Department of Geology and Geography at Harvard University, and Dr. Geoffrey W. Crickmay, Asst. State Geologist in Georgia, further also to those gentlemen who have kindly given him their advice on the subject: M. Raguin, of the Geological Survey of France, M. Louis Dangeard, Professor of Geology and Mineralogy at the Faculty of Sciences of the University of Clermont-Ferrand, Professor G. D. Hubbard of the Oberlin College, Dr. Henry G. Knight, Chief of the Bureau of Chemistry and Soils in Washington, D. C., Dr. Stephen Taber, State Geologist in Columbia, South Carolina and Dr. S. W. Mc Callie, State Geologist in Atlanta, Georgia.

Helsingfors 12 November 1931.

J. J. Sederholm.

EARLIER CONCEPTIONS OF THE RELATIONS OF THE BOTHNIAN SCHISTS AND THEIR SUPPOSED SUBSTRATUM.

It is an axiomatic truth that every sedimentary formation has had an underlying floor consisting either of other sediments or of crystalline rock masses. It is however in many cases difficult to find any trace of this substratum in Archaean areas of sedimentary schists which generally have vertical dips and are very often intimately mixed with granites. But even when the substratum is not found, one must always ask which of the layers of the sedimentary formations are overlying, which subjacent, and on which side have originally been the rock masses which once formed the floor of the whole series of sediments.

About forty years ago the present writer discovered, in the neighbourhood of the town of Tampere (Tammerfors) in southwestern Finland, a formation of crystalline schists of Archaean age which certainly were supracrustal, partly sedimentary, partly volcanic. All their primary features were astonishingly similar to those of modern rocks, showing that the conditions of rock formation at that early date of the earth's history were quite analogous to those now prevailing. Since the time of its discovery, this area of schists has been the battlefield of controversies between adversaries and adherents of the uniformitarian, or »actualistic» doctrine, the adherents of this doctrine trying to apply it in explanation of the rock-forming processes in Bothnian and, in general, in Archaean times; the opponents, on the other hand, maintaining that more exceptional forces were then in operation.

As in any case the supracrustal character of this series could be regarded as proved, it was natural to ask whether the rocks of their floor could be found anywhere. N. of these belts of schists, which usually have an E.—W. strike, great areas of granites occur which in general possess a homophanous, non-gneissose texture and are clearly intrusive into the schists. S. of these schists, again, occur other highly metamorphic schists, mixed with granites which are mostly gneissose in texture.

Where the Bothnian schists show an alternation of different layers, some of which were originally clays, while others were silts or sands (fig. 1), it is evident that the subjacent layers are always on the southern side of each upper layer, indicating that the floor of the whole formation must be sought for at the southern side of the area.

On both sides of Lake Näsijärvi the schists, here forming the largest area, were mainly in contact with porphyritic granites outcropping south of them. These granites differed, in their gneissose textures, from the homophanous granites N. of the schists. The

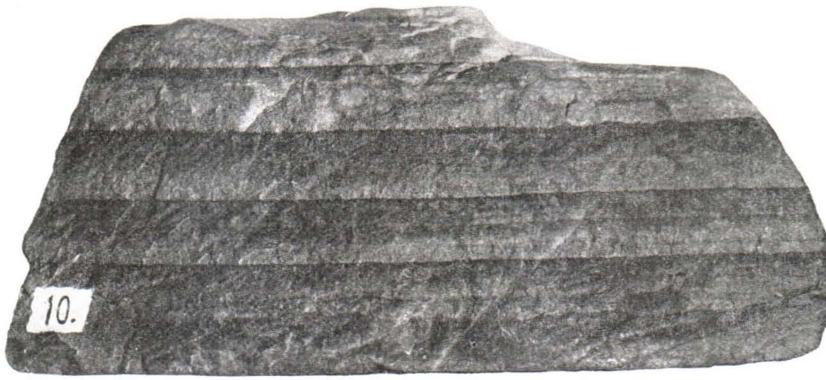

Fig. 1. Bothnian schist showing an alternation of originally sandy and clayey layers, from Lielahti in Ylöjärvi. 1 : 2 of the natural size.

contacts between the gneissose granites and the phyllites were often rather sharp, with no distinct dykes or other definitely intrusive phenomena next to the contacts. Moreover, strong tectonic movements had obviously taken place along the contact surfaces.

The present writer tried to explain the phenomena here observed by assuming that the gneissose granites were older and formed the floor upon which the sedimentary schists had been deposited. Where intrusive phenomena apparently existed, they were explained, he thought, as due to the intrusion of mylonitized granite in a solid state or, in some cases, to the intrusion of another granite, younger than the main mass of gneissose granite.

In other areas of Bothnian schists, lying N. W. of Tampere, these schists were found to be in contact with other schists and with diorites and granodiorites. Certain porphyritic rocks of a dioritic composition, that have been called lavialites, occurred also near to the contacts. At one place next to the contact, a conglomerate (fig. 2) was found which contained pebbles of lavialite and of quartzitic schists. Both these rocks outcrop S. of this conglomerate which the present writer regarded as basal.

Further, N. of the church of Lavia, another peculiar contact rock was found in a small area of diorite N. of the little lake of Naarajärvi. The Bothnian mica-schists showed a sharp contact with a breccia (fig. 3), consisting of fragments of diorite, cemented by a

Fig. 2. Conglomerate with crystalline matrix, containing pebbles of lavialite, quartzite, etc. S. W. of Harju in Suodenniemi.

mass which, in parts, had the composition of a quartzite or a quartzitic schist, in parts consisted mainly of calcite. This breccia was cut by narrow veins of a metabasaltic rock, and it passed by gradations into a typical diorite.

The present writer thought that this breccia had been formed through the superficial weathering of the diorite in Bothnian times. The fragments had been cemented partly by products of weathering, partly by sedimentary material.

The writer's view concerning the relations of the schists and the gneissose porphyritic granite S. of them was contradicted from the beginning by several geologists, as the late Professor Wiik, Holmquist and others. On the excursion connected with the International Geological Congress in 1897, the outcrops E. of Tampere were visited by many eminent geologists, among others Heim and Baltzer, who had such wide experience regarding mechanical contacts. All the visiting geologists seemed to agree that the granite was later than the schists, not a part of their floor. The contacts in Lavia could

Fig. 3. Breccia of Lake Naarajärvi. Horizontal rock surface near the northern contact. 1 : 7 of the nat. size.

not be visited during this excursion. In general, the writer's view that there existed next to the areas of schists N.W. of Tampere, a floor of older rocks, met with more contradiction than approval. But it won the important endorsement of Dr. Gavelin, the present Director of the Geological Survey of Sweden. As to the porphyritic granites of the Tampere region, however, also Gavelin thought that they were intrusive into the schists.

Later, in 1912, Dr. E. Mäkinen, of the Geological Survey of Finland, was entrusted with the making of a revisional survey of these areas, with the special purpose of studying the contact phenomena and solving the controversial questions. By diligent search, and especially by rolling away from the rocks the cover of mosses, he was able to find many new interesting outcrops, showing contacts between schists and porphyritic granites. In some of them the phenomena of intrusion were so definite (fig. 4) that the present writer became fully convinced that the granite was younger than the schists. That conclusion does not necessarily involve their being quite as young as the granites of the great central area N. of the schists. These have been intruded at an epoch when the Bothnian schists already had

Fig. 4. Fragment of Bothnian schist in porphyritic granite near the northern contact of the granitic area. Horizontal rock surface N. of Lake Paalijärvi in Kangasala. 1 : 12 of the nat. size.
Photo E. Mäkinen.

their present vertical position. The porphyritic granites S. of the schists, again, have probably been intruded into more flatlying layers and have taken part in the movements by which these were raised to a vertical position, and became at the same time highly mylonitized in parts.

As to the contacts in Lavia, it was more difficult to arrive at an agreement. Dr. Mäkinen was able to show that a great part of the diorite in the area N. of the church of Lavia (which rock had been regarded by the present writer as older, all over this area, than the schists) showed intrusive contacts with the schists. Later the present writer found new evidence tending to show that the intrusive diorite was later in age than the diorite of the contact breccia at Lake

Naarajärvi. The younger diorite contained angular fragments of this breccia. Moreover, he pointed out that the existence of conglomerates intercalated with the schists and containing pebbles of granodioritic rocks proved beyond doubt that there were two different diorites, one older and one younger than the Bothnian sedimentary schists. Dr. Mäkinen, although admitting the correctness of that conclusion, thought that these diorites did not differ very much in age. He maintained that the porphyritic lavialite also belonged to the same eruptive series which he regarded as not really plutonic, but hypabyssic and in part effusive, and formed through eruptions which had taken place during the deposition of the Bothnian sediments, thus intraformational in character. As to the contact breccia of Lake Naarajärvi, he thought that it could be explained as an eruptive (or intrusive) breccia. According to his theory, one part of the diorite had consolidated earlier and had been broken into pieces, which were later cemented together by other parts of the same intrusive masses and by schists which had been remelted through the action of the dioritic magma. We will discuss this explanation later on.

Mäkinen's view won favour with many geologists, especially in Sweden, e. g. with Holmquist who at the same time emphasized the great importance of this locality. It was rather generally felt that the theory of an unconformity marked by plutonic rocks disintegrated by subaërial weathering and separating the rocks which have been called Bothnian from older supracrustal rocks, had not stood the test of criticism. Many geologists regarded it as proved that the Archaean complex was indivisible.

The idea that the supracrustal schists of Middle Sweden, or what is now there called the Leptite Formation (the Svionian of the present writer) and the Bothnian, are different in age, was however first enunciated by an eminent Swedish geologist, Professor Törnebohm, who may be regarded as the founder of the Fenno-Scandinavian school of Pre-Cambrian geology. He thought that the difference in petrological character between the Bothnian schists of the Tampere area and the old iron-bearing schists of Middle Sweden was so great as to suggest a different age. The same conception has also been voiced by Dr. Gavelin, who, after a journey in Finland in 1911, while, as already mentioned, subscribing to the present writer's view as to the age relations of the Bothnian and the adjacent rocks, in opposition to Professor Holmquist and other Swedish geologists strongly emphasized the difference in character between the most common Archaean schists of Sweden and the Bothnian schists of southwestern Finland.

During recent years, the same opinion has become rather general among Finnish geologists too. Independently of the position which they took in the controversy concerning the contacts of the Bothnian rocks, many of them became convinced that the great difference in the petrological character between the Swedish Leptite Formation and the Bothnian series of Finland is enough to justify their separation. In the former acid metamorphic volcanic rocks of peculiar composition and their tuffs, iron ores, limestones, in some areas also quartzites, are the most characteristic rocks, while among the Bothnian schists thick beds of conglomerates and basic volcanic rocks (metabasalts or uralite-porphyrites) are of common occurrence, and there are, in most regions, no limestones or quartzites.

However, the direct proofs of an unconformity were, as already mentioned, thought to be lacking. It must in fact be admitted that the contact rock at Lake Naarajärvi gave rather slender evidence in favour of the present writer's opinion that there was a great break below the Bothnian.

When the modern tectonic methods that have lately been developed in Switzerland and other Alpine countries were introduced into Finland by the activity of Dr. Eug. Wegmann, a new revision of the interesting areas in the neighbourhood of Tampere became necessary. This was entrusted to Mr. E. Mikkola who in the summer of 1928 mapped once more the areas N.W. of Tampere with the special object of getting an idea of the tectonic structure of this interesting region. Mr. Mikkola performed this task in an able way. Already the earlier work of Dr. Mäkinen, which did not however aim at a more complete re-mapping of this region, had shown that it was possible to improve the older maps in important particulars. The latest survey essentially modified the map also as to the extension of the different rocks. Especially as to the region most to the N.W., in Lavia and Kankaanpää, the new mapping gave a much clearer picture of the geological features. The conglomerates containing pebbles of diorite were found to be more continuous than had been known before, and could be traced over large areas. Further, not only tuffs of metabasaltic rocks, but also effusive sheets of typical volcanic uralite-porphyrites were discovered. Dykes of metabasalt intersected the diorites at several places, while other granodiorites were obviously later than the metabasaltic rocks. Thus new evidence was found that two diorites, differing in age, existed in the region.

Extensive outcrops of contact rocks, showing characters very similar to that of the Naarajärvi breccia, were discovered during this survey. In the neighbourhood of the schists, the diorite was brecciated on a large scale and the fragments cemented by a rock very similar to the adjacent schists. Mikkola was inclined to explain these phenomena in the same way as Mäkinen, assuming that a refusion of the schists through the action of dioritic magma or, in other words, a palingenesis on a large scale, had taken place.

In the autumn of 1928 the present writer visited these outcrops together with Mr. Mikkola and Dr. Wegmann, but had not sufficient time for a more detailed revision. He felt rather inclined to admit the possibility of Mäkinen's and Mikkola's explanation of the phenomena, which in theory was nearly related to his own ideas of the possibility of a palingenesis of older rocks through the influence of intrusive masses. However, neither the writer nor any other geologist had before observed quite similar phenomena of a magmatic nature. Neither the well-known »Red Rock» of Pigeon Point in Michigan which has originated through the action of diabasic magma on a sandstone, nor the peculiar phenomena of the Vestervik area in Sweden, where a gneissose granite has undergone refusion at the contact with dykes of diabases, showed any greater analogy with the phenomena in question. The assumption of a palingenesis of this character must appear to most geologists as a still bolder conclusion than the previous, tentative explanation of the present writer. Further, the fact remained that conglomerates with pebbles of a similar diorite existed in the same region, showing that there was also a diorite which was older than the sediments in question. Two diorites of different age certainly existed. The assumption that they belonged to the same eruptive series would mean that, as Mäkinen thought probable, both rocks had solidified very near to the surface. These diorites, however, have the texture of deep-seated rocks, and the admitted relation between the older diorite and the porphyritic lavialite had not been proved. Thus there was still a long way to a final solution of the remaining riddles of that interesting area.

In the summer of 1930, the present writer had an occasional opportunity to study, during an excursion in the Plateau Central of France, rock masses which had been subject to a secular weathering through which breccias, cemented by sand or silt, had been formed on a large scale. The similarity, m u t a t i s m u t a n d i s, between these phenomena und those observed at the contacts of the Bothnian schists was striking. The writer therefore returned to the latter in order to make a renewed study of these peculiar contact rocks. He thinks that he has been able, by this study, to arrive at a final explanation of the fascinating phenomena in question and will here briefly summarize the new observations which entirely confirm his former conclusions.

OUTLINE OF THE GENERAL GEOLOGY OF THE REGION.

By the continued revision of the geology of the area in question in 1931, the present writer has again been assisted by Mr. Mikkola who has mapped the most important part of the region in 1 : 5 000. The rolling away of the cover of mosses revealed an astonishing number of earlier unknown facts. The zones of breccias were found to possess much regularity and considerable length, and W. of them, at a distance of 50—70 m, parallel zones of conglomerate with dioritic pebbles were discovered and could be followed for several kilometers. Other conglomerates were found N.E. of the dioritic area. Also the earlier known conglomerate S. of Harju in Lavia was found to have at both sides continuations, lying, according to the opinion of the present writer, near the contact with the older schists outcropping S. of the Bothnian area.

The detailed map drawn in 1 : 5 000 by E. Mikkola, and published in 1 : 20 000 (fig. 5), shows that part of the Bothnian area where the supracrustal rocks formed by subaërial disintegration have their greatest extension, while another map in 1 : 50 000 shows the general geology of the region.

The area of rocks which on the older general geological map were designated as Bothnian mica-schists has, as already mentioned, a more complicated structure than was thought earlier. The mica-schists, which often are feldspathiferous, are intercalated with conglomerates, breccias and »meta-arkoses» consisting of disintegrated dioritic material. Intercalated with the schists a narrow belt of diorites, shown also on the older map, occurs. Their extension is greater and their form less regular than indicated there. All the rocks mentioned have a very close genetical connection, the dioritic gneisses being such portions of plutonic masses as have preserved enough of their original character to be easily recognized, while the meta-arkoses and breccias consist of dioritic masses that have been more changed, mainly by secular weathering (and subsequent metamorphism), and the conglomerates and mica-schists are clastic rocks which consist of such material formed by the disintegration of the diorites as has been transported a greater distance. The petrological thesis which is the basis of this preliminary description will be proved in detail by further evidence.

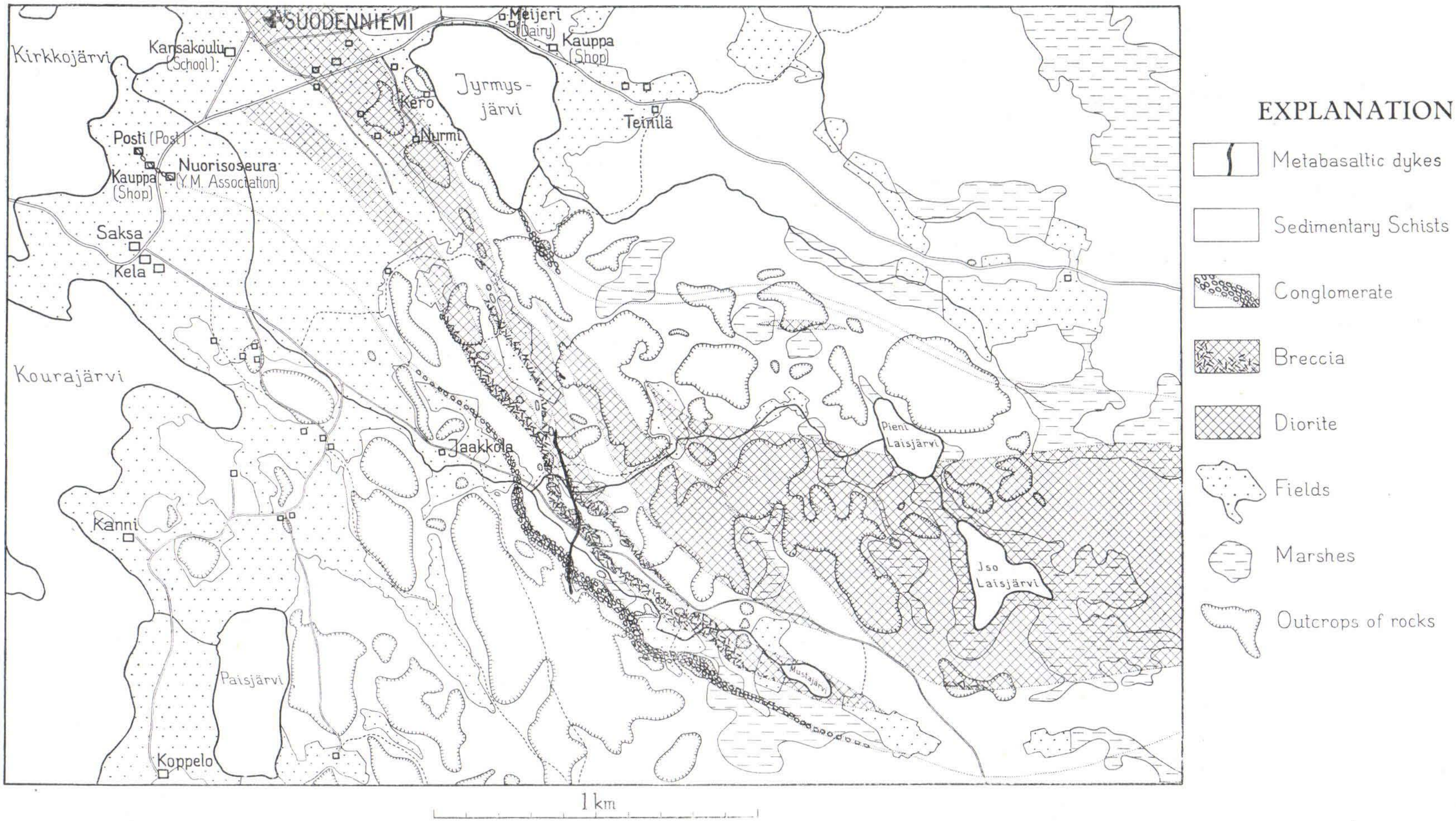

Fig. 5. Map of the Suodenniemi area of breccias, conglomerates and diorites. Drawn by E. Mikkola. 1 : 20 000. (The house of the Nuorisoseura [Y. M. Association] now belongs to the Civil Guards).

All these schists generally strike in N.W. directions, although with many local variations (cf. the maps). The dips are nearly vertical. In the region N.E. of the church of Suodenniemi occurs another zone of porphyritic supracrustal rocks which have a basic composition. These are uralite-porphyrites, or, in other words, metabasalts, and their tuffs; both have now a metamorphic habit. These metabasalts occur as dykes in the sedimentary area and are thus somewhat younger than the Bothnian schists, although chronologically closely associated with them.

S.W. of the Bothnian schists other schists occur which belong to their floor. Among them mica-schists, partly migmatitic, and amphibolitic schists of varying composition and grain prevail. Also a porphyritic rock occurs which has a dioritic composition and has been called l a v i a l i t e. This name is not intended as a petrographical designation, but rather a geological term by which this rock, which has a rather peculiar appearance and geologically plays a certain rôle, may for greater convenience be briefly designated. Scarce outcrops of schists probably belonging to the older series occur N.E. of the Bothnian schists, too.

Besides the older diorite, whose weathering has produced the material of the sediments, another younger diorite of similar appearance occurs which is clearly intrusive into the Bothnian schists and the uralite-porphyrites.

Finally, porphyritic granites outcrop in a large area at the boundary of Lavia and Suodenniemi, and also in the S.E. part of the area. They are younger than all the rocks mentioned above and intrude them at the contacts in numerous dykes and veins.

A section through the present area and the region W. of it, showing the tectonic structure, has been drawn, with the aid of Dr. Wegmann, by Mr. Mikkola (fig. 6). There are, as shown by this stereogramm, two axial depressions in sections 6—7 and 13—17. The culmination between them is at its highest in sections 9 and 10. In the depression, the zone of schists becomes broader». The greatest part of the schists designated as tuffitic have later been shown to be arkose-like in character. Whether there are at any places intercalations of tuffitic rocks, is still an open question. The changes introduced in the map have also in other ways lead to a modified conception of the features shown in the stereogramm. Of the porphyritic granite, Mikkola says: »Its intrusion seems to have been later than the migmatitization. The great homogeneous mass in sections 8—12, rises with steeply inclined boundaries at the axial culmination of the range of schists, and seems to have penetrated the neighbouring

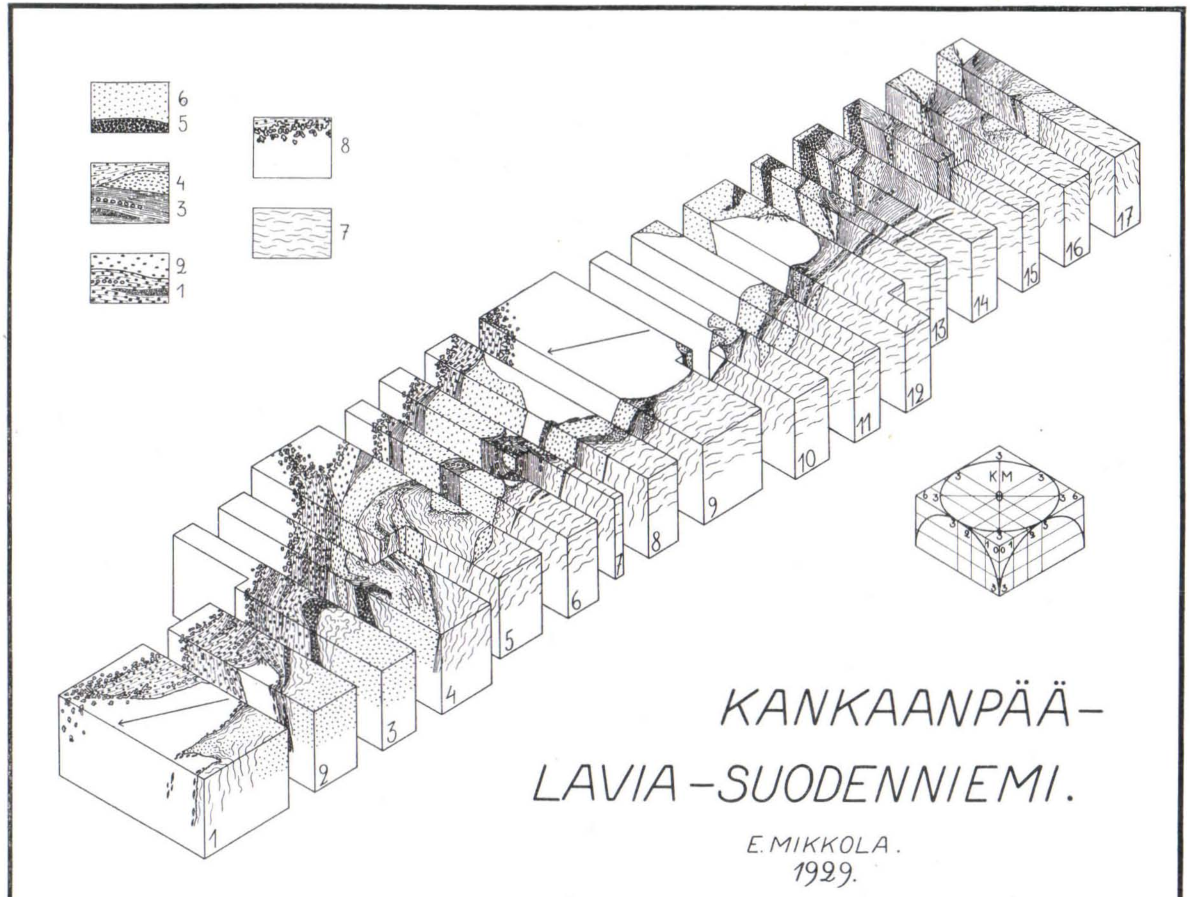

Fig. 6. Stereogram of the Bothnian area of Kankaanpää—Lavia—Suodenniemi drawn by E. Mikkola. 1=Metamorphic tuffs and plagioclase-porphyrites; 3=Schists, in the upper horizon tuffitic, with intercalations of conglomerates and plagioclase-porphyrites; 5=Uralite-porphyrites; 2, 4 and 6=Diorites; 7=Migmatitic schists; 8=Granite.

rocks while they were in a plastic state. It has pushed aside the schists of the depressions so as to become funnel-like in form and has forced the culminations to become a broad arch. Along the contacts of the porphyritic granite, in sections 1—9, this granite has strongly assimilated the adjacent rocks.»

PETROLOGICAL DESCRIPTION OF THE DIORITIC AND GRANITIC ROCKS.

THE OLDER DIORITE.

The older diorite is most typical in the region N.W. of the church of Suodenniemi. It is a rather dark rock with a gneissose texture, but homogeneous in composition. It is composed of plagioclase, green hornblende, biotite and quartz, with accessory grains of titanite. The plagioclase has in some cases formed crystals 5—10 mm long, but they are now broken and subdivided into smaller fragments and filled by inclusions consisting of biotite, forming small flakes, actinolithic hornblende and rounded grains of quartz and secondary feldspar. The plagioclase varies in composition, in different varieties of these diorites, between that of an oligoclase and a labradorite.

This diorite, which has quite the character of a plutonic rock, passes by gradations into a variety which is still more gneissose, with more highly granulated feldspar, containing an increasing quantity of biotite flakes and of small rounded grains of quartz and feldspar. This pitted appearance of the feldspar is characteristic of the more highly metamorphic varieties of the older diorite. At the same time the constituents are often drawn out, so that the rock has a fibrous texture.

The dioritic pebbles in the conglomerates of the region which obviously consist of the same rock, show, as is often the case with pebbles in metamorphic conglomerates, the primary character of the rock better preserved than the varieties outcropping in greater masses. The crystals of plagioclase are better preserved in form, less broken, granulated and intergrown with biotite flakes. There are, however, among them also varieties of the pebble rocks that are darker in colour, and then they also often show irregular contours, obviously having been partly weathered before they were deposited in the conglomerate, and in this case the primary texture is also more obliterated. This is still more the case with the dioritic fragments of the breccias of Suodenniemi and Lavia. Fig. 7 is a microphotograph of a diorite forming an angular fragment in the breccia of

Lake Naarajärvi in Lavia. The labradorite crystals show a characteristic pitted appearance, having been intergrown with grains of quartz, plagioclase, biotite, zoisite, etc.

Fig. 7. Older diorite with pitted labradorite crystals from the breccia of Lake Naarajärvi in Lavia. Nicols +. 18 ×.

The chemical composition of the older diorites of the adjacent Lavia region is shown by the following analyses made by Dr. Eero Mäkinen. For comparison, also the analysis of a lavialite, made by the same analyzer, is communicated.

	Quartz-diorite, N. of Lake Naarajärvi in Lavia.		Quartz-diorite, pebble in conglomerate. Välimäki, Lavia.		Diorite-porphyrite (lavialite) Lake Lavijärvi in Lavia.	
	Percent	Mol. prop.	Percent	Mol. prop.	Percent	Mol. prop.
SiO_2	60.01	1 000	54.40	907	55.18	920
TiO_2	1.06	13	0.76	10	0.80	10
Al_2	16.61	163	18.59	182	18.61	182
Fe_2O_3............	0.79	5	1.46	9	2.74	17
FeO	6.70	93	7.99	111	5.23	72
MnO	Traces	—	0.40	6	0.42	6
MgO	3.24	81	3.61	90	3.09	77
CaO	5.94	105	6.62	118	9.09	163
Na_2O	3.05	49	3.13	50	2.40	39
K_2O	1.95	21	1.25	14	2.05	22
P_2O_5	0.27	2	Traces	—	Traces	—
H_2O	0.71	—	1.62	—	0.60	—
Sa.	100.33		99.83		100.21	

In the Naarajärvi rock, the high content of silica may possibly be due to secondary influences, as an accumulation of quartz has taken place in some portions of the rock.

There are also gabbroid rocks associated with the diorites, but those which are not due to an addition of basic material during processes of secular weathering, seem all to belong to the younger diorite.

THE PORPHYRITIC GRANITE.

The coarse porphyritic granite which outcrops in the N.W. and S.W. parts of the area shown by the map is usually light reddish, occasionally more greyish and characterized by its porphyritic texture. Larger crystals of perthitic microcline occur which are 2—3 cm in diameter and are surrounded by a groundmass consisting of mineral grains which measure 2—5 mm, mainly microcline, oligoclase, quartz, biotite and hornblende, with some accessory epidote and zoisite, titanite, apatite and fluorite, the latter being otherwise a rare constituent of the granites of the central area.

It is usually entirely homophanous, non-gneissose.

Most of the quartz is granulated, but has originally been rather xenomorphic. Myrmekite is often present.

This granite is the youngest of the plutonic rocks of the region. The present writer holds it possible that some of the pegmatites occurring in the adjacent areas are genetically connected with it.

THE YOUNGER DIORITE.

The diorite which is intrusive into the schists and into the uralite-porphyrite is macroscopically often rather similar to the diorite which has delivered the material to the sediments. Also chemically it is not very different, as results from the following analyses of younger diorites from Lavia made by Dr. Eero Mäkinen.

This diorite shows chemically a greater variety than the older diorite, varying between a grano-diorite and a gabbro-diorite, occasionally even a gabbro, in composition. In the latter, cummingtonite is occasionally present. The plagioclase of these rocks varies between an oligoclase (An 30) and a bytownite (An 78).

Microscopically there is a marked difference, especially in some varieties which are not gneissose at all. The plagioclase is free from the minute interpositions of biotite, etc., which characterize the feldspar of the older diorite. In some cases the original idiomorphic form is almost entirely preserved which is never the case with the older diorite.

Younger diorites from Lavia, analyzed by E. Mäkinen.

	Grano-diorite. W. of Välimäki, Lavia.		Quartz-diorite. 2 km N.W. of Lake Naarajärvi, Lavia.		Quartz-diorite, N. of Lake Naarajärvi, Lavia.		Diorite. Western Lavia.		Gabbro-diorite. Western Lavia.	
	1		2		3		5		6	
	Per-cent	Mol. prop.	Per-cent	Mol. prop.	Per-cent	Mol. prop.	Per-cent	Mol. prop.	Per-cent	Mol. prop.
SiO_2	66.18	1 103	63.80	1 063	61.38	1 023	56.06	934	50.52	842
TiO_2	0.48	6	0.69	9	0.85	11	0.60	8	1.50	19
Al_2O_3	16.25	160	15.82	155	16.52	162	17.61	173	19.64	192
Fe_2O_3	0.50	3	0.61	4	0.75	5	1.65	11	1.73	11
FeO	4.35	61	4.06	57	6.23	86	7.59	106	8.16	114
MnO	0.25	4	Traces	—	Traces	—	0.16	2	0.58	8
MgO	2.17	54	2.72	68	2.72	68	3.38	85	3.49	87
CaO	3.46	63	5.62	100	5.21	93	7.26	130	7.16	129
Na_2O	2.80	45	3.21	52	3.53	56	3.47	56	3.41	55
K_2O	3.90	41	2.77	30	1.97	21	1.67	18	2.11	22
P_2O_5	Traces	—	0.20	1	0.35	2	Traces	—	Traces	—
H_2O	0.35	—	0.64	—	0.86	—	0.95	—	1.50	—
Sa.	100.69		100.14		100.37		100.40		99.80	

Some secondary biotite has been formed, but as larger irregular crystals, not as minute flakes. The quartz has been granulated, but within the original borders, and it is not intergrown with the other minerals (fig. 8; cf. fig. 7).

Fig. 8. Grano-diorite N. of Lake Naarajärvi in Lavia. Nicols +. 18 ×.

There are more gneissose varieties of this diorite, which are due either to the assimilation of schistose rocks or to tectonic influences that were active before the final consolidation of the rock. Also in these varieties the feldspar and the biotite are well separated, and no such intimate secondary intergrowth of these minerals as in the older diorites is visible.

This difference between the two diorites is however not always so conspicuous that it would be possible to separate them on this evidence, if their relations to other rocks was not so obviously different.

Around the small area of younger diorite S. of Lake Paisjärvi in Suodenniemi, numerous dykes and veins occur, intersecting the adjacent schists. The rock of these dykes is sometimes porphyritic, containing slender crystals of oligoclase in a darker groundmass. This porphyritic rock, which certainly belongs to the younger diorite, has a certain resemblance to the »lavialite» which occurs in the pre-Bothnian complex, with the difference that in the latter the porphyritic crystals are commonly shorter and broader. As there are two diorites, one older and one younger than the Bothnian schists, it is no wonder that there are also two porphyrites. The existence of this younger porphyrite, clearly cutting the Bothnian schists, is a fact of great importance, because it gives the clue to the understanding of dykes of similar character cutting the Bothnian schists of Lavia and Kankaanpää, N.W. of this region.

THE METAMORPHIC SEDIMENTS AND RESIDUAL DEPOSITS.

FINE-GRAINED MICA-SCHISTS.

The prevailing rock among the Bothnian sediments of the region have been designated phyllites, but may equally well be called fine-

Fig. 9. Fine-grained mica-schist from the region S. E. of Jaakkola in Suodenniemi. Nicols ∥. 13 ×.

grained mica-schists. They are often feldspathiferous, and grade into rocks that may be called meta-arkoses. These are rocks consisting of weathered dioritic material that has not been transported any more considerable distance.

The fine-grained schists are generally rather uniform in composition, and the bedding is only marked by stripes of biotite. Sometimes they show an alternation of layers of different grain and composition, and then have some similarity to the »varved» schists of the areas at Lake Näsijärvi, N. of Tampere. N. of Lake Pieni Laisjärvi a boulder was found where dark fine-grained phyllitic layers were intercalated with thin layers composed mainly by plagioclase crystals.

In close connection with the conglomerates, feldspathiferous schists were found which show this phenomenon in a still more pronounced form. They will be described later on.

CONGLOMERATES WITH DIORITIC PEBBLES.

Conglomerates with pebbles of diorite embedded in a crystalline matrix have a wide distribution in the present region. One layer, called the Kittilä conglomerate, because the best outcrops occur in the

Fig. 10. Conglomerate with dioritic pebbles. E.S.E. of Jaakkola, Suodenniemi.

forest of the village of Kittilä, has a length of 7 km. The thickness of the vertical beds is often 20—30 m, in some cases considerably more.

Fig. 10 shows a sloping surface of a rock consisting of this conglomerate in E. Suodenniemi. The pebbles are well rounded and often very little deformed by tectonic action. Many of them consist of a diorite which is rather coarse-grained, but medium-grained varieties also occur. One very light pebble consists of a rather fine-grained rock which is probably more acid than the other pebbles. A few pebbles consist of a fine-grained, light sedimentary rock.

In the rock shown in fig. 11, which is a conglomerate N. of Karimaa, W. of Kirkkojärvi in western Suodenniemi, the first outcrop of the Kittilä conglomerate discovered (in 1928), middle- and fine-grained pebbles prevail, but also coarser-grained occur.

The grain and composition of the pebbles of the conglomerates has in many cases been influenced by secondary agencies. In a conglomerate where some pebbles are well rounded and have very definite contours, there are others that have more indistinct forms and grade into the surrounding cement. The latter pebbles are often darker, and their primary texture is very much obliterated. They are obviously fragments of a weathered diorite which contained finely dispersed limonitic decomposition products.

Fig. 11. Conglomerate with dioritic pebbles. N. of Karimaa, W. of Kirkkojärvi. 1 : 8 of the nat. size.

Sometimes, although very rarely, pebbles occur which consist of a porphyritic rock that has a dark ground-mass rich in hornblende, and resembles the so-called lavialite. No gradations have been observed between these pebbles and those of typical diorite. The fine-grained varieties of the diorite sometimes, although rarely, show an indistinct porphyritic texture, but they are light in colour and do not resemble the lavialite.

In some parts of the conglomerates, a few pebbles consist of sedimentary rocks, either dark schists or a white quartzitic rock of sandstone-like appearance. It is no doubt a meta-psammite.

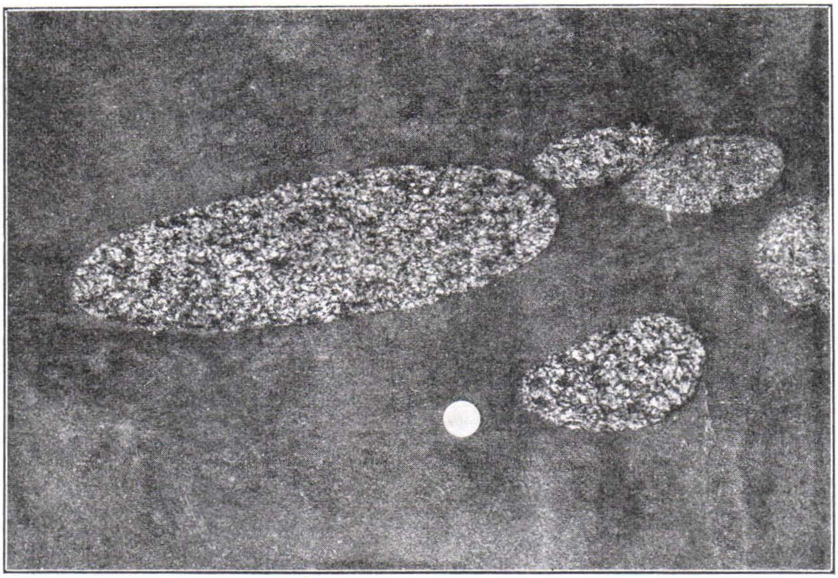

Fig. 12. Conglomerate with scattered pebbles of diorite in a schistose cement. Near Välimäki in N. Lavia. 1 : 5 of the nat. size.

The material of the pebbles consists mainly of smaller fragments of the same diorite of varying size. When they are finer-grained and biotite is more abundant than elsewhere, dark mica-schist-like varieties, containing more scattered pebbles, occasionally occur, but generally the matrix has the character of an arkose.

In Lavia, a broad zone of such a conglomerate with scattered pebbles occurs. The rock surrounding the pebbles is rich in biotite and schist-like in appearance (fig. 12). This peculiarity has been much emphasized by some observers who regarded it as a strange circumstance that a pelitic sediment could contain isolated, sometimes very big pebbles. No doubt the currents which carried the sedimentary material and rounded the pebbles varied very much in velocity, and therefore material with varying size of the grain was deposited, but it is erroneous to think that the schist has originally been pelitic. It consists, also in this case, mainly of rather large fragments of dioritic minerals, although mica is more abundant than at other places.

In other parts of the same conglomeratie zone the pebbles lie crowded in the same way as in the conglomeratec of Suodenniemi (cf. fig. 60).

Fig. 13. Conglomerate with dioritic pebbles and arkose consisting of dioritic gravel. House of the Civil Guards in Suodenniemi. 1: 6 of the nat. size.

A locality of much interest, which belongs to the conglomeratic belt of Suodenniemi and was discovered during the revisional work of the present writer in 1930, lies close to the House of the Civil Guards (earlier Nuorisoseura) in Suodenniemi. Here a cut through a rock was made in 1929, when the high road was reconstructed. In the northern part of the cut a conglomeratic rock was detected (fig. 13). It contains isolated, well-rounded pebbles, while most of the fragments have irregular forms and obviously were decomposed when they were imbedded in the conglomerate; they are also darker than the well-rounded pebbles. In the greatest part of

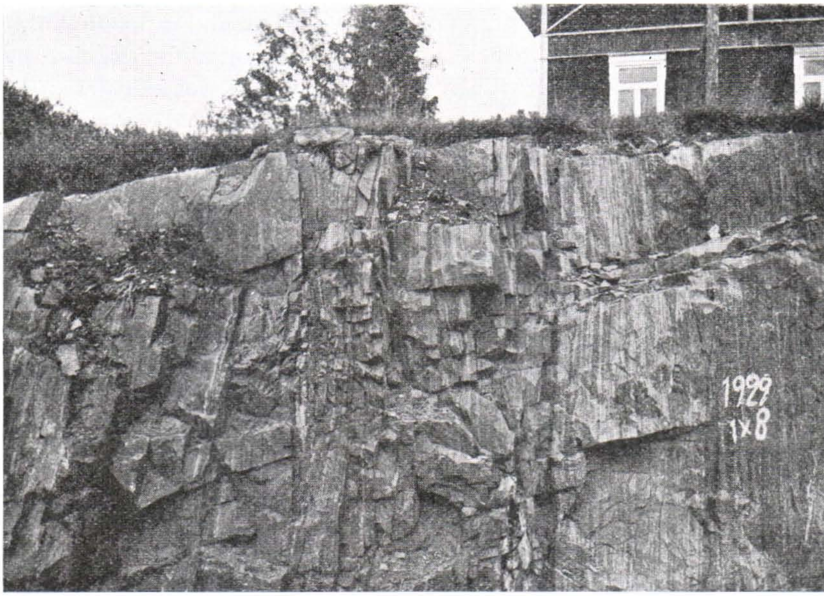

Fig. 14. Meta-arkose alternating with layers of a meta-psammitic mica-schist. Suojeluskunnan talo (House of the Civil Guards) in Suodenniemi.

Fig. 15. Meta-arkose alternating with layers of a meta-psammitic mica-schist. Detail of the cut shown in fig. 14. Ca. 1 : 6 of the nat. size.

the cut (fig. 14), the rock shows an alternation of dioritic, gravelly, and finer-grained material, resembling somewhat in composition the prevailing schists of the region. This bedding (fig. 15) must as usual be due to a variation in the action of the agencies by which the sedimentary material was transported.

This is the place where the evidence is most convincing for the assumption that not only the conglomerates, but also the medium- and fine-grained sedimentary schists have to a great extent been formed out of material derived from the weathered diorite.

Fig. 16. Microphotograph of dioritic meta-arkose from Suojeluskunnan talo in Suodenniemi. Nicols +. 13 ×.

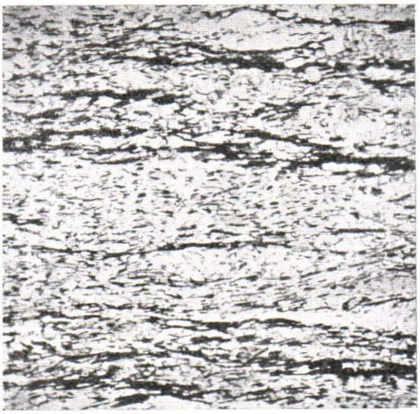

Fig. 17. Microphotograph of meta-psammitic mica-schist alternating with meta-arkose from Suojeluskunnan talo in Suodenniemi. Nicols ‖. 13 ×.

Striped rock such as that shown in figs. 14 and 15 might be mistaken for an injection gneiss, and similar rocks of the region have in fact been so interpreted by some geologists. But the sections make it entirely clear that the feldspathiferous portions of figs. 14—15 have the same origin as the irregularly dispersed, gravelly portions of the conglomerate shown in fig. 13. These layers of feldspathic material are by no means to be regarded as drawn out pebbles. The pebbles of fresh rock are not usually much flattened in the conglomerates of dioritic material in this region. The simultaneous occurrence of the rounded pebbles and the irregularly distributed material shows that the latter consisted of gravelly portions of the diorite which because of its decomposed state could not form distinct pebbles.

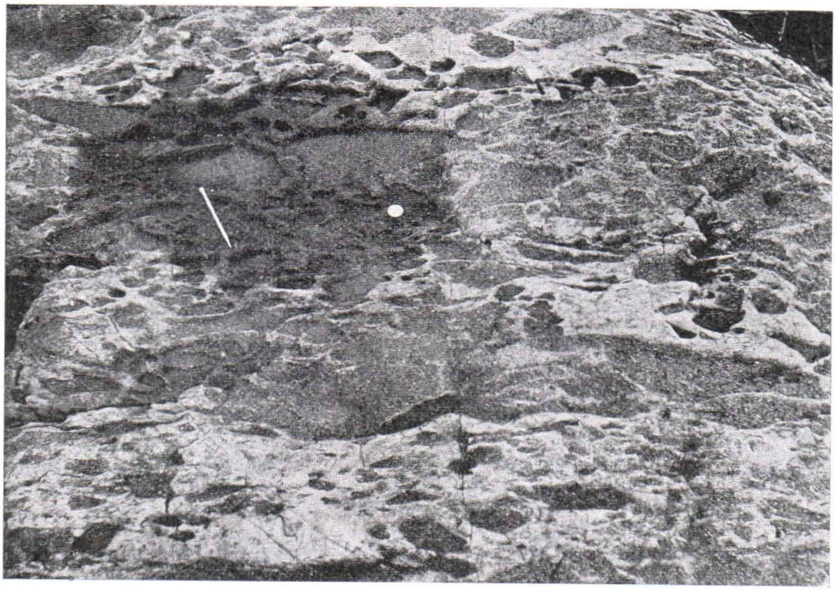

Fig. 18. Breccia S. E. of Jaakkola in Suodenniemi. Horizontal surface. Ca. 1 : 10 of the nat. size.

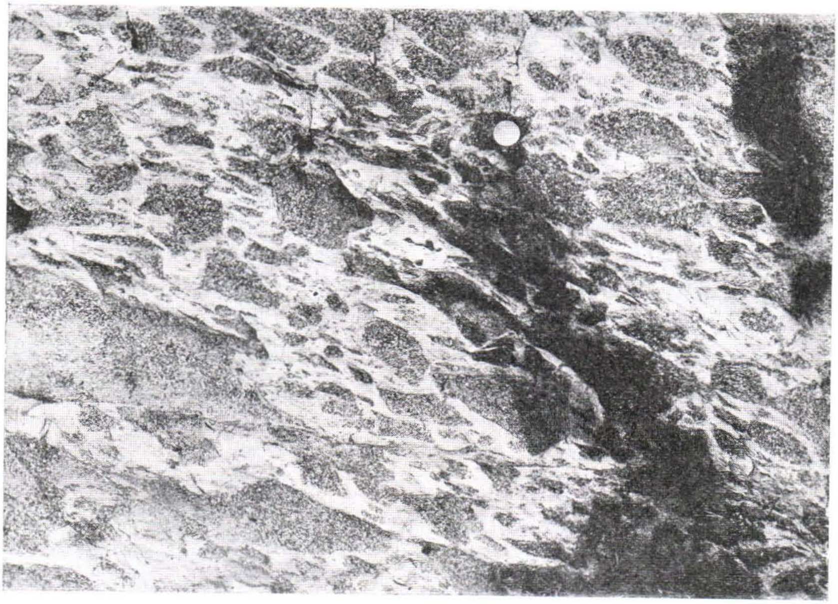

Fig. 19. Breccia S. E. of Jaakkola in Suodenniemi. Horizontal surface. Ca. 1 : 7 of the nat. size.

The figs. 16 and 17 show the microscopical structures of this arkose and of the intercalated finer-grained schist. In the former the plagioclases of the diorite are still well preserved, although they have been mechanically broken. Between them lies a mass consisting mainly of green hornblende. The schist consists mainly of mineral grains that measure less than 0.2 m in diameter. Dark stripes rich in biotite alternate with such as contain much quartz.

THE BRECCIA OF JAAKKOLA.

Some hundred metres S.E. of the farm called Jaakkola extensive outcrops of the breccia occur whose discovery and study gave renewed interest to the geology of the region. It has a breadth of 20—30 m and can be followed along considerable distances. At both sides, it shows

Fig. 20. Cement between the fragments in the Jaakkola breccia. Nicols ‖. 13 ×.

Fig. 21. Fine-grained mica-schist S.E. of Jaakkola. Nicols ‖. 13 ×.

sharp, vertical contacts with the adjacent schist. The same is true also as to other occurrences of the same breccia (fig. 22).

The figs. 18—19 show horizontal surfaces of rocks consisting of this breccia. The fragments are of varying sizes, the biggest measure 0.5 m and more in length, the smallest only a few mm. The forms are mainly angular, although the corners are sometimes rounded. The fragments consist of a diorite which is easily recognizable in the bigger fragments, although gneissose in appearance and showing the same changes as some of the pebbles in the conglomerates passing over into arkoses. The smallest fragments are more changed and show outlines fading into the surrounding cement.

This cement between the fragments of the breccia is very similar to the fine-grained schist of the neighbourhood. In the narrower veins, it sometimes consists mainly of quartz with some mica, but usually biotite is abundant. Muscovite occurs as scattered crystals, feldspar in varying quantities, sometimes also light-green hornblende. Garnets, titanite in small grains and calcite are often present. Feldspar and hornblende are most common in such portions as are obviously almost completely decomposed fragments. In some parts of the cement an indistinct schistosity is visible.

By comparing fig. 20, which is a microphotograph of this cement, with fig. 21 which shows the adjacent schist, we realise the great similarity of these rocks; two analyses made by Dr. L. Lokka of varieties showing also macroscopically a very great resemblance to each other, also show this likeness.

Cement of the breccia and fine-grained mica-schist S.E. of Jaakkola, analyzed by Dr. L. Lokka.

	Fine-grained rock cementing the breccia. S.E. of Jaakkola in Suodenniemi.	Fine-grained mica-schist S. E. of Jaakkola in Suodenniemi.
SiO_2	74.02	75.09
TiO_2	1.42	0.58
Al_2O_3	12.61	13.20
Fe_2O_3	0.16	0.49
FeO	2.94	1.84
MnO	0.03	0.04
MgO	0.36	0.23
CaO	3.17	2.01
Na_2O	3.16	4.56
K_2O	1.16	1.52
P_2O_5	Traces	Traces
H_2O+	0.77	0.56
H_2O-	1.11	0.09
Sa.	99.91	100.21

A little more to the north, another zone of the same breccia occurs, separated from it by a narrow zone of fine-grained mica-schist.

When regarding the rock surfaces, we are aware of the artificial character of the theory which tries to explain this breccia as due to intrusive processes. The diorite always forms fragments, the cementing mass is a fine-grained sedimentary schist. There are nowhere any dykes or veins of diorite in the schist, nor in general the slightest evidence of an intrusion either from the side of the one or the other rock.

The sharp contact between the breccia with numerous fragments of diorite and the adjacent schist (Fig. 22) would also be impossible to explain, if the diorite was younger than the schist. The breccia obviously existed as such when the sedimentary schist was deposited.

The most interesting and distinct contact between the breccia and the schist is that which was found by Mikkola 50 m N. of the road leading eastwards from Jaakkola, in the northern belt of breccia, about 150 m E. of the metabasaltic dykes. This contact rock is shown in the drawing of fig. 23 and in the photographs in fig. 24—25. The former is a sketch showing the general character, but is

Fig. 22. Mica-schist in contact with breccia. The fissures filled with schistose cement are intersected by the contact surface. E.S.E. of Jaakkola in Suodenniemi.

exact as to the more important parts, especially those next to the contact.

As we are aware there is, in this instance, no boundary at all between the schist and the cement of the breccia, and some fragments of diorite lie detached from the breccia entirely surrounded by the schist. Next to the contact, there are some slabs of diorite which are more continuous than at other places. At a distance of 1.5 m from the contact there is, instead of masses of fragments, a less fractured mass of diorite, containing only sparse veins of the cementing schist, but N. of it breccia again occurs.

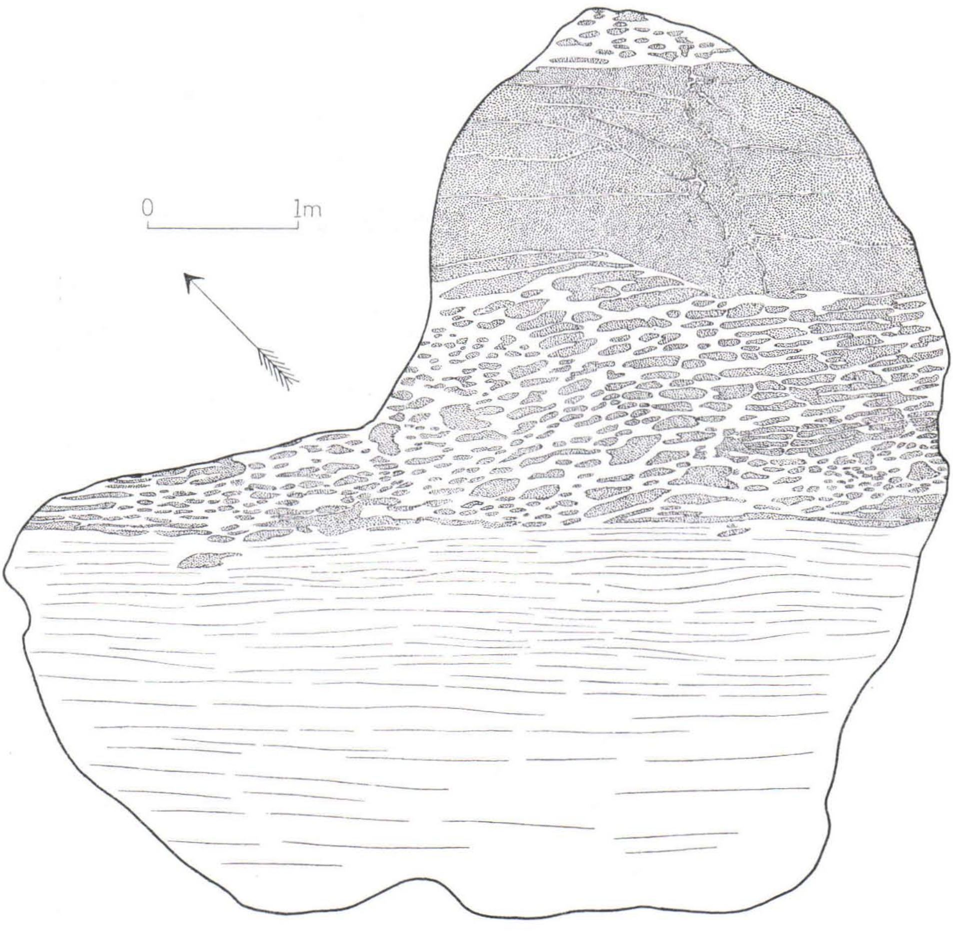

Fig. 23. Map of a horizontal rock surface showing the contact between brecciated diorite (dotted) and mica-schist (white) E. of Jaakkola in Suodenniemi, 1: 50 of the nat. size.

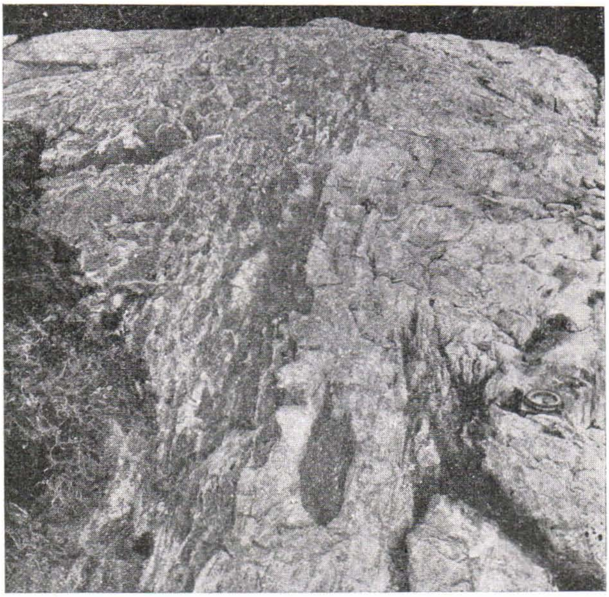

Fig. 24. Breccia and mica-schist in contact. Part of the rock surface shown in fig. 23, seen from N.W.

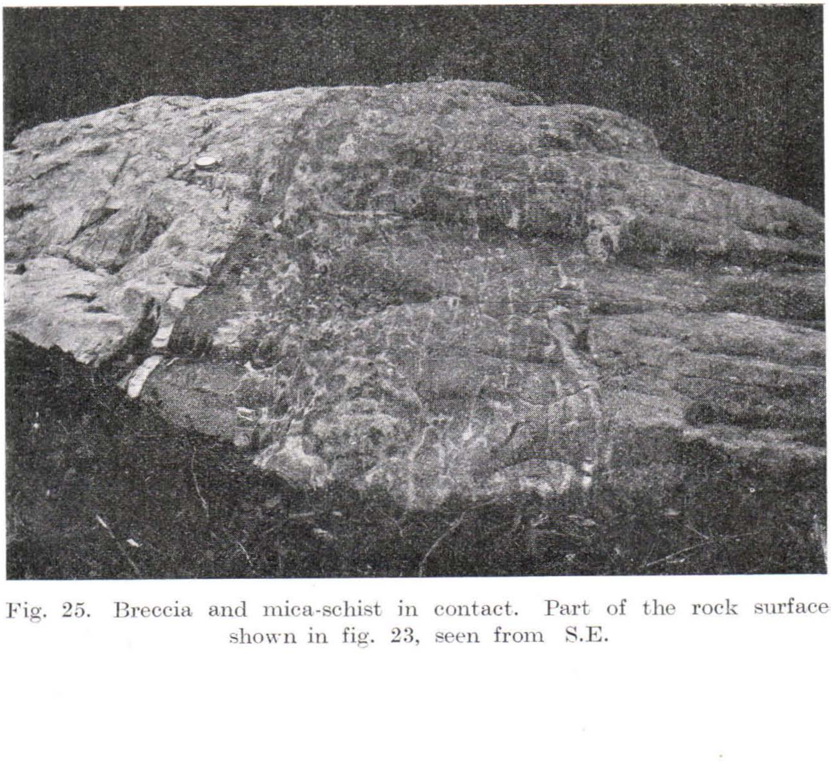

Fig. 25. Breccia and mica-schist in contact. Part of the rock surface shown in fig. 23, seen from S.E.

There is not the slightest sign of intrusion by the diorite. The schist shows a distinct bedding near to the contact, but is otherwise absolutely similar to the cement of the breccia. As it is the same schist that contains a thick intercalation of conglomerate 70 m more to the south, its character of a true sediment cannot be doubted. If we wish to regard this schist either as a primary, or palingenetic eruptive mass, then we may as well ascribe a similar origin to the conglomerate! Nobody who has any respect for facts could, standing before this contact, explain it by assuming that the diorite was

Fig. 26. Sharp contact between diorite (dark) and mica-schist in the area S. of Lake Jyrmysjärvi in Suodenniemi.

younger than the schist, or that the schist has been »injected» in the diorite. It is a residual sedimentary breccia overlaid by a normal sediment in a slightly metamorphic condition.

There are occasionally sharp contacts also between the schist and a diorite showing no brecciation. Such contacts occur at several places in the region S. of Lake Jyrmysjärvi in Suodenniemi. (fig. 26). Occasionally there are pegmatitic veins in the schist near the contact, but this red pegmatite belongs to the younger granites of the region and has nothing to do with the diorite.

Cf. also the microphotograph in fig. 27 which shows a contact between the schist and the diorite of the small area N.W. of Lake Vähä Laisjärvi.

If we admit the possibility of a palingenesis of the schist, a process which is, hovever, not exemplified anywhere else at similar contacts, we should expect to find a mica-schist of the coarse crystalline character that occurs in intimately granitized rock masses, not as here a fine-grained rock with a texture that does not indicate any particularly high degree of metamorphism.

It is also impossible to assume that this breccia has been formed by tectonic movements. The character of such friction-breccias is well known. The fissures are usually irregular in breadth and direction and often branching. They do not end abruptly at the contact of an adjacent rock. The fragments that have originated by crushing have

Fig. 27. Fine-grained mica-schist and diorite in contact.
Region N.W. of Lake Vähä Laisjärvi in Suodenniemi. Nicols ‖. 13 ×.

forms which are rather typical, and an irregular mixture of fragments and cement is characteristic of these breccias.

On the other hand, phenomena analogous to those which have been observed here, are, as already remarked at the outset, very common in rock masses that have undergone secular weathering. The present writer has tried, by correspondence with colleagues in different parts of the world, to get material for a comparison with modern phenomena. Professor Milon in Rennes has been kind enough to send to him the photograph which is reproduced in fig. 28. It shows a boulder of granite lying in a Quarternary terrace on the northern shore of the island of Batz in Brittanny (Dept. Finistère). During weathering, this boulder has been divided into a number of smaller fragments which are separated by an arenaceous mass. By the courtesy of Professor Kirtley Mathers at Harvard, the present writer has also received some photographs showing analogous phenomena, rocks of diabase that have been divided by weathering into a great number of smaller fragments.

Every geologist acquainted with the surface geology of crystalline areas in regions which have a temperate climate and have not undergone glaciation, is familiar with similar processes. The geologists of Fenno-Scandia have had less opportunity to study these phenomena, because the products of secular weathering have here been obliterated

Fig. 28. Boulder of granite lying in a Quaternary terrace and changed by weathering into a heap of fragments. Photo Y. Milon.

during the Ice Age. In countries with a warmer climate we meet other forms of surface weathering. We shall later return to the question of the climatological differences causing different types of superficial products of weathering.

In the present case the occurence of conglomerates with dioritic pebbles (partly associated with dioritic meta-arkoses) lying at a distance of 60—70 m from the breccias, add much to the arguments in favour of an explanation of the present breccias as residual rock masses. Taking into consideration the evidence from the whole of this area, the proofs seem to be so complete that it may appear unnecessary toil to give the argumentation for this thesis in such detail.

But, on the one hand, the occurrence of rocks formed by secular weathering in very old Archaean areas is a fact of so great importance, that it well deserves to be proved as completely as possible. On the other hand, the present writer has met so much contradiction of his arguments, not only when they were first propounded for the explanation of the inconsiderable and rather enigmatic area of breccia at Lake Naarajärvi, but also later, from colleagues who have tried to defend with the utmost persistence almost every possible position of retreat, that he is anxious to have these arguments thoroughly refuted and the discussion, which has lasted more than 30 years, finally settled.

One of the objections raised is that the diorite of the pebbles of the conglomerate may belong to a different diorite from the fragments of the breccia, because the former are often coarser-grained and show a better primary texture. As already pointed out, the pebbles of the conglomerate are by no means uniform in texture; there are such as have quite the same grain as the diorite of the breccia. Moreover, the primary texture has obviously been modified by later influences. This is true both of the diorite occurring in greater masses and that of the pebbles of the conglomerate. In both cases an earlier existing coarse texture has been obliterated by the partial destruction of the larger feldspar crystals.

Both direct observations of the pebbles and everything which we know about massifs of diorites and similar rocks, make it probable that varieties of different texture occurred in the same rock masses. One part of the pebbles of the conglomerates may have been derived from upper portions of mountains, lying near to the coast, another part from lower portions where both the primary textures and the relations to the weathering processes have been different.

The question whether the diorite is an abyssic or a hypabyssic rock, which has played a great role in the earlier discussion, will be treated later on.

The breccia of Jaakkola is cut by dykes of m e t a b a s a l t (uralite-porphyrite) which have a breadth of 40 cm—2 m. The contact lines are not rectilinear, but sinuous, giving the impression that the fissure into which the magma was injected was not a solid rock, but an nonhomogeneous mass of gravel (fig. 29). A continuation of these dykes is found in the adjacent conglomerate and S. of it. Here the breadth of the dykes is sometimes 5 metres. On the map in fig. 6 only one continuous dyke is shown, but there are at some places at least two parallel fissure dykes. These metabasalts are no doubt genetically connected with the uralite-porphyrites that outcrop in the area N. of the mica-schists. As there is little doubt that this rock mass, which was originally of volcanic origin, belongs to the same series as the Bothnian mica-schist, the occurrence of these dykes also makes a pre-Bothnian age of the diorite more probable.

The rock of the dykes is a typical uralite-porphyrite, showing 2—3 mm long, broad crystals of uralite in a schistose groundmass, consisting of green actinolithic hornblende, flakes of biotite, grains of plagioclase, occasionally of quartz. Magnetite occurs as rounded

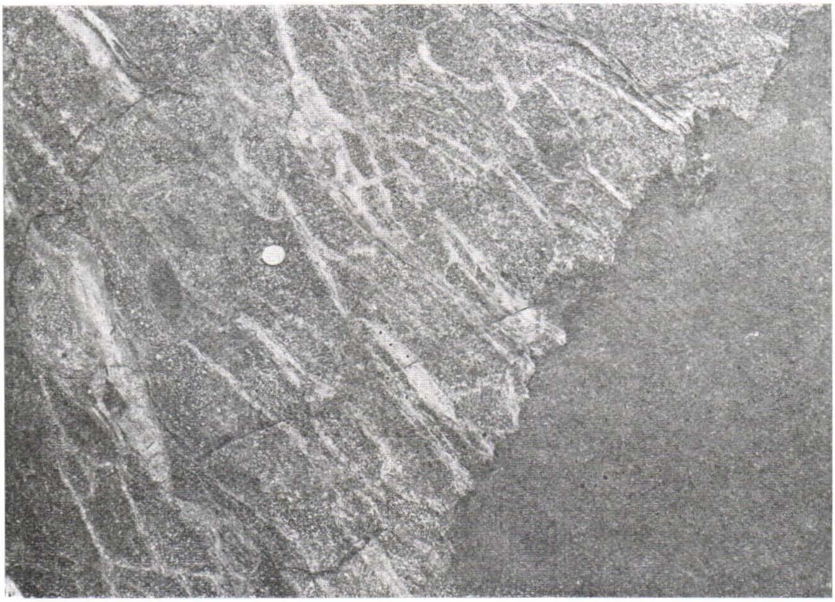

Fig. 29. Breccia in contact with a metabasaltic dyke rock. Horizontal rock surface S. E. of Jaakkola in Suodenniemi. 1 : 8 of the nat. size.

grains which are certainly secondary. The porphyritic uralite-crystals are often full of inclusions of biotite, ore and plagioclase. In some cases only the cores of the porphyritic crystals contain these interpositions. The rock is highly metamorphic, but was no doubt originally a basalt, belonging to the group of volcanic rocks which are closely associated with the sedimentary schists of Bothnian age.

The dykes of the Jaakkola region seem to be a continued to the south, where uralite-porphyrite was observed about 1 km N.N.W. of Lake Kuusjärvi. The whole zone of dykes should thus have a length of at least two kilometres.

It is a fact of great interest that dykes which intersect the strikes of the schists at right angles are thus continuous, showing how little deformation of the rocks has occurred since the eruption of the metabasalt.

Other narrow dykes of a similar metabasalt occur E. of Paisjärvi, in the S.W. corner of the area shown in the map in fig. 5.

These are a little more faulted than the dykes of Jaakkola.

These dykes were found after the printing of the preliminary edition of this pamphlet and are not shown on the map in fig. 5, p. 18.

DIORITIC META-ARKOSES AND SCHISTS N. E. OF LAKE VÄHÄ LAISJÄRVI.

Immediately W. of the boundary between the parishes of Suodenniemi and Mouhijärvi, a zone of a diorite-like rock begins, stretching westwards. Some portions of the rock are rather homophanous and

Fig. 30. Microphotograph of a dioritic meta-arkose from the area N.E. of Lake Vähä Laisjärvi. Nicols +. 13 ×

similar to the more typical diorite, but generally they differ from it both in composition (cf. the analyses on p. 41) and texture. Some portions are spotted or striped in an irregular way. others more schistlike with a well developed parallel texture. The feldspars have no distinct limits, but through them have grown flakes of biotite and crystals of amphibole, etc., like weeds in a field (fig. 30).

Occasionally fragment-like inclusions of a fine-grained micaschistlike rock, surrounded by a light-coloured rim of a rock, rich in quartz, occur (fig. 31). They remind one of fragments of schist in a plutonic rock and may possibly have that character. In any case, there are other inclusions which certainly have another origin.

They are rounded and show a centric structure, and their material is very rich in hornblende. Similar rock varieties occur as vein-like stripes, too, and are in an irregular way mixed up with the diorite-like mass (fig. 32).

Also in boulders all kind of transitions are found between a more typical gneissose diorite and spotted and striped rocks of the most varying appearance.

Fig. 31. Meta-arkose (decomposed diorite), containing fragments of mica-schist. N.E. of Lake Vähä Laisjärvi in Suodenniemi. 1 : 6 of the nat. size.

More to the west, we observe near to each other outcrops of the dioritic gneiss-like rock and such of schists. N. E. of Lake Vähä Laisjärvi there is a gradual transition between both rock formations.

Farthest from the schist, the rock is most like a diorite. Nearer to the contact, it becomes spotted in a peculiar way, containing nodules of a schist-like mass which in some cases look like small pebbles (fig. 33). The rock shows here a well developed bedding. Angular inclusions occasionally also occur. Gradually, this rock passes into a schist rich in hornblende and containing small garnets. The microphotograph of this rock in fig. 34, as well as the analysis show that it already differs very much from the diorite in composition and

Fig. 32. Meta-arkose (decomposed diorite). N.E. of Lake Vähä Laisjärvi in Suodenniemi. 1 : 9 of the nat. size.

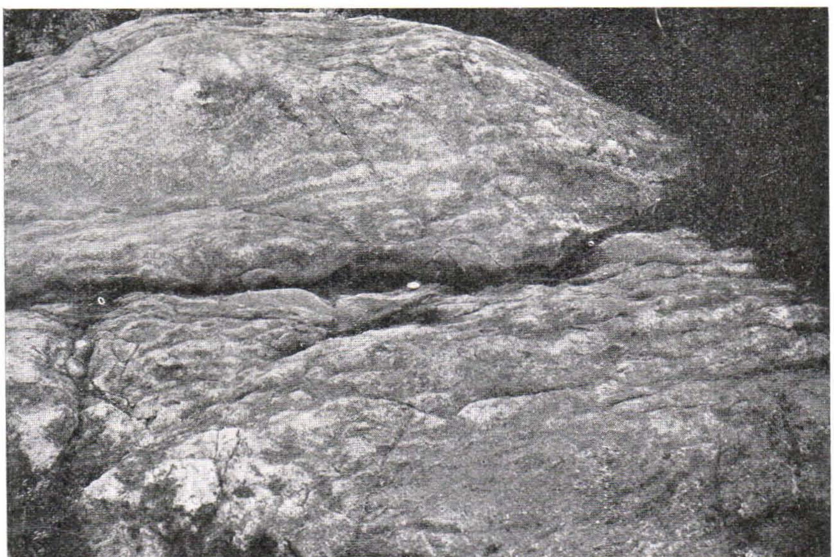

Fig. 33. Meta-arkose showing distinct bedding and containing nodules of schist. N.E. of Lake Vähä Laisjärvi in Suodenniemi. Ca. 1:15 of the nat. size.

texture, although it consisted originally of decomposed dioritic material.

Only a few metres from this outcrop a typical schist is visible, in the beginning rich in amphibole and plagioclase (fig. 35, cf. the following analysis) but a little farther possessing the character of a fine-grained mica-schist or phyllite, such as are common in the present area.

There is nowhere any limit between these rocks, but, on the contrary, the most indubitable gradations.

As will be remarked when comparing the analyses which have been made by Dr. L. Lokka, with those on p. 20, the middle-grained diorite-like rock, which is no doubt an arkose, has a composition which is not very far from that of a diorite. Only, there has been a decrease of soda and an increase of silica and lime.

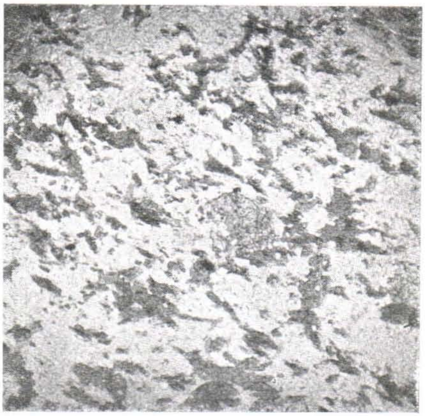

Fig. 34. Microphotograph of a garnetiferous schistose meta-arkose N.E. of Lake Vähä Laisjärvi. Nicols ∥. 13 ×.

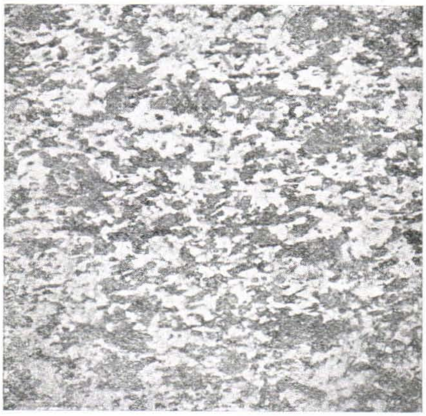

Fig. 35. Microphotograph of an amphibolitic schist. N.E. of Lake Vähä Laisjärvi. Nicols ∥. 13 ×.

In the schistose meta-arkose containing garnets there is less silica and still more lime.

The »amphibolitic schist» has been formed out of decomposed dioritic material that has been transported and washed by the waves, and therefore its composition is rather different from that of the residual rocks (cf. the analysis).

Rocks from the transition zone between dioritic meta-arkose and schist E. of Lake Vähä Laisjärvi in Suodenniemi, analyzed by Dr. L. Lokka.

	Meta-arkose (decomposed diorite) N.E. of Lake Vähä Laisjärvi	Schistose meta-arkose N.E. of Lake Vähä Laisjärvi	Amphibolitic schist N.E. of Lake Vähä Laisjärvi
SiO_2	66.16	56.02	53.90
TiO_2	1.87	3.46	2.91
Al_2O_3	19.53	16.23	16.82
Fe_2O_3	0.49	0.65	0.74
FeO	5.06	6.31	7.41
MnO	0.09	0.20	0.18
MgO	2.34	2.30	4.45
CaO	7.55	11.76	7.81
Na_2O	2.96	1.31	3.31
K_2O	2.89	0.78	1.11
P_2O_5	Traces	Traces	Traces
H_2O+	0.93	0.98	1.49
H_2O-	0.06	0.09	0.10
Sa.	99.93	100.09	100.23

THE CONGLOMERATIC ZONE OF LAKE JYRMYSJÄRVI.

S. of Lake Jyrmysjärvi a conglomerate was found by Mikkola in 1931 not very far from the contacts of the dioritic areas. As shown by fig. 36, it contains a number of pebbles, some well rounded, some

Fig. 36. Conglomerate S. ot Lake Jyrmysjärvi in Suodenniemi. 1 : 7 of the nat. size.

more angular. In its general character it is however more similar to a conglomerate than to a breccia, but it passes into varieties with smaller fragments that may be called meta-arkoses or meta-greywackes. Some of them contain numerous small angular fragments of grey quartz, similar to that which sometimes occurs as cement in the breccias of the region. Other pebbles consist of a dark amphibolitic rock, but in others we recognise the peculiar texture and mineral composition of the porphyritic lavialite. This fact is of great interest, because it shows that conglomerates where the pebbles mainly consist of lavialite, like the conglomerates with dioritic pebbles, occur near to the floor of the sedimentary formation. E. of this outcrop of conglomerate, a belt of feldspathiferous rocks stretches in an E.N.E. direction to the region N. of Lake Vähä Laisjärvi.

THE CONGLOMERATIC ZONE AT THE SOUTHERN CONTACTS OF THE AREA OF BOTHNIAN SCHISTS.

Perhaps more interesting than any other conglomerates of the region are those which occur along the southern contacts of the Bothnian zone. To them belongs the so-called conglomerate of Harju which was discovered during the first survey of the region. It is situated 850 m W.S.W. of the farm of Harju and only 300 m S.S.W. of the new farm of Rinne, immediately S. of the road to Ylinen Vehkajärvi, 200 km E. of the place where the road to Rinne branches off. It is a very typical conglomerate containing well-rounded pebbles of a varying composition, in a crystalline matrix rich in quartz and feldspar (fig. 37; cf. fig. 2).

In large boulders more to the east a variety occurs where only some of larger fragments are rounded, while others are angular (fig. 38). The conglomerate thus passes by gradations into a breccia.

The present writer regarded this rock from the beginning as a basal conglomerate, because it contained pebbles derived from the rock-masses outcropping S. of it, among them the characteristic diorite-porphyritic rock called lavialite.

Mica-schists, however, were found closely associated with the conglomerate, also S. of it, and these mica-schists were rather similar to those connected with the lavialite, and there also seemed to be a general coincidence of the strikes on both sides of the assumed unconformity. Mäkinen therefore thought that the rock was no real basal conglomerate, but intraformational in character, as were also, in his opinion, the conglomerates of the same area containing

Fig. 37. Conglomerate with a pebble of »lavialite». S.W. of Harju in Suodenniemi. 1 : 6 of the nat. size.

Fig. 38. Conglomerate passing into a breccia. S.W. of Harju in Suodenniemi. 1 : 7 of the nat. size.

dioritic pebbles. Mikkola arrived at the same conclusion on a second survey of the region.

The proofs of unconformity could in fact be regarded as weak so long as only one single outcrop of this conglomerate was known. One swallow does not make a summer. In June 1931, however, when the present writer and Mikkola were working together at the survey of the region, the latter found a further continuation of this conglomerate to the N. of Lake Ylinen Vehkajärvi and S. of Lake Palojärvi, partly outcropping as small rocks and

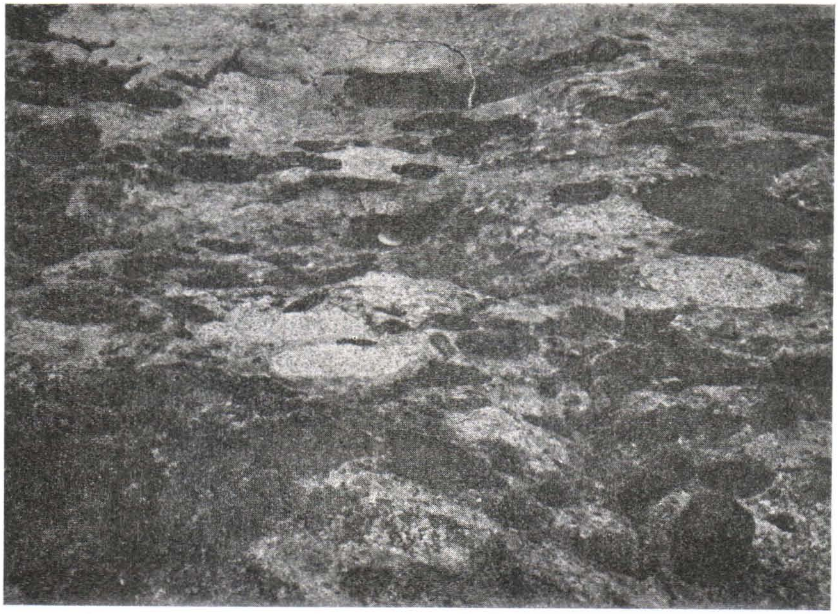

Fig. 39. Conglomerate with flattened pebbles. Boulder W. of Vanhakulku in Suodenniemi. Ca 1 : 5 of the nat. size.

partly as big boulders which were obviously derived from a near outcrop. That made the whole length of the conglomeratic zone about 2 km.

Later, the present writer found a continuation also to the east. 500 m E.S.E. of the Harju conglomerate, a large area was strewn with big boulders of conglomerate, some of them measuring more than 20 cubic metres, and no doubt indicating a near outcrop. The direction of the glacial striae makes it impossible to derive them from the Harju outcrop.

Nearly 1 km more to the S.E., and S. of the farm of Koski, were found numerous smaller boulders of different varieties of conglomerate and arkose, similar to those at the former places, but probably derived from a more easterly outcrop.

Finally, 1 700 more to the E.S.E., an area was found overstrewn with big conglomeratic boulders, immediately W. of Vanhakulku, W. of Lake Kourajärvi. The pebbles here are more flattened by orogenetic action than those at other places (fig. 39). They must be derived from a near outcrop.

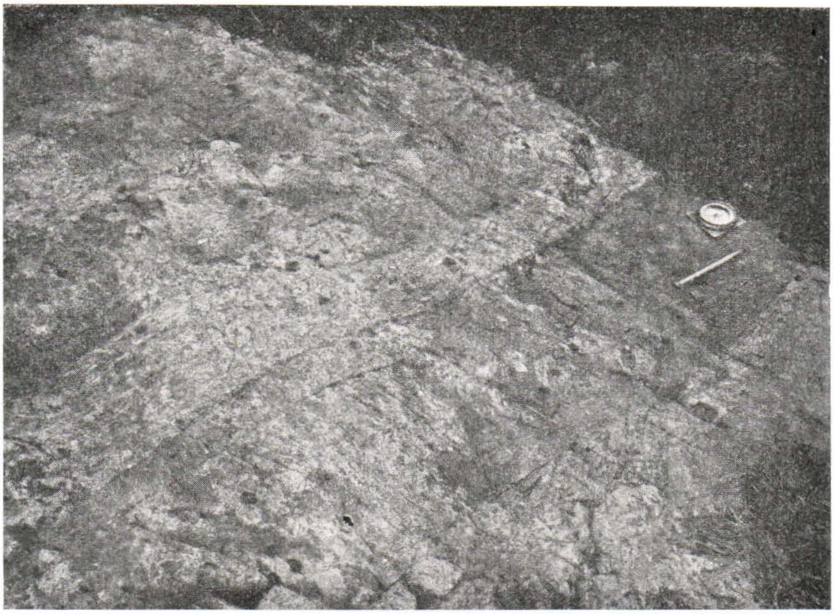

Fig. 40. Layers of conglomerate with flattened pebbles alternating with layers of mica-schist. E. of Lake Paisjärvi in Suodenniemi. Ca. 1 : 8 of the nat. size.

This conglomeratic layer, from Palojärvi to Vanhakulku, may be designated as the Pajuniemi conglomerate, because it stretches through the territory of that village.

S.E. of Vanhakulu there occurs a sudden change in the strike of the rocks, both those containing the conglomeratic layer and the older rock masses. At the boundary a younger diorite has been intruded which sends out dykes into the adjacent schists.

Here also conglomeratic layers were found, forming a continuation of the zone already described. They are in the northermost part, E. of Lake Paisjärvi, at some places less typical, consisting mainly of small flattened fragments the character of which it is difficult to determine (fig. 41), but in some places consisting of wellrounded pebbles. This rock forms several layers intercalated with meta-arkoses. Another conglomeratic layer was found S.E. of this locality, in the region S.E. of the farm Anttila; the schists are here penetrated by numerous dykes and veins of diorite.

Lastly a thicker layer of typical conglomerate occurs in the schists of Hautavuori, N.W. of Lake Kuusjärvi. It also lies near to the boundary of the Bothnian schist.

We may confidently map the conglomeratic layer as continuous from the region S. of Lake Palojärvi to Vanhakulku, along a distance of 6 km, and very probably the conglomeratic zone S.E. of it, two kilometres in length, was also continuous before the dislocations connected with the eruption of the younger diorite in the region S.E. of Paisjärvi. This would make the whole length at least 8 km.

This conglomeratic layer does not lie immediately at the base of the Bothnian schists, but very near to it, its position thus being identical with that of the conglomerate containing dioritic pebbles in the Jaakkola area. And just as these are derived from rocks outcropping near the conglomeratic layer, so we find, at the southern contacts, all those older rocks which outcrop next to the Bothnian zone as pebbles in the conglomerates. These therefore, no doubt, belong to the basal parts of the Bothnian sedimentary formation.

PETROLOGICAL DESCRIPTION OF THE CONGLOMERATE.

The conglomerate of the outcrops in the western part of the zone all belong to the same type, although showing variations in the relative numbers of the pebbles of different character.

Although the conglomerate of Harju has already been described in detail in the earlier memoir, a short description will be given here of the conglomerates of the western part of the zone, N.E. of Lake Ylinen Vehkajärvi, with special reference to observations of features not previously known.

THE PEBBLES.

Among the pebbles there are such as certainly consist of metamorphic sediments. Among them a crystalline quartzite (fig. 41) is represented by a small number of pebbles. It consists mainly of grains of quartz with denticulated contours, with smaller quantities of biotite, hornblende, microcline etc. Mica-schists also occur as pebbles, and are similar to those outcropping S. of the belt of Bothnian schists, although, as is often the case with pebbles in

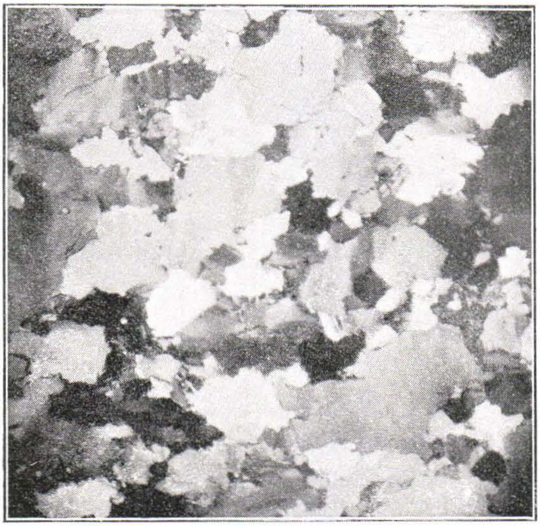

Fig. 41. Crystalline quartzite as pebble in the conglomerate of Harju. Nicols +. 18 ×.

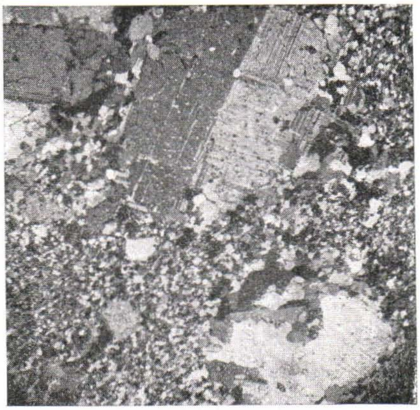

Fig. 42. Meta-andesite occurring as pebble in the conglomerate N.E. of Ylinen Vehkajärvi. Nicols +. 11 ×.
Photo W. W. Wilkman.

metamorphic conglomerates, a little less changed than the outcropping rock.

Some of the pebbles are macroscopically similar to fine-grained granites. They consist of granular rocks rich in feldspar, which is preponderantly plagioclase. In thin sections it becomes evident that they are not granitic, but belong to a series of volcanic, partly possibly hypabyssic rocks, and sediments derived from such material. Thus a pebble of an almost white feldspathiferous rock consists of crystals of andesine, measuring a few mm in diameter, and a fine-grained groundmass, composed of feldspar, mainly plagioclase, some quartz, microcline in microperthitic intergrowth with the plagioclase, a little titanite, zoisite and apatite (fig. 42). It is a porphyritic (meta-andesitic) rock, probably of volcanic origin. Another similar white rock shows microscopically a fine-grained mass, consisting mainly of feldspar, partly oligoclase, partly microcline, and quartz. The individual grains measure 0.1—0.3 mm. A few larger crystals of quartz and oligoclase occur some of which measure 3 mm in length. The texture reminds one as much of a metamorphic sedimentary rock as of an eruptive (fig. 43). It is possible that it is a variety of the meta-andesites. Another pebble has macroscopically a dioritic appearance, but under the microscope, it also shows meta-andesitic characters. It is composed of crystals, with a middle diameter of 2 mm, of labradorite and green hornblende, which may have been substituted either for primary augite or brown hornblende, and surrounded by very fine-grained mass of plagioclase and hornblende, etc.

Conspicuous among the pebbles are some consisting of a porphyritic rock with short primatic crystals of plagioclase, in a dark groundmass. It is the diorite-porphyrite known as »lavialite» which outcrops in the pre-Bothnian area S. of the conglomeratic zone. The rock of the pebbles is slightly less metamorphic than the outcropping rock, but otherwise entirely similar to it. The porphyritic labradorite crystals usually measure 3—5 mm in breadth and 5—8 mm in length; sometimes they are smaller. Uralite crystals also occur occasionally, but are few in number and irregularly dispersed. The groundmass is a fine-grained aggregate of plagioclase and secondary green hornblende in prismatic crystals. Microcline and quartz are usually present, sometimes as secondary inclusions in the porphyritic crystals which may look as if they have small perforations (fig. 41). Also hornblende, biotite and magnetite occur as secondary inclusions in the feldspar crystals and as constituents of the groundmass. Titanite in small grains is also present.

Other pebble rocks rich in amphibole differ from the »lavialite» in the smaller size of the plagioclase crystals, or in containing mainly uralite instead of plagioclase as porphyritic constituents. While the lavialite is probably a hypabyssic rock, these varieties are more

Fig. 43. Meta-andesite, or andesitic arkose, occurring as pebble in the conglomerate N. E. of Ylinen Vehkajärvi. Nicols + . 11 ×.
Photo. W. W. Wilkman.

Fig. 44. Lavialite as pebble in the conglomerate of Harju. Nicols + . 18 ×.

likely effusive. Other similar rocks show no traces of a porphyritic texture, but are composed of similar minerals in smaller grains, and more irregularly arranged. They may be tuffs of volcanic rocks, or transported and re-deposited weathering products of such rocks.

A great part of the pebble rocks may be designated amphibolitic schists, or hornblende gneisses. They are composed by green hornblende, either as slender crystals or as irregularly shaped actinolith fibres, together with biotite, quartz, feldspar and ore in varying quantities. They are, no doubt, sedimentary rocks, because they are found alternating with beds of mica-schist in the area of pre-Bothnian schists, but it is difficult to say to what extent they are tuffs, or sediments formed by transported material. In any case these deposits are derived from porphyritic rocks of dioritic or andesitic composition.

Among the basic pebbles are such as contain epidote, and some which show a dark contact zone rich in hornblende. These pebbles have probably been affected by weathering, before they became constituents of the conglomerates, since similar phenomena, which can only be explained in this way, have been observed both in the conglomerates of other localities and in breccias.

THE CEMENT.

The cementing mass between the pebbles shows a varying composition. It is often rich in quartz. Plagioclase, microcline, green hornblende, biotite, diopside, magnetite and pyrite occur in varying quantities (fig. 45). The primary constituents are not easily recognized, as the rock has undergone strong secondary changes. The present writer has previously called it gneissose. But its general character is not very different from that of the contact breccias of the same region, formed by the weathering of a diorite and cemented by sedimentary material. After all, the cement of the conglomerates is not so much more crystalline than that of the breccias which are connected with rocks that may be termed schists rather than gneisses. There is, in many cases, no very distinct schistosity in the cement of the conglomerates. The indistinct contours of the pebbles and the coarseness of the cement may be partly primary phenomena. Some pebbles show boundaries which are defined by an impregnation with pyrite or magnetite, originally probably limonite, which obviously has covered them before the metamorphic changes took place. In other cases, the outlines may have become faded because the outer portions were a little weathered, and easily allowed the formation of secondary minerals at their contacts with the cement.

In any case the conglomerates are, as shown by the figures, very typical, and there is not the slightest doubt about their origin.

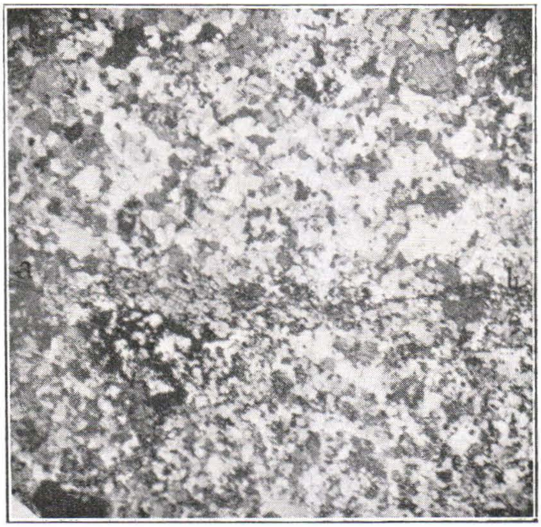

Fig. 45. Cement (upper part in the figure) and pebble whose outline is marked by pyrite (below the line a—b). Conglomerate of Harju. Nicols + .18 ×.

THE META-ARKOSE.

The arkose which occurs S. of the conglomerate is closely associated with it, mainly composed of grains of quartz and feldspar,

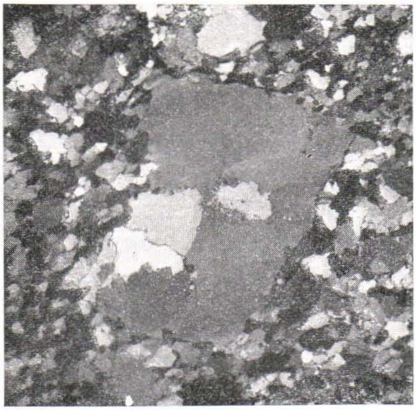

Fig. 46. Meta-arkose with fragments of quartz. N.E. of Ylinen Vehkajärvi. Nicols + . 11 ×.
Photo W. W. Wilkman.

measuring 0.1—0.5 mm in diameter, and small flakes of biotite. This mica-schistlike mass contains larger angular fragments of quartz which measure up to 5 mm in length. A few traces of a clastic texture are still visible in this crystalline schist (fig. 46).

COMPARISON BETWEEN THE ROCKS OF THE CONGLOMERATIC PEBBLES AND THE ROCKS OUTCROPPING S. OF THE AREA OF BOTHNIAN SCHISTS.

Although the contact of the Bothnian schists and the rocks of the floor cannot be exactly traced S. of the conglomeratic zone owing to the lack of outcrops, there is no doubt about the existence of a break in the succession.

There is a marked contrast in the general character of the schists on both sides of this boundary line. The Bothnian schists are dark, rather homogeneous and uniform rocks, and their strikes run straight and regularly. Scarcely any minute foldings occur. Only some varieties, especially the arkoses, are more crystalline than the others which are, on the whole, not much more metamorphic than the well-preserved schists of the Bothnian areas next to Lake Näsijärvi. Also the well-preserved character of the pebbles of the conglomerates, which are in most cases very little sheared, shows the moderate amount of gliding which the rocks have undergone.

The older schists again, lying immediately S. of the supposed contact line, are in several outcrops represented by typical mica-schists showing strong folding, even in detail, and a schistosity marked by glittering flakes of biotite and muscovite which makes them very different from the dull-coloured younger schists. The former regularly contain, over large areas, accumulations of muscovite which are obviously pseudomorphs of staurolith crystals. It seems by no means certain that these stauroliths have originated through the action of any pre-Bothnian granite. They may just as well be due to a granite later than the younger schists, but, in any case, it must have been the difference in petrological character and in position of the older schists that has caused them to react differently to tectonic movements and granitization than the younger ones.

This marked difference in the behaviour of the schists of different ages is also shown by the very varying strikes of the older schists, as is apparent on the maps, in contrast to the regularity of the strikes of the Bothnian zone. It is true that the area of older schists has not been surveyed in the same detail as the younger zone, but, in any case, sufficiently so to make it possible to map the general features.

The older mica-schists are, as already remarked, intercalated with narrow zones of typical »lavialite», almost wholly similar to the rock of certain pebbles. The floor of the Bothnian lies to the S. of the conglomerates, and has suffered decay at the time of their deposition.

The above remarks refer especially to the pre-Bothnian complex S. of the western part of the conglomeratic zone where the unconformity is very clear and obvious. In the eastern part, N. of Lake

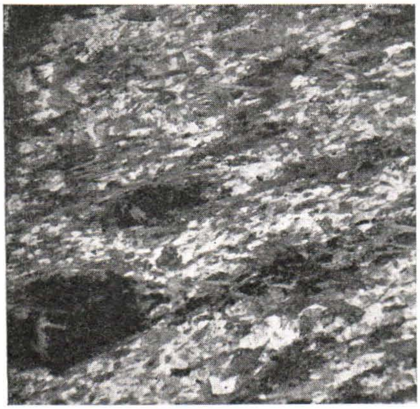

Fig. 47. Bothnian amphibolitic schist (meta-arkose formed out of amphibolitic material). Hautavuori N.W. of Lake Kuusjärvi. Nicols ||. 11 ×.
Photo W. W. Wilkman.

Mouhijärvi, things are, as has been stated, a little different. The conglomerates become more sheared at the point where the boundary line turns to the S.E., and the conglomeratic layers become thinner and less regular. At several places the younger schists in the region between the lakes Kourajärvi and Paisjärvi, and also in Hautavuori, contain intercalations of amphibolitic schists (fig. 47), in some cases with bigger plagioclase crystals. These schists are no doubt arkoses formed out of the material of the older amphibolites.

In the area S.W. and S. of the contact line marked by the conglomerates, mica-schists similar to those in the western outcrops occur, intercalated with typical lavialites, and also with amphibolitic schists which seem to be sediments. Next to the younger schists, amphibolitic schists form a broader zone than at other places. They are sometimes fine-grained, resembling in character the mica-schists and grading into them; in other cases, again, medium-grained and more similar to eruptive rocks of the diorite family. In the S.E., there is an area of porphyritic rocks which differ from the lavialite in containing more slender plagioclase crystals, and not the short prismatic ones which are commonly characteristic of this rock. Varieties with predominating uralite crystals also occur. It is not quite certain whether they are not areas of diorite-porphyrites associated with the younger diorite, although it seems more probable that the rocks in question are varieties of the lavialite.

In the same region, there are also light rocks associated with the schists which seem to be feldspathiferous quartzites. Amphibolitic schists however predominate. The map of this region has been drawn mainly according to the survey of Mikkola, and the boundary line between older and younger schists according to the observations of the present writer. It is possible that a more detailed survey would slightly modify the map in these parts, but the scantiness of outcrops along this zone makes it improbable that a further continuation of the conglomeratic zone to the east could be traced.

In an earlier publication, the schists of the region N. of Lake Mouhijärvi were referred to the Bothnian, especially because such primary features as cross-bedding has been observed in them. Mikkola has also observed a conglomeratic structure in the older schists E. of Lake Kankaanjärvi, W. of Lake Kourajärvi. It is by no means so distinct as the conglomeratic structure of the Bothnian schists, but is in any case another proof of the fact that normal sediments occur also in the area S. of the Bothnian schists. Thus we observe, next to the Bothnian area, not only a floor consisting of plutonic diorites, but also normal supracrustal rocks, sediments and volcanics which were weathered at the time of the deposition of the younger series and yielded the material not only of the pebbles of the conglomerates, lying near to the bottom of the Bothnian, but also much of the material of the finer-grained sediments.

The occurence of weathered plutonic rocks, forming the floor of a sedimentary series, is indicative of an unconformity. Such a contact as that in the south, between two series of sediments separated by a break, proves still more definitely the existence of that unconformity.

THE BRECCIA OF LAKE NAARAJÄRVI IN LAVIA.

When comparing the breccias of the Jaakkola area and other rocks of the neighbourhood with the contact breccia earlier discovered N. of Lake Naarajärvi in Lavia, about which so much has been written, we are aware of the analogy of these phenomena. Only there are, at the latter place, two diorites of different ages, which circumstance makes the conditions much more complicated. As the earlier discussion has been written in Swedish, it may be advisable here briefly to relate the arguments in English, reproducing most of the illustrations. It is true that these phenomena have lost part of their interest since the discovery of similar rocks whose origin is so much clearer. In any case, the little outcrop of breccia at Lake Naarajärvi shows features which have not been observed in other localities and have much interest especially from a chemical point of view.

The breccia of Lake Naarajärvi forms a little »roche moutonneé» with a height of a few metres and an almost horizontal upper surface. It is now so overgrown with lichens and mosses that it is difficult to discern the finer features. In 1914 it was laid entirely bare by Dr. Mäkinen who stripped off all the covering mosses. He mapped it in great detail, and one of his maps is here reproduced. (fig. 48). They are specimens of very accurate work. This little rock has, in comparison to its area, been investigated in greater detail and also photographed more completely than most other outcrops of pre-Cambrian rocks.

The circular area of breccia is surrounded by mica-schist, encircling it almost completely. In the centre we observe a medium-grained dioritic rock in which as much of the primary character is left as in the better preserved varieties of the Suodenniemi diorite. It contains numerous quartzitic veins, subdividing the rock in fragments (fig. 3) which become more numerous, and often also more basic, the nearer they lie to the outer contacts.

Part of them have the composition of a dark basic gabbro. This dark rock forms the whole of some of the fragments, but often only the rims, while the central portions are dioritic (fig. 49). The dark zones are however very irregular (fig. 50) and sometimes obviously lie along fissures (fig. 51).

In the outermost portions of the breccia, the dark fragments are often surrounded by a lighter zone, rich in diopside and garnet, and this mass forms the whole of some of the fragments.

The cement between the fragments is often quartzitic (figs. 49—51). In other cases it consists of a schist which may even show a distinct

Fig. 48.

Fig. 48. (On the opposite side).
Geological map of the area N. of Lake Naarajärvi N. of the church of Lavia, drawn by E. Mäkinen. Scale 1 : 2222.

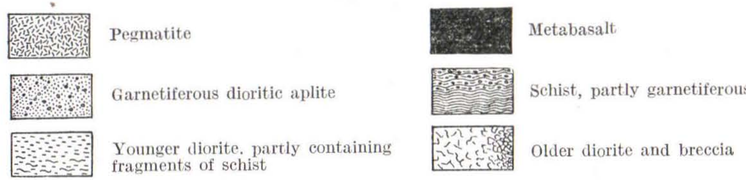

Fig. 49. Breccia of Lake Naarajärvi, near the northern contact.
1 : 7 of the nat. size.

Fig. 50. Breccia of Lake Naarajärvi, near the S.W. contact.
1 : 7 of the nat. size.

Fig. 51. Breccia of Lake Naarajärvi. Zone rich in hornblende next to a fissure. 1 : 6 of the nat. size.

Fig. 52. Cement in the breccia of Lake Naarajärvi, showing bedding, in the N.E. part of the area. 6 of the nat size.

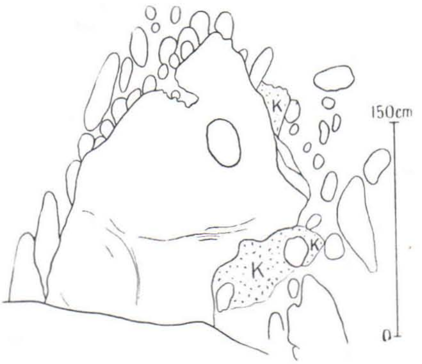

Fig. 53. Vertical surface next to the western contact of the breccia of Lake Naarajäri. K = calcitic cement. 1 : 52 of the nat. size.

Fig. 54. Western contact of the breccia of Lake Naarajärvi, showing pebble-like inclusions in the adjacent schist.

bedding (fig. 52), and next to the contacts with the surrounding schist the cement consists in great part of calcite (fig. 53). Here the fragments are rounded and the breccia becomes conglomeratic in character (figs. 54—55).

The contact with the adjacent schist is always sharp (fig. 56), even when the cement is similar to the schist in composition. Next to the contact, the schist occasionally shows a distinct bedding, and contains pebble-like inclusions of highly altered diorite (fig. 57). Some of these rounded fragments consist of the variety rich in garnet and diopside.

The cement of the breccia is often rather similar to that of the Jaakkola breccia, especially when it is quartzitic (fig. 58). In other cases, it contains more feldspar. The texture is exactly like that of sedimentary schists. The existence of a calcitic cement at some places further shows that it cannot have an eruptive origin.

Like the breccia of Jaakkola, the rock of the Naarajärvi hill is cut by narrow veins of a metabasaltic rock which is here fine-grained,

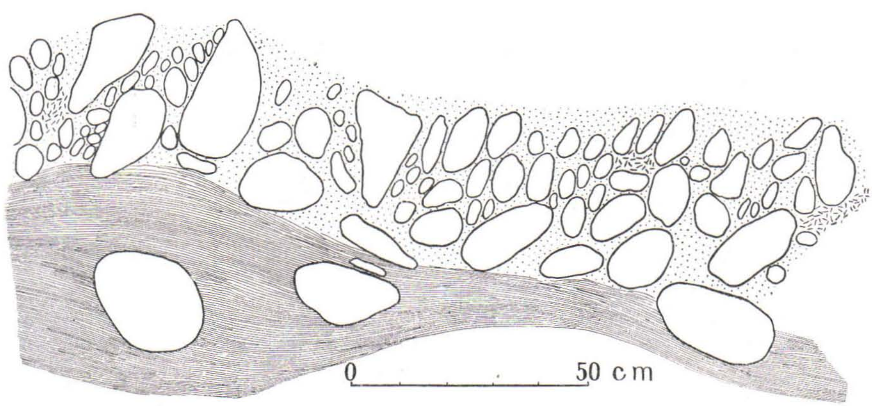

Fig. 55. Map of the rock surface shown in fig. 42. 1 : 16 of the nat. size.

almost aphanitic. The breccia is further cut by a narrow vein of a younger diorite, rich in garnet, and N.E. of the hill of breccia large outcrops of a diorite occur which contains sharply defined fragments of breccia (fig. 59) and also penetrates it in numerous veins. Pegmatitic dykes occur, possibly connected with this younger diorite which E. of the breccia is clearly intrusive into the schist.

The existence of this younger diorite, in appearance rather similar to the older one, added much to the difficulty of explaining the breccia of Naarajärvi. Most observers found it difficult to assume that the conditions could be so complicated that there were two very similar diorites of different ages. They preferred to think that the brecciation was a primary phenomen; that the dark portions of the fragments had been earlier consolidated than the main mass and had been later brecciated during the continued intrusion of the magma.

The interpretation given by the present writer, according to which the older diorite had been disintegrated by subaërial weathering

Fig. 56. Contact between breccia and schist at the northern side of the area N. of Lake Naarajärvi. 1 : 7 of the nat. size.

before the deposition of the schist, has been corroborated by the observations now made in Suodenniemi. Some portions of the breccia of Jaakkola are entirely similar to parts of the Naarajärvi rock. That it is a residual rock mass therefore seems indubitable. There has been a more abundant deposition of limonitic and calcitic material between the fragments and in part within them, in the Naarajärvi rock than in that of Jaakkola. A similar accumulation of finely dispersed limonitic

Fig. 57. Schist next to the southern contact of the breccia of Lake Naarajärvi. A distinct bedding is visible, and the schist contains a rounded inclusion of decomposed diorite (to the left, a little above the coin). In the lower left corner breccia is visible. 2 : 7 of the nat. size.

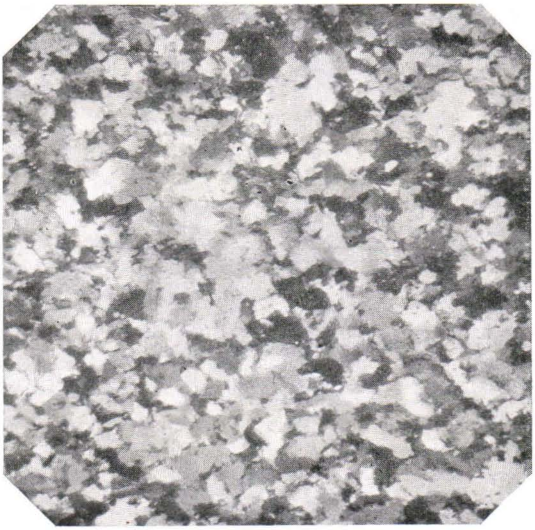

Fig. 58. Quartzitic cement in the breccia of Lake Naarajärvi, near the northern contact. Nicols +. 20 ×.

Fig. 59. Fragment of the breccia of Lake Naarajärvi, included in an aplitic variety of the younger diorite. N. E. of the circular area of older diorite. 1 : 10 of the nat. size.

Fig. 60. Conglomerate containing pebbles of diorite and one pebble of a rock rich in diopside and surrounded by a rim rich in hornblende. W. of Välimäki in Lavia. 1 : 5 of the nat. size.

material, which has later been taken up in the silicates, has obviously taken place in the contact rocks of Lake Pieni Laisjärvi.

The texture of the darker pebbles, as revealed under the microscope, is not that of an intrusive gabbro, although the composition sometimes comes near to it. The dark minerals are obviously secondary, shelf-like crystals of hornblende sometimes lying across the contacts of the fragments, and heaps of garnet lying parallel to their outlines. The calcitic part of the cement, mixed with small crystals of epidote, has still less likeness to a magmatic rock.

In the better preserved diorite the individual plagioclase crystals contain numerous small rounded inclusions of quartz, etc., so that they have a pitted appearance (fig. 7).

Also in the conglomerates of Lavia containing dioritic pebbles, occasionally occur such as are dark and possess a zonal structure (fig. 60), thus being similar to the pseudo-gabbroid fragments in the Naarajärvi breccia.

THE METABASALT OF THE NORTHERN AREA.

The »uralite-porphyrites» of the area N.E. of the Church of Suodenniemi which are no doubt of the same age as the dykes in the Jaakkola area, are often highly metamorphic (fig. 61) the pyroxene and the primary ores having been changed into rather

Fig. 61. Highly metamorphic uralite-porphyrite S. of Korpela in Suodenniemi. To the right a crystal of uralite. Nicols × . 18 ×.

compact actinolith. The form of the augite crystals changed into uralite is however still recognizable. As there are intercalations of rocks with rounded, pebble-like inclusions of varieties which do not differ so much in their composition from the surrounding rock, it seems certain that part of it has a tuffitic character. Another part consists of metamorphic rocks which are more homophanous in appearance and no doubt have originally been basalts.

PLUTONIC CHARACTER OF THE DIORITES.

An important question concerning the present rocks which has been very much discussed, is whether the diorite which has provided the material for the sedimentary deposits and is a part of their floor, is a deep-seated or a hypabyssic rock. Those geologists who have tried to explain the Naarajärvi breccia as an eruptive (or intrusive) breccia, have been apt to minimize the importance of the occurrence of dioritic pebbles in the conglomerates of the region, regarding the diorite as »intraformational» in character, and as a hypabyssic, not a really abyssic rock. Two arguments have been presented in favour of this theory. One is the likeness in chemical character between the two diorites and between them and the lavialite, which is certainly very great (cf. the analyses p. 22 and 24), and the other is the assumed gradation between the latter rock and the older diorite.

Diorites are such common rocks, always showing similar variations, that it is difficult to prove an identity of geological age merely by chemical arguments. Basaltic and granitic rocks also occur in almost all formations, often very similar in composition, and nobody has yet assumed that they are synchronous simply because they possess a common chemical character.

As to the texture, the similarity between the lavialite of the pebble shown in figs. 2 and 37, and the pebbles in the Välimäki conglomerate shown in fig. 12, which have been called lavialitic, must be admitted to be very vague, or rather non-existent. On the one hand, a typical porphyry, with a dark ground-mass, on the other a granular rock with a texture exactly like that of a typical granite. In the pebbles, gradations between the lavialite and fine-grained effusive rocks occur, but any indubitable gradations between the lavialite and the diorite have not yet been found. Even the most highly metamorphic of the coarse-grained varieties of the lavialite retain something of their porphyritic character, while the prevailing varieties of the diorite show a very uniform granitic character. If their textures are to be called hypabyssic, the same may be said about almost any diorite or granite. The occasional occurrence of some porphyritic pebbles among those of diorite is in this respect not decisive.

Even if the lavialite and the equigranular diorite could be proved to belong to the same magmatic series[1], which is in itself not impossible, that would not change the evidence of the dioritic pebbles. It is the average character of the rocks of the pebbles, as well as that of the rock masses that have undergone secular weathering, which is decisive; and this general character is certainly that of an abyssic rock. This circumstance becomes especially clear when we compare the dioritic pebbles of the present conglomerates in Suodenniemi and Lavia with the pebbles in the conglomerates of the areas near Lake Näsijärvi. In the latter, porphyritic rocks of varying chemical composition

[1] From the evidence given in this paper it is clear that the diorites and associated rocks of the Lavia-Suodenniemi area do not belong to one magmatic series, as Mäkinen admitted, but to two different series whose intrusions were separated by a period of unknown length. Moreover, one of the rocks which Mäkinen referred to this series of differentiation, the so-called gabbro from the contact breccia N. of Lake Naarajärvi in Lavia, is not a rock with a primary composition, but a diorite which has been enriched with iron, magnesia and lime during a process of secular weathering.

To the older, pre-Bothnian series belong the rocks whose analyses are quoted on page 22, to the younger one those quoted on page 24.

The analyses of the magmatic series of Mäkinen have been quoted in several pamphlets discussing differentiation phenomena, lately by E. Tröger in his interesting article Zur Sippenteilung magmatischer Gesteine (N. Jahrb. f. Min., Geol. u. Pal. 62, Beil.-Bd., A, p. 278). There is a certain danger in using such series of analyses without a thorough knowledge of the geological relations of the rocks in question.

As to the Archaean rocks of Finland, no doubt very complete differentiation series exist, among rocks which undoubtedly are genetically connected. Thus we find, among the pre-Bothnian plutonic rocks, gradations from ultrabasic and basic rocks through diorites and monzonites to granodiorites and even, although soda granites are the most prevalent in this series, to granites rich in potash (e. g., a granite from Eckerö, among the Aland Islands).

Among the volcanic and hypabyssic rocks intercalated with the Bothnian sediments at Lake Näsijärvi, and in the areas of Bothnian volcanics, we find again a very complete series of differentiation which is also represented in the pebbles of the conglomerates of the upper parts of the Bothnian. These eruptive rocks grade from trachytes and quartz-andesites (or quartz-diorites) to andesites and basalts.

Among those plutonic rocks, again, that intrude the Bothnian sediments and metabasalts, we find a differentiation series ranging from peridotites through gabbros to diorites, granodiorites, soda and potash granites.

Especially in the Bothnian and post-Bothnian series the complexity is rather great, and it seems uncertain whether the analyses will easily fit into any schematic subdivision.

occur, of which it is characteristic that they show all gradations between effusive rocks and hypabyssic varieties which sometimes show textures that are similar to those of real abyssic rocks, but never exactly like them. No such granular rocks as the diorites of Suodenniemi and Lavia are represented among these pebbles.

The younger diorites resemble often very much the older ones, and their contacts are, e. g., in the region N.E. of the church of Lavia, and in northern Suodenniemi, entirely those of plutonic rocks. The diorite forms veins and lenses in the schists and contains fragments both of schist, breccia (cf. fig. 59) and of uralite-porphyrite. The contrast between these intrusive contacts and the contact relations of the older diorite and the Bothnian schists is very conspicuous.

As stated above, porphyritic varieties of the younger diorite have been observed in the area S. E. of Lake Paisjärvi. Rocks with such textures are associated with most plutonic granites and diorites, even those of the largest areas. So we find them, in Finland also, with the granites of the great central areas, and in several places associated with the gneissose granites of the oldest group. The occurence of porphyritic varieties of the diorites, in the area under discussion, does not alter the fact that the diorite, especially in the large area in the north, is as typical a plutonic rock as any other diorite.

For all these reasons, the conclusion seems fully justified that the subaërial erosion processes in pre-Bothnian and Bothnian times had continued long enough to expose rocks which had been consolidated at a greater depth. The younger sediments were deposited on a floor which partly consisted of deep-seated rocks and partly of sediments which were already metamorphic in character.

Therefore the unconformity below the Bothnian cannot be unimportant. Moreover, there is, as already observed, over large regions a marked contrast in the general character of the Bothnian rocks and those supracrustal rocks of Finland and Sweden that are certainly older than the gneissose granites, and associated plutonic rocks.

The magnitude of that break in the succession cannot be measured in any individual area. Such rocks as volcanic basalts, and sediments formed subaërially or deposited in the estuaries of rivers, on an uneven floor, may still mark only an episode in a period of general diastrophism. The case is different if we find, between two widely extended formations of plutonic rocks which intrude older supracrustal rocks, thick deposits of normal sediments, among them also quartzites and limestones. Then it is difficult to think that the break was inconsiderable. Such sediments occur in other parts of Fenno-

Scandia. The two principal formations of old Archaean plutonic rocks (granites and associated diorites, gabbros etc.) occur over wide areas and show similar features everywhere. And they are so different in their general character that they must be separated even from a petrological point of view. They are also quite different as to their distribution.

Future publications will give further proofs of the thesis here defended, that the oldest supracrustal rocks of the region in question belong to a cycle which is different from that comprising the Bothnian and other series in northern and eastern Finland which equally are intermediate in age between the two oldest plutonic groups.

Contacts which show analogy to those under discussion, i. e. as to their original features, such as they were before the metamorphism of the rocks took place, are very common in younger formations. An example, observed by the present writer in 1896, is the contact between the Jotnian sandstone and the underlying labradorite and rapakivi granite which show evidence of having been decomposed before the deposition of the sandstone.[1]

M^me^ Jérémine has shown that the granite forming the substratum of the Cambrian conglomerates in La Hague, Manche, suffered decomposition before the deposition of the Cambrian. Also here, the relations between these rocks had previously been interpreted differently.

Basal conglomerates which pass by gradations into regenerated granites, decomposed to a large extent before the sediments were superimposed, occur at many places among the so-called Kalevian rocks of eastern and northern Fenno-Scandia. Although many of the so-called Bodenschiefer (basal schists) of Frosterus were later proved to be mylonitized granites, there are many among them for which his interpretation is no doubt correct.

In post-Palaeozoic formations such phenomena are still more common.

INADEQUACY OF THE NOMENCLATURE OF THE METAMORPHIC CLASTIC ROCKS HERE DESCRIBED. CHARACTER OF THE WEATHERING PROCESSES AND CLIMATOLOGICAL CONDITIONS OF THE BOTHNIAN TIME.

The nomenclature of residual and sedimentary rocks is still very imperfect, especially concerning such clastic rocks as have later

[1] This locality was formerly regarded as doubtful, because veins of a younger granite-like rock, associated with the post-Jotnian olivine diabase, were regarded as possibly belonging to the rapakivi granite (Geol. För. Stockh. Förh. Bd. 19, p. 32, note 1).

undergone metamorphism. Therefore, few of the designations that have been used in the present pamphlet are entirely adequate. It is only in the absence of better terms that such names as breccias, arkoses, phyllites, mica-schists, etc., have been used for the rocks described. The term leptite which is so much favoured in Sweden as a designation for fine-grained feldspathiferous schistose rocks, has not been used here at all, because this word rather generally has got the meaning of a geological term mainly used for certain rocks of the old iron-ore-bearing formation of central Sweden. These leptites are thought to have an effusive or tuffaceous origin. If the name leptite were used in the present case, according to its original definition, as a term covering all fine-grained schistose rocks rich in feldspar, then the conclusion would be drawn that many leptites are normal clastic rocks that have been formed out of material originated by weathering and have nothing to do with volcanic action.

Arkose usually means a rock which is closely associated with quartzitic sandstones and has been formed by similar processes as these, although the decomposition of the crystalline rock masses and especially of their feldspar constituents has been less complete than in the sandstone. In the present case, there is no association between the »meta-arkoses» and quartzitic sandstones. The latter rocks do not occur in the Bothnian formations in question.

Breccia is a name by which have been designated rocks of the most heterogeneous origin which have only this in common that they consist of angular fragments, cemented by a material of varying character. When we use the same term for eruptive and intrusive breccias, for friction breccias and other tectonic breccias, and for breccias formed by subaërial disintegration, then we unite under a common designation things which are genetically as different as, e. g., orbicular granites, variolites and conglomerates to which all is common their rounded inclusions.

In a systematic treatment of clastic rocks, it will be necessary to start from a detailed study of the processes of disintegration under varying climatological conditions. Until now, most petrologists of the northern countries have devoted little interest to these phenomena. In countries which have once been glaciated, rock masses originated by weathering processes play no very conspicuous role. Weathering is regarded more as a nuisance, than as a process worthy of the keen interest of the petrologist, as well as all other geologists.

There is not even yet any generally accepted name for residual rocks originated through the disintegration of solid rock masses. Merrill's term r e g o l i t h refers to the »entire mantle of unconsolidated material, whatever its nature and origin», thus also to material which has been transported by wind, water, or ice. Merrill finds the term saprolite, suggested by G. F. Becker (16th Ann. Rep. U. S. Geol. Survey, III, p. 289),[1] objectionable as conveying the idea of putridity. In fact the Greek work *σαπρός* means rotten and refers to the decomposition of organic material. But there is another Greek word *σαθρός* which exactly corresponds to weathered, and therefore we may simply designate residual rocks originated through weathering with the name sathrolith, or, preferably, in conformity with similar terms proposed before, sathrolite.

Merrill's important book on Rocks, Rock Weathering and Soils was for a long time the best treatise on these processes. Lacroix' epoch-making treatise on lateritic rocks and several other similar studies have added much to our knowledge of these phenomena. Harassowitz' lately published memoir on laterite should also be consulted by every student of sedimentary rocks.

The present writer has received, by the courtesy of several colleagues in France and the United States, photographs illustrating the weathering processes in regions with different climates, and also some very interesting descriptions of these phenomena. It is obvious that the disintegration processes by which breccias are formed, and also the chemical weathering, act very differently under varying climatological conditions. In northern climates, a fissuration generally takes place. In a temperate climate, such as that of northern France, Germany, and New England, the fissuration is accompanied by the formation of grit, sand and silt between the greater fragments, but the chemical action is not very strong and mainly restricted to such portions through which ground water has percolated. As already remarked, the breccia of Jaakkola seems to have originated under climatological circumstances similar to those which have been observed in the countries mentioned, or perhaps even in a still colder climate.

In the United States, the disintegration processes of New England are very different from those in the states S. of Washington. In the South, fissuration occurs, but by the protracted action of the weathering the main part of the rock is changed into a clayey material,

[1] A similar term saprosorite has been earlier proposed in Finland for the easily decaying rapakivi granite (H. J. Holmberg, Materialier till Finlands geognosi, Finska Vet. Soc. Bidrag, 4, 1858, p. XV). Eskola has lately proposed to use the Finnish word moro as a designation for the grit formed by the decomposition of the rapakivi.

while only the bigger fragments remain as slightly changed boulders. This kind of weathering, which is well exemplified in photographs kindly sent to the present writer by Dr. G. W. Crickmay in Atlanta, Ga., and in Dr. Mc Callie's descriptions of road materials of Georgia, is related to that occurring in tropical regions, e. g., in Ceylon.

The weathering phenomena of Bothnian time have no similarity to these types of weathering, nor to weathering in a desert climate. Neither kaolin nor lateritic products of weathering have been formed in the present case.

We may confidently say that the subaërial disintegration of the rock masses in Bothnian and pre-Bothnian time indicates a temperate or cold climate, with a mean temperature rather below than above 10° Centigrade.

This conclusion is entirely in conformity with observations in the areas near Lake Näsijärvi where the schists show an alternation of clayey and sandy material (cf. fig. 1). The latter has not been a quartz sand (as is the case, e. g., with the coarser layers in the Ladogian schists N. of Lake Ladoga that show a similar varved structure), but has contained much plagioclase feldspar as fragments which have, however, been in part replaced by biotite during the metamorphism. Even small fragments of hyalopilitic volcanic rocks occur occasionally as minute grains which have not suffered weathering at all. Both the kind of stratification of these sediments, which reminds one very much of varves, and their chemical character are very similar to those of glacial clays and indicate a climate which has been so cold as to allow the freezing of the rivers in winter time. The bigger pebbles of syenitic rocks show feeble signs of weathering.

Frosterus has also emphasized the great difference in chemical character between the meta-pelitic sediments at Lake Näsijärvi and the Cambrian blue clay of adjacent regions, and by his reasoning arrives at the conclusion that the climate of the Bothnian time was similar to that now prevailing in regions which are undergoing glaciation.

That the climate was moist, is evident also from the thickness of many varves, indicating rivers rich in water at summer time.

Even when the weathering processes act rather feebly, they will result in the formation of great masses of decomposition products, if they continue during sufficiently long periods. If, again, the weathering has been very intense, the existence of considerable quantities of »s a t h r o l i t i c» products does not give the same evidence of the length of time during which the process has been going on, as it does in the present case where the process has acted more slowly.

The absence of any more luxuriant land-vegetation in Bothnian time has of course made a difference from the conditions in modern time. The amount of humic acids in the ground water percolating through the uppermost portions of the soil must have been insignificant. The formation of soils of the p o d s o l type, common in northern climates, and characterized by a white upper portion and a lower portion enriched with limonite, might not have occurred in any typical form in Bothnian time. But even if the leaching was then less intense than at present, it may have caused a deposition of limonitic and calcitic material at the deepest level of the zone of weathering.

To conclude, the present writer thinks that he has been able to show that even in very old Archaean formations rocks exist that have been formed by subaërial weathering under conditions similar to those existing in the same regions at the present day. Uniformitarian geology has thus, by its progress downwards, definitely brought these old Archaean formations under its sway, and it does not seem likely that its new landmarks will ever be moved backwards.

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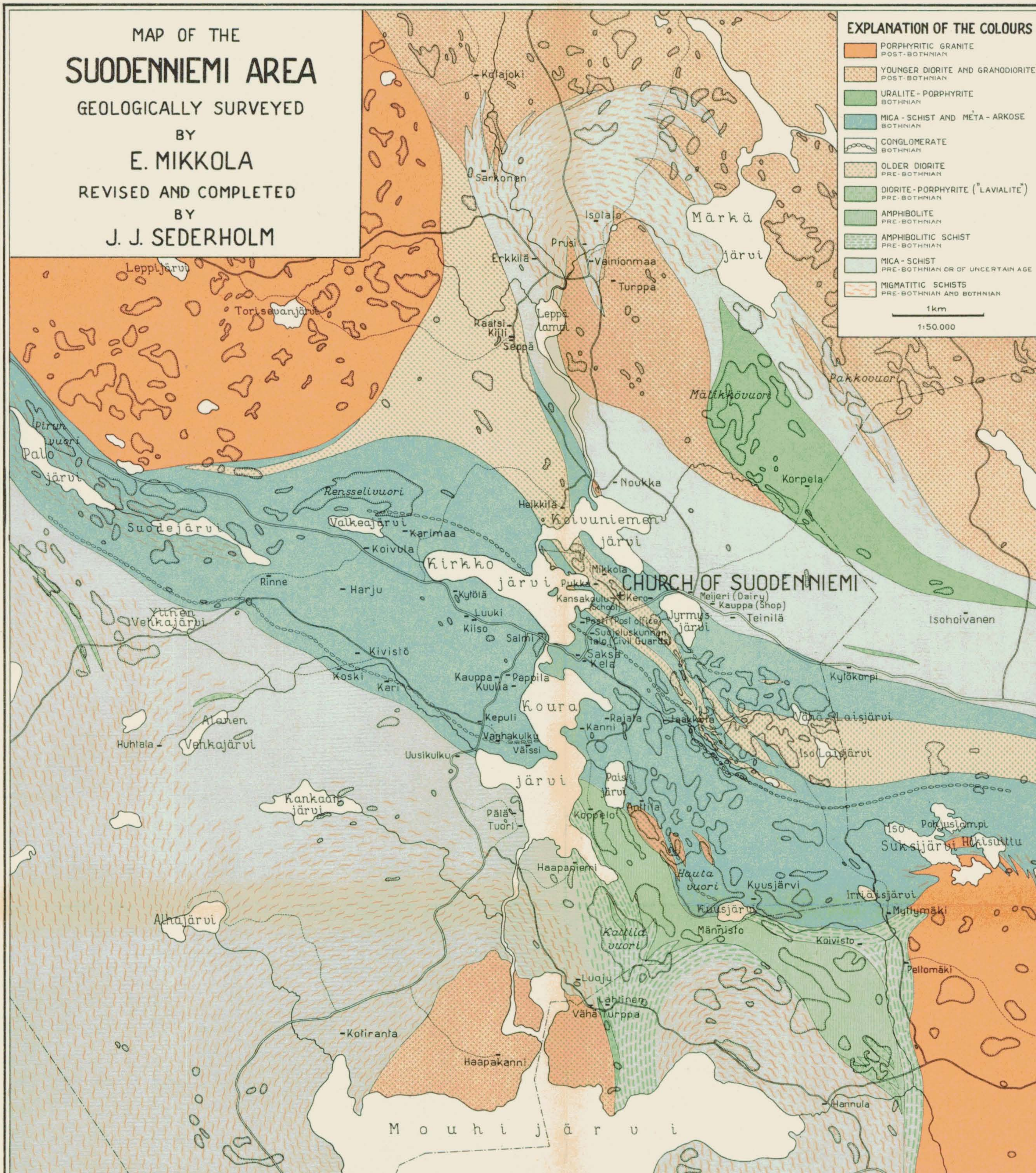

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