GEOLOGINEN TUTKIMUSLAITOS

BULLETIN
DE LA
COMMISSION GÉOLOGIQUE
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SUOMEN GEOLOGISEN SEURAN JULKAISUJA
MEDDELANDEN FRÅN GEOLOGISKA SÄLLSKAPET I FINLAND
COMPTES RENDUS DE LA SOCIÉTÉ GÉOLOGIQUE DE FINLANDE

XXIII.

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XXIII.

HELSINKI

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1.

THE METEORITE FROM VARPAISJÄRVI

BY

W. A. WAHL AND H. B. WIIK

I. GENERAL AND PETROLOGICAL DESCRIPTION

BY

WALTER WAHL

This stone, which was found in 1913 in the grounds of the small-holding Aromäki in the village of Lukkarila, Varpaisjärvi parish, Kuopio province, Central Finland, has not been described so far. Only a short notice has been published in Prior's Catalogue of Meteorites (British Museum), First Appendix 1927, p. 46. (Here the name is given as »Varpaisjairi», the date of discovery as 1923 and its character as a grey chondrite.)

The stone was found by the small-holder Jooseppi Lyytinen of Aromäki in the year 1913 whilst digging a ditch through marshy meadowland at Tyhäsuo. The stone attracted Lyytinen's attention, partly because he knew the bog to be free from stones and partly on account of its black colour and singular appearance. Judging from the fragment now left and from the description recently given, verbally, to the author by a brother of Jooseppi Lyytinen, who is still living in the village of Lukkarila, the stone was a highly orientated stone of conical shape, obviously very similar to the stones of Luotolaks and Allegan. According to accounts by several people who have seen the entire stone, its size must have been about one and a half times the size of the Luotolaks stone, *i. e.* of the size of a child's head, and the total weight something between 1,5—2 kgs.

Farmer Lyytinen took the black stone to his house, where it was kept for years on the floor in a corner of the kitchen. Soon after the discovery of the stone the Rev. Kl. Hymander (= Hyvämäki), the Rector of Varpaisjärvi parish, visited the village of Lukkarila and heard of the stone. On inspecting it, he suspected that it might be a meteorite and chipped off a corner with a hammer and sent this piece to the late Professor J. J. Sederholm at the Geological Survey, Helsingfors. Here it was immediately recognised that the fragment was a piece of an orientated stony meteorite. The stone does not seem to have been very closely examined at this time, only a small thin section for microscopic examination being cut. Professor Sederholm sent to Varpaisjärvi a young member of the survey staff, who measured and photographed the stone, but as the owner did not wish to part with the stone it was not acquired for the Helsingfors collection.

The clergyman's letter and also the information gathered by the survey and the photographs of the main portion of the stone have been lost, or at least it has not been possible to locate them at present.

During the last week of July 1914 Dr. L. H. Borgström went to Varpaisjärvi in order to examine the stone. On arriving at the parsonage he was informed that the meteorite had been sold by farmer Lyytinen to a travelling tradesman. As the first World War broke out that same day, Dr. Borgström did not insist on visiting the Lyytinen farm, which in those days was rather distant from the Varpaisjärvi highway, but returned hurriedly to Helsingfors.

Whilst visiting Kuopio in September 1948 the present author decided to use the opportunity to drive over to Varpaisjärvi to try to obtain some further information on the meteorite.

There are at present a great number of families bearing the name Lyytinen living in the village district of Lukkarila and the neighbouring village of Pyöreämäki, and at the first five Lyytinen-farms visited nobody had ever heard of a meteorite. Then, however, I was informed that a very old man and former owner of Aromäki farm was still living in the district, and I managed to locate him. He said that his brother, now deceased, had found the black stone, and he gave a fairly good description of it. He remembered also that the parson had chipped off a corner with a hammer and sent the piece to Helsingfors. He said the stone had for more than twenty years remained in the kitchen corner on the floor, but that on the death of Jooseppi Lyytinen the house had been sold and later on sold once again. Several years ago when passing by the house he had seen the stone lying on a stone- and brick-heap not far from the house. We went there together and searched for the stone for several hours. During this search the present housewife returned home, and on hearing what we were looking for she said that once, several years ago when cleaning her kitchen, she had decided to rid her home of that black stone, which had always been a nuisance when sweeping the floor, and in spite of the tradition that there was something very extraordinary about the stone, and some people even believing it to have fallen from heaven, she at last carried it out on a stone heap. The last time she had seen it, was about two years ago when she saw her small boys and their friends playing with the stone and noticed that they had managed to break it into several pieces. Then the boys were questioned, but they were only able to state that the stone, formerly hard, had become so soft after remaining outdoors several winters and freezing, that they were able to carve the white interior with a knife and it then broke into pieces and some of the boys carried off pieces with them. However, none of the boys were now able to find any piece of the old black stone. (The rumour conveyed in 1914 to Dr. Borgström that the stone had been sold was thus evidently incorrect.) The fate of this meteorite left by the Geological Survey with its rural owners, its lying about for years on the floor, passing with the small cottage from one owner to another, until it was ultimately thrown on the scrap heap, disintegrated and lost, shows how futile it is to respect the wishes of the finder of a meteorite to keep it as a curiosity at his rural home instead of it being acquired for a museum. This stone was — as the piece still remaining shows — an exceptionally well orientated stone and thus of considerable interest.

When all the meteorites belonging to the Geological Survey of Finland were transferred some twenty years ago to the Collections of the Mineralogical Museum of the University of Helsingfors, the 118 gr. piece originally sent in by the Rev. Hymander came into the possession of this museum. It is now the only remaining portion of the Varpaisjärvi stone and the present description is in reality only a description of the material of this small fragment of the stone.

SHAPE AND SIZE OF THE STONE. GENERAL CHARACTER OF THE STONE

The remaining fragment of the meteorite is shown in Fig. 1, Plate I, in natural size. As is clearly seen from the photograph, this little stone is only a fragment of a much larger one which has been much of the same singular shape as the stony meteorite from Allegan, of which Merrill has published some good pictures.[1] The Allegan stone is also only a piece, about half, of a larger, highly orientated, stone possessing a high, rounded, somewhat conical front surface. The corner piece, the bottom surface and the shape of the border between front surface and bottom surface are very similar in both these stones.

The howardite of Luotolaks (the only stone preserved of this fall) is also very similar in shape and orientation, as seen on comparison with the picture published by Arppe [2]. The size of the Allegan stone was, however, about five times that of the Varpaisjärvi one, while the Luotolaks stone was only about two thirds of the size of that from Varpaisjärvi.

The stones from Luotolaks and Varpaisjärvi are the two most beautifully orientated stones in the Helsingfors collection of meteorites.

The weight of the preserved portion of the Varpaisjärvi meteorite shown in the picture, was 118 gms before material for investigation was cut from the interior surface. The shape of the fragment has not been noticeably altered by cutting material for investigation from the interior surface of the stone which is not seen in the plate.

The crust of the Varpaisjärvi stone is dull, black and much thinner on the front surface, about 0.4—0.7 mm. thick, than on the bottom surface, where it is more slaggy and from 1—1,2 mm. thick. The picture shows quite distinctly the stream lines of the molten material of the crust as it flows down the sides of the rounded, high, conical front surface

[1] G. P. Merrill a. H. N. Stookes. Proc. Wash. Acad. Sci. vol. 2. (1900) 41. Fig. a. G. P. Merrill. United States Nat. Museum Bull. 94. Pl. 11. Fig. 2.

[2] A. E. Arppe. Acta Soc. Scient. Fennica T. 18 (1865) Plate 1.

of the meteorite and gathers on the lower surface, forming a thickened border line between front surface and bottom surface, ridge-like in places, exactly as in the pictures of the Allegan stone. The thick crust on the bottom surface is in places of a slaggy character and locally carries small bubbles which have burst open before the crust solidified in this shape.

PETROGRAPHICAL PROPERTIES OF THE STONE

On a broken surface the meteorite is nearly white, the surface being of a dense and hard appearance. No chondrules can be distinguished on such a surface. Also very little troilite and still less nickel-iron are visible on a broken surface, but when the stone is cut with a diamond-steel blade both nickel-iron and troilite become visible on the cut surface, as well as some single chondrules. The silicates are all quite white and on visual inspection it is not possible to distinguish between different kinds of minerals.

In thin section the stone is seen to be made up of a fine-grained assemblage of mineral grains and some nickel-iron and troilite grains. The first section cut showed no chondrules at all, but in several other sections a few chondrules are seen. Some mineral grains are somewhat larger than the rest, but no large mineral grains or large fragments of minerals can be seen in the sections. The principal portion of the mineral grains has a high refractive index and consists of grains of bronzite and olivine, but between these, small areas of lower refractive index are seen, which are mostly only indistinctly doubly refracting, but in places show remnants of plagioclase twinning. These mineral grains of lower refractive index than the bronzites and olivines must therefore be considered to represent all stages of an alteration of plagioclase into maskelynite. The analysis indicates that there is about 15 % feldspar silicates present, and this agrees fairly well with the estimated amount of maskelynite.

Only few chondrules, have been found in the thin sections. The largest one, fairly circular in shape, and about three mm. in diameter is composed of enstatite grains. Also most of the others are more or less perfectly rounded enstatite chondrules. One chondrum of the »barred olivine chondrum» type has been found. The chondrules, although round, have not such a sharp outer border against the surrounding assemblage of bronzite and olivine grains as have the chondrums of the »spherical chondrites», but seem to grade more or less gradually into the surrounding granular mass. Where a radial structure can be traced in the enstatite chondrules it is not distinct as in the ordinary chondrules of this type in the spherical chondrites, the radial fibres being mostly broken up into chains of grains which have taken the place of what seems to have been originally a fibrous structure.

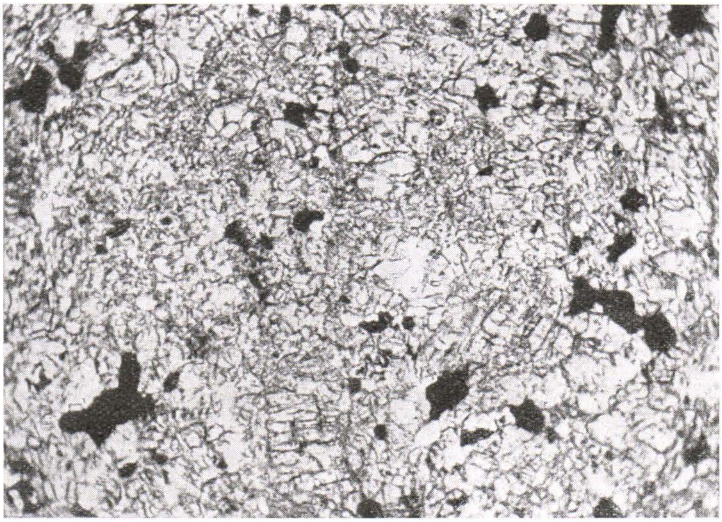

Fig. 1.

The principal mass of mineral grains, containing no chondrules, shows a kind of »pavement structure» rather than a tuffitic structure. Fig. 1. Both the present structures of the main mass and the appearance of the few chondrules indicate that it is a granular structure of secondary character, originating from the heating up of an originally tuffitic mass of grains, containing a few sparse chondrules and metallic grains, whereby a certain amount of recrystallization by »thermo-metamorphism» has taken place. The original tuffaceous character has thus been replaced by a kind of more evengrained »pavement structure» and also the alteration of the fibrous structure of the enstatite chondrules into a more granular structure appears to have been caused by thermometamorphism.

THE STRUCTURE OF THE CRUST

As mentioned, the crust of the Varpaisjärvi stone is much thinner on the front surface than on the rear one. Unfortunately, the central, (uppermost front) portion of the stone has been lost and the crust of this part cannot therefore be investigated, but a section was cut from the uppermost edge of the stone shown in Fig. 1, Pl. I, at right angles to the crust and to the stream lines on it. The three principal zones of the crust of stony meteorites, as first described by Brezina [1] and especially by Tschermak [2] and later by several other investigators [3] are well

[1] A. Brezina, Sitzungsberichte Akad. Wien LXXXV (1882) pp. 335—344.

[2] G. Tschermak, Die microscopische Beschaffenheit der Meteoriten erläutert durch photographische Abbildungen, Stuttgart 1884—85 p. 20.

[3] Compare E. Cohen, Meteoritenkunde II pp. 99—116.

developed in the crust on the front side of Varpaisjärvi. Reckoned from the outside inwards we have first a thin, opaque black »skin» of a thickness of only 0.05 to 0.1 mm. (measured with a micrometer ocular), somewhat varying in thickness in different places. The surface between this outermost skin and the next zone of the crust ist fairly distinct, but not quite even and sharp, and the inner part of the thin »skin» is in places somewhat transparent and contains small corroded fragments of mineral grains of the meteorite. This is evidently the zone where the melting of the material of the meteorite takes place. The outermost zone contains numerous small bubbles.

The second zone of the crust is remarkably transparent and clear, all dark inclusions and dustiness having disappeared. This zone is 0.1 to 0.2 mm thick and corresponds to what Tschermak designates as the »Saugzone». It lies between the zone of melting and the inner, third zone and is made up of the mineral constituents of the meteorite and possesses the same structure as the bulk of the meteorite, with the exception that all dark and dusty and metallic particles have disappeared. The third, innermost zone of the crust of the front side forms a mainly black band of uneven appearance and thickness, varying between 0.2 and 0.4 mm. in thickness. Here and there between the black mass are clearer portions where it can be seen that this zone, which corresponds to what Tschermak has called the »Imprägnationszone», is really only part of the interior of the meteorite which has been impregnated from without with black matter. The border line between this black zone and the main, inner portion of the stone is quite uneven.

Fig. 2, Pl. I, shows a section cut at right angles through the comparatively thick crust of the rear side of the meteorite. Also here the principal zones of the crust of stony meteorites as first described by Brezina and Tschermak are well developed. In addition we find here, between the thin outermost zone and the clear »Saugzone», a fairly broad transparent glassy zone, forming a fourth zone. The outermost zone forms a thin black opaque skin on the glassy second zone and is seen only on the left and the right hand portions in Fig. 2, Pl. I. In the middle part it has been broken off in preparation, adhering as it does only very loosely to the second zone. As far as can be judged from the thin section this outermost thin zone, which is only 0.05 mm. thick, is really only the outermost oxidized and opaque »skin» of the glassy zone of the meteorite. In the crust from the front side of Varpaisjärvi — as we have seen — and in other stony meteorites the outermost zone (corresponding to zones one and two in Varpaisjärvi) is quite thin and black and opaque throughout and between it and the clear »Saugzone» no glassy more or less transparent zone whatsoever has been developed.

As distinctly seen in Fig. 2, Pl. I., the border line between the second, glassy zone and the third zone, the »Saugzone» is quite sharp. There is, however, no such sharp border between the third zone and the dark, innermost or fourth zone, nor between this dark innermost zone and the interior mass of the meteorite. The outermost zone as well as the second, glassy zone which is 0.4—0.5 mm. thick contain small bubbles, which at places where they occur at the surface of the crust are open towards the exterior. The glassy second zone of the crust is in addition full of small needle-shaped crystallites of a colorless mineral, showing a parallel extinction between crossed nicols, which is probably enstatite or bronzite. These needle-shaped crystallites have mostly crystallized in bundles at right angles to the outer surface of the crust, as well shown in Fig. 2, Pl. I. In some instances these needle-shaped crystallites are seen to extend into the outermost thin opaque zone, which is much thinner than the length of the needles. This shows that the outermost »skin» is really only a modified thin outermost portion of the glassy zone, probably formed from the glass by oxidation of the iron components of the silicates by action of the oxygen of the air. These two outermost glassy zones, one and two of the crust on the rear side, must be regarded as made up of the molten material from the front surfaces which has flowed over the edges and spread on to and over the rear surface. Whilst cooling fast when the stone fell to the ground the molten mass was chilled so quickly as to solidify as a glass with the separation of only the most readily crystallizing component, the enstatite, as needle-shaped crystallites.

The third zone of the crust — which is from 0.2—0.4 mm. thick — is, in thin sections, the most transparent portion of the whole meteorite. It is composed of mineral grains similar to those forming the interior of the meteorite and must thus be regarded as part of the meteorite which during formation of the crust has been altered so much as to become more clear and transparent than the interior of the stone. In the outer part of the third transparent zone, adjoining the glassy zone, clusters of crystallites similar to those in the glassy zone are observed in places, but they are here smaller in size and not orientated at right angles to the outer surface. It seems that part of the molten glass has in such places penetrated into the outer part of the clear zone and on later solidifying crystallites have been developed also here. The third clear zone of the crust has probably been formed in such a way that this portion of the stone has been heated from without sufficiently strongly to cause easily molten substances, probably principally the troilite, to migrate inwards towards the cold interior of the stone, the third zone thereby becoming clear and transparent.

The material from the third, clear zone migrating inwards towards the cold interior of the meteorite solidified rapidly here, probably, in part at least, in the form of the black amorphous modification of the iron sulphide causing this outer porous zone of the interior of the meteorite to be unevenly but strongly impregnated and blackened, thus forming the fourth, innermost zone of the crust of the meteorite, about 0.5 to 0.7 mm. thick but uneven in thickness and appearance. Such a view of the formation of the third, clear zone (Tschermak's »Saugzone») and the fourth blackened zone (Tschermak's »Imprägnationszone») is strengthened by a previous investigation by the author [1] of the crust of the stony meteorite of »Mern,» in which it was shown that in treating an uncovered section of crust with hydrochloric acid hydrogen sulphide was evolved from the innermost zone which readily became transparent, the outer dark silicate glass not being altered to transparency by this treatment. This shows that the inner black mass rendering the innermost zone opaque is not dark silicate glass impregnating it but FeS fairly easily soluble in acids. By investigating the innermost black zone of the crust of the meteorite of »St. Michel» in reflected light Borgström[2] has later found that it contains troilite, partly as fine veins, and he also regards the blackening of this zone as caused by troilite.

Only a few cases of the occurrence of such a transparent glass as the comparitely broad glassy second zone in the crust of the rear side of the Varpaisjärvi stone have been observed in other meteorites. Thus Borgström [3] describes a slightly transparent inner border of glass as a second zone of the crust of the stone of »Shelbourne», and he says that the transparency of the glass is here caused by large amounts of very small crystallites. In Shelbourne the outermost zone of the glassy portion of the crust is, however, thicker than the transparent inner portion, whereas in Varpaisjärvi the transparent portion is about ten times as thick as the outermost opaque »skin».

In a section of »Mocs», Cwa, at right angles to the crust, the author has observed a similar glassy second zone inside the slaggy outermost zone, which here is thicker than the glassy zone. In the amphoterite of »Bandong» there occurs a second transparent glassy zone similar to that in Shelbourne; this contains numerous small needle-shaped crystallites which are larger than those in Shelbourne, but much smaller than the crystallites of the glassy zone in Varpaisjärvi.

In the case of the highly orienteted chondrite of »Waterfall» (= »Bowden») the author has observed on the rear side of the stone a slaggy crust which is still thicker than on Varpaisjärvi. Here the outermost glassy zone of the crust contains still more and larger crystallites than in Varpaisjärvi. Waterfall is similar in shape to Varpaisjärvi and of about the same circumference but flatter, and shows similar strongly developed stream- and drift-lines on the front surface.

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[1] W. WAHL, Die microskopische Beschaffenheit des Meteoriten von Mern, bei A. BREZINA, K. DANSKE Vid. Selsk. Skrifter 7 Raekke, Naturvid. o. Mathem. Afd. VI. 3 (1909) b. pp. 120—123.

[2] L. H. BORGSTRÖM, Bull. Comm. géol. Finl. N:o 34 (1912) pp. 21—26.

[3] L. H. BORGSTRÖM, TRANS. R. Astron. Soc. Canada 1904 p. 69.

The author has further observed such glassy zones containing crystallites in the crust of the stones of »Lixna», »Santiago de Chile» (=»Cobija»), »Baratta» and «Kernouvé».

If we compare the structure of the crust on the front surface of Varpaisjärvi with the structure of the thick crust on the rear surface, we see that the principal differences are the occurrence of the comparatively thick glassy second zone containing the crystallites and of a fairly sharp and even border line between the glassy zone and the clear third zone in the crust on the rear side. These differences evidently depend on the different conditions under which the crusts on the front and on the rear surface have been formed. When the meteorite at its cosmic speed enters the atmosphere of the earth it has the low temperature of interplanetary space. The strong friction against the air causes the outhermost surface to be heated until it melts, and in a strongly orientated stone, which presumably has all the time been travelling in the same position, a considerable portion of the front surface is being molten and gradually wears off, a more or less rounded conical front surface being developed, the molten material flowing down the sides, to a great extent dropping off at the edges but in parts flowing over to the rear surface and spreading over this. The front surface is continuously being worn off and sculptured anew and there is therefore no very distinct border line between the first and the second zone; since this border all the time moves inwards and the molten material flows away no thick glass zone forms here on ultimate solidification of the crust. The clear second zone and the black innermost zone are also continually moving inwards at the same rate as the outermost surface is being worn off and the heating of the material inside the zone of melting is proceeding inwards. Some of the sulphur of the troilite near the outer surface is oxidized, forming SO_2 and together with other volatile components forming the bubbles in the outermost »skin» zone. Some of the melting troilite will move inwards, always keeping at a certain distance inwards from the hotter zone where the silicates melt and in this way it is always being pushed inwards towards the porous cold interior, where it is sucked up and chilled, forming the black innermost zone of what is generally reckoned as belonging to the crust, although it really, together with the clear zone, represents the outermost not yet molten zone of the meteorite proper.

The surface of the rear side under the molten outer zones of the skin is as we see from Fig. 2, Pl. I, bordered by a distinct sharp line. This obviously represents the cross-section of an original border surface, which here, in a sheltered position, has not been worn off by any friction of the air. On such a surface the hot molten silicate glass formed on the front surface has spread, causing the material of the surface to be strongly heated and in part form volatile gaseous products givingrise to bubbles in the outer glassy zones, and in part being sucked up by the material inside and moving inwards from the heated surface. The clear zone inside the original outer surface is thus also here being produced, together with the black impregnation zone inside of it. It seems, however, that only in strongly orientated stones as Varpaisjärvi and Bowden and a few other ones are such thick crusts containing fairly thick glassy inner zones of the outer glassy crust developed on the rear side.

The structure of the crust of the Varpaisjärvi stony meteorite has here been dealt with at some length because it is the most prominent feature of this meteorite.

THE MINERALOGICAL COMPOSITION.

The mineralogical composition of the Varpaisjärvi stone, as calculated from the analysis, is as follows:

$NaAlSi_3O_8$	6.02 %	15.08 %	Felspar silicates
$KAlSi_3O_8$	1.34		
$CaAl_2Si_2O_8$	7.72		
$FeSiO_3$	7.70	28.71 %	Pyroxene silicates
$FeTiO_3$	0.32		
$MnSiO_3$	0.26		
$MgSiO_3$	20.43		
$CaSiO_3$	—		
Fe_2SiO_4	11.30	38.78 %	Olivine silicates
Mg_2SiO_4	27.48		
$3CaO \cdot Na_2O.P_2O_5$	0.71		Merrillite
$FeCr_2O_4$	0.96		Chromite
Fe, Ni, Co	8.78		Metal
FeS	6.97		Troilite
	100 %		

From the above description we see that the meteorite of Varpaisjärvi is white, containing very few chondrules and somewhat more nickel-iron grains than troilite. Judging from the first small section which was cut and which contained no chondrules at all, the stone ought to be placed among the achondrites in the group of amphoterites. It certainly contains fewer chondrules than do the pieces of the amphoterites of Jelica and of Vavilovka in the Helsingfors collection.

However, the Varpaisjärvi stone contains more nickel-iron than do the Jelica and Vavilovka stones and the remainder of the amphoterites, and is also perhaps too dense and hard a stone to be classified among the achondrites. It is very similar to the St. Michel stone which Borgström tentatively classes as a »rhoditic chondrite», although Varpaisjärvi is not veined and brecciated like the St. Michel stone. Also the St. Michel stone is, however, too hard and dense and contains too much nickel-iron to be classified among the achondrites. Besides, the Varpaisjärvi and St.

Michel stones contain too much feldspar silicate to be classed as amphoterites and are in this respect similar to the white chondrites. It seems therefore most appropriate to refer both the Varpaisjärvi and St. Michel stones to the »white chondrites», Varpaisjärvi to Cw and St. Michel to Cwa.

Both the Jelica and Vavilovka specimens have a brecciated and tuffitic structure, containing large and small angular fragments of grainy bronzite — olivine stone in a tuffaceous mass of bronzite and olivine splinters and chondrules, also appreciable quantities of troilite and nickel-iron are present. Both these stones were earlier classified among the white chondrites, but have more recently been transferred to the amphoterites. They contain, however, more chondrules and nickel-iron than the other members of the group. By analogy with the »howarditic chondrites» they could be styled as »amphoteritic chondrites», forming a distinct group in the Rose-Tschermak system of classification.

In Table I the analyses of the Varpaisjärvi and St. Michel stones are compared with those of Jelica and Vavilovka and Roda and with the analyses of the white chondrites of Lanzenkirchen and Wittecrantz.

Table I.

	I	II	III	IV	V	VI	VII
SiO_2	39.28	39.52	39.86	41.12	39.07	39.96	50.38
TiO_2	0.17	0.02	0.07	0.17	—	—	—
Al_2O_3	4.32	3.31	4.26	2.54	1.88	1.63	2.86
Cr_2O_3	0.66	0.56	0.44	0.36	0.50	0.15	0.64
FeO	12.68	13.44	12.61	14.94	21.29	18.08	14.91
MnO	0.14	0.41	0.07	0.15	0.19	0.77	0.22
MgO	23.94	24.60	23.58	25.40	25.34	25.32	27.10
CaO	1.88	1.64	1.66	2.12	1.23	1.80	1.42
Na_2O	0.83	1.32	2.29	1.16	0.12 (Na₂O + K₂O)	1.61	0.38
K_2O	0.23	0.13	0.27	0.14		0.26	0.31
P_2O_5	0.28	0.18	0.11	0.16	—	—	0.04
Silicates	84.41	85.13	85.22	88.26	89.62	89.58	98.26
Fe	7.58	7.85	8.16	7.66	1.63	1.79	—
Ni	1.09	1.16	1.10	0.75	0.83	0.93	—
Co	0.11	0.13	0.06	0.02	0.05	0.06	—
Metal	8.78	9.14	9.32	8.43	2.51	2.78	—
Fe	4.43	3.86	3.32	2.20	4.49	4.33	1.10
S	2.54	2.22	1.90	1.26	2.58	2.49	0.63
Sulphide	6.97	6.08	5.22	3.46	7.07	6.82	1.73
Total	100.15	100.35	99.76	100.15	99.20	99.18	99.99

I Varpaisjärvi
II St. Michel
III Lanzenkirchen (0.09 % Fe_2O_3 calc. as. FeO)
IV Wittecrantz
V Jelica
VI Vavilovka (0.23 % chromite calc. as FeO and Cr_2O_3
6.82 % troilite calc. as Fe and S.)
VII Roda

Also this comparison of the analyses shows that Varpaisjärvi possesses the greatest resemblance to the »white chondrites» and ought to be classified with these.

With regard to the chemical investigation of the Varpaisjärvi meteorite, described in the latter part of this paper, it is of interest to note that the total amount of Ni obtained in the bulk analysis of the meteorite 1.17 %, and the Ni amount of the extracted nickel-iron, 1.09 %, agree within the limits of accuracy of the analytical methods. We must therefore conclude that all the nickel and the cobalt (to which similar conditions apply) is contained in the nickel-iron of the meteorite and that the silicates and the troilite contain neither nickel nor cobalt, which is in agreement with the chemical equilibria between iron, nickel, cobalt and the amount of oxygen which is insufficient to oxidize the entire amount of iron.[1]

II CHEMICAL INVESTIGATION OF THE VARPAISJÄRVI METEORITE

BY

H. B. Wiik

The Varpaisjärvi Meteorite was analysed according to the same analytical methods that have been described in a recent publication on the meteorite of McKinney[2].

The results are given in the following Table II.

Table II.

SiO_2	39.28	46.49
TiO_2	0.17	0.20
Al_2O_3	4.32	5.12
Cr_2O_3	0.66	0.80
FeO	12.68	15.01
MnO	0.14	0.17
MgO	23.94	28.41
CaO	1.88	2.23
Na_2O	0.83	0.98
K_2O	0.23	0.28
P_2O_5	0.28	0.33
H_2O+	0.21	—
H_2O-	0.10	—
Silicates	84.72 %	100.02

[1] W. A. Wahl, Beiträge zur Chemie der Meteoriten. Zeitschr. anorg. Chem. 69 (1910) 55 (esp. pp. 69—76).

[2] H. B. Wiik, A Chemical Investigation of the McKinney Meteorite, Comm. Societ. Scient. Fenn. Phys.-math. XIV (1950) No 14.

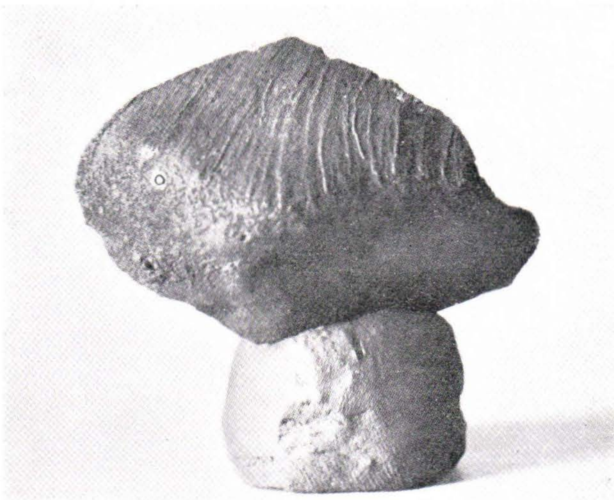


Fig. 1

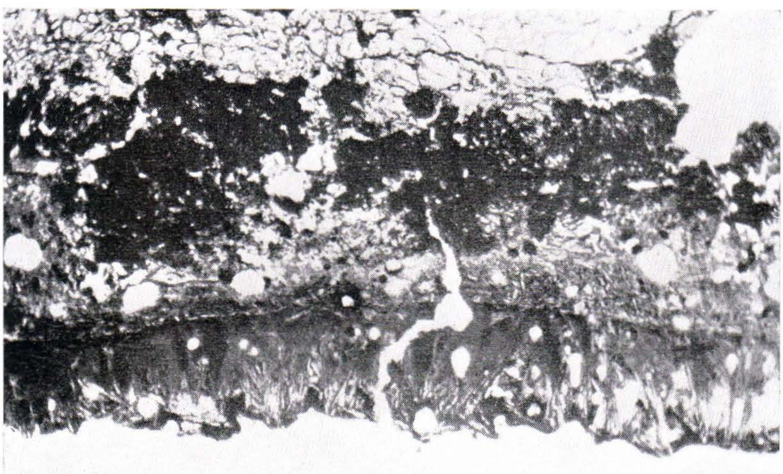


Fig. 2

W. A. Wahl and *H. B. Wiik:* The Meteorite from Varpaisjärvi.

Fe.	7.58	86.35
Ni	1.09	12.40
Co	0.11	1.25
Metal	8.78 %	100.00
Fe	4.43	
S	2.54	
Sulphide	6.97 %	
Total	100.47 %	

ANALYTICAL RESULTS

For the determination of SiO_2, TiO_2, total Fe as Fe_2O_3, Al_2O_3, Ni, Co, CaO and MgO a portion of exactly one gram of the powdered meteorite was used.

SiO_2 from the hydrochloric acid solution 0.3889 gr. + 0.0039 gr. recovered from the sesquioxides = 39.28 % SiO_2.

Sesquioxides, total = 37.08 %.

TiO_2 determined colorimetrically in the acid potassium-sulphate melt of the sesquioxides = 0.17 %.

Fe_2O_3 contents of the sesquioxides, determined by reduction and titration with $KMnO_4$ = 31.26 %.

Cr_2O_3 determined colorimetrically in a separate portion of the meteorite powder = 0.66 %.

P_2O_5 from a separate portion = 0.28 %.

Al_2O_3 = 37.08 — (0.39 + 0.17 + 31.26 + 0.66 + 0.28) = 4.32 %.

Ni ——— 0.0117 gr. = 1.17 %
Co ——— 0.0010 gr. = 0.10 %
CaO ——— 0.0188 gr. = 1.88 %
MgO ——— 0.6614 gr. Mg_2P_2O = 0.2394 gr. MgO = 23.94 %

For the determination of the metallic constituents of the stone a 2 gr. portion was used, and was treated with mercury-ammonium chloride solution in the manner described in the paper on the meteorite of McKinney. Fe was titrated with a N/20 $KMnO_4$ solution, 27.2 cm^3 being used, corresponding to 7.58 % FeO. Unfortunately, this solution was lost before Ni and Co had been determined in it. A new extract of a smaller portion, 0.5873 gr. of the meteorite powder with mercury-ammonium chloride yielded only 6.88 % Fe together with 0.99 % Ni and 0.10 % Co. Since the determination of the metallic constituents of such small a portion as 0.58 gr. must be regarded as less accurate than the determination on a 2 gr. portion, only the proportions between Fe: Ni : Co obtained in the analysis of the 0.58 gr. portion were used in calculating the percentages of the metallic constituents. We obtain thus for the metallic constituents of the Varpaisjärvi meteorite 7.58 % Fe, 1.09 % Ni and 0.11 % Co.

The total amount of iron as determined in the sesquioxide portion was 31.26 %. In this are included the metallic iron 7.58 %, the iron of the troilite 4.43 % Fe, and the iron of the silicates and of the chromite, which has to be accounted for as FeO. 7.58 + 4.43 = 12.01 % Fe corresponds to 17.17 % Fe_2O_3. If we subtract this amount from 31.26 % there remains 14.09 % Fe_2O_3, which corresponds to 12.68 % FeO.

MnO and P_2O_5 were determined on a half-gram portion.

MnO was determined colorimetrically: 0.14 % MnO.

P_2O_5 was separated by molybdate precipitation and determined as $Mg_2P_2O_7$. 0.0022 gr. $Mg_2P_2O_7$ obtained, corresponding to 0.28 % P_2O_5.

S and Cr_2O_3 were determined on a half-gram portion.

Chromium was determined colorimetrically before the determination of S.

$BaSO_4$ = 0.0925 gr., corresp. to 0.0127 gr. S and 2.54 % S.

Na_2O and K_2O were determined by the Lawrence-Smith method on a half-gram portion.

NaCl + KCl = 0.0097 gr. K_2PtCl_6 = 0.0061 gr. corresp. to 0.0019 gr. KCl or 0.23 % K_2O.

NaCl by difference 0.0079 gr. corresp. to 0.83 % Na_2O.

H_2O— 0.8862 gr. taken gave 0.0009 gr. H_2O corresp. to 0.10 %.

H_2O total, determined according to Penfield.

0.8778 gr. gave 0.0028 gr. H_2O corresp. to 0.31 %.

H_2O + = 0.31 % — 0.10 % = 0.21 % H_2O +.

On account of the small amounts of material available no further determinations were made. Already for the above determinations about 10 % of the remaining stone was used an approximately equal amount being used in preparing sections for the petrographical investigation.

2.

ON THE STRUCTURE OF A TILTED DOME NEAR TAMPERE IN SOUTHWESTERN FINLAND

BY

M. HÄRME AND J. SEITSAARI

INTRODUCTION

Half a century ago, Sederholm published his classical investigation of the Tampere schist area (Sederholm 1897). In this memoir Sederholm described petrologically the supracrustal rocks and their relation to the granites occurring in the area. Later on some tectonical features of the supracrustal formation have been dealt with by Neuvonen and Matisto (1948). During the last four years the present authors have carried out field work in the schist area on the eastern side of Lake Näsijärvi, and in this connection attention has been paid also to the structure of granite plutons. In the following preliminary report the authors will present some structural features of one such pluton and its relation to the adjacent supracrustal rocks.

THE ROCKS

East of Lake Näsijärvi, in the parishes of Teisko and Aitolahti, the supracrustal formation is situated between extensive areas of plutonic rocks. A huge stock or massif of so-called Central granite is found on the northern side and a porphyritic granite occurs on the southern side. The area of the latter massif widens out eastwards. The supracrustal formation consists for the most part of slates, in addition to leptites, tuffites, *etc.* All these rocks are more or less foliated. A comparatively small granite stock (about 8 km. in diameter) occurs in the middle of the supracrustal formation, on both sides of the Teisko and Aitolahti parish boundary. This little massif is bounded on all sides by supracrustal rocks (see map). In this connection the authors will call this body the »Värmälä massif», because a great part of it lies in the area of Värmälä village (Teisko parish).

Both the supracrustal rocks and the Värmälä massif are well exposed, only the contact proper being most often covered by Quaternary deposits.

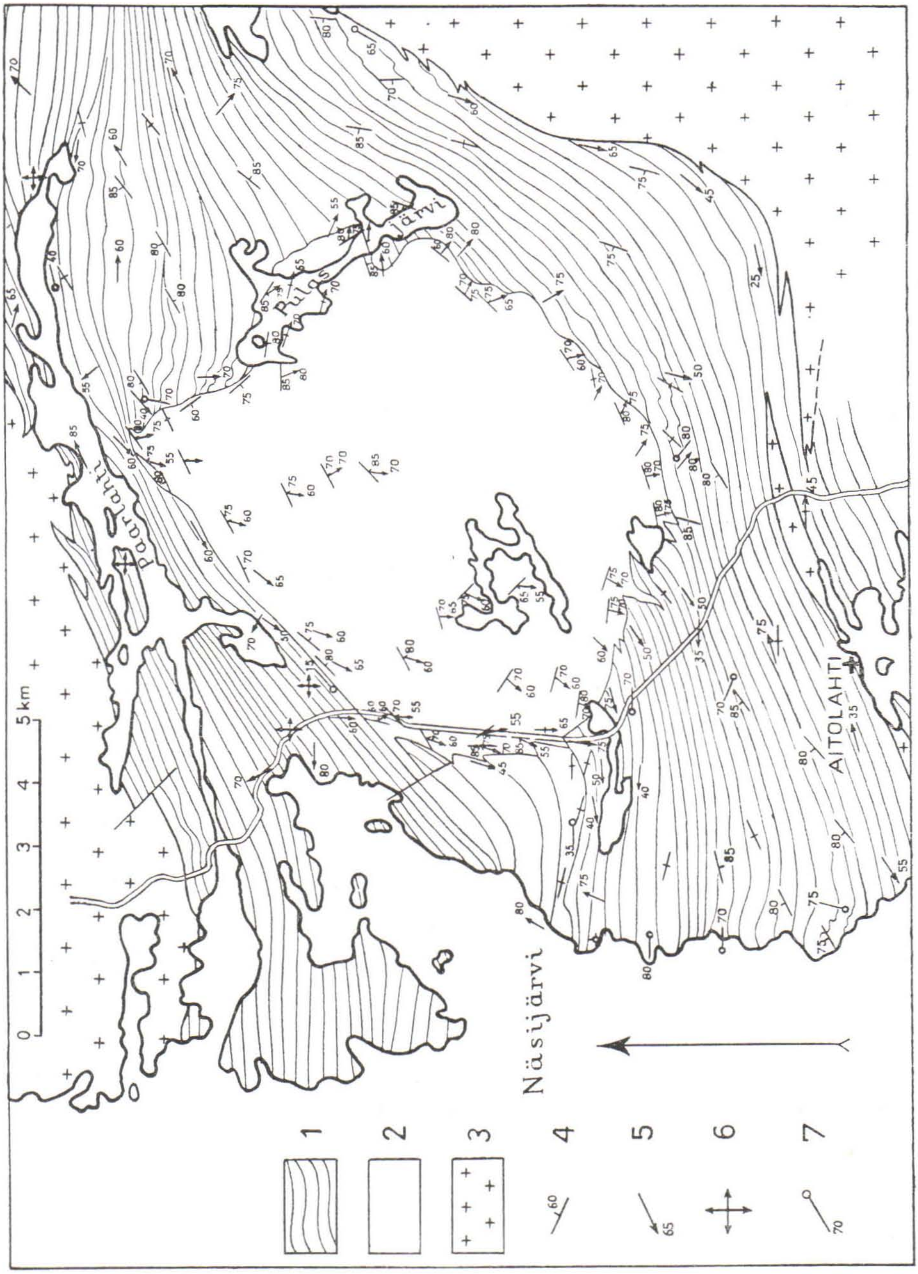
The Värmälä massif, which is younger than the supracrustal formation, is approximately circular in shape. On its NW-side it runs parallel to the vertical strata of the country rocks. On the SW-side this stock cuts the strata, but has also intruded as projections between the layers. On the SE-side it transgresses the strata in some degree, but in general the contact follows the strike of the vertical bedding. The NE-side of the Värmälä massif is of a more discordant character, although the boundary is not entirely rectilinear.

STRUCTURES

In the Värmälä granite the foliation is not strong, but is, however, usually discernible. The strike shows obvious regularities. On the SW and NE margins of the stock the strike is NW, whereas on the SE and NW borders it trends NE. Without exception the dip is steeply to the S. The lineation (E. Cloos 1946) appears in the granite as an orientation of the feldspar and quartz grains, and it has been determined on the basis of the longitudinal directions of these mineral grains. The lineation is commonly better developed than the foliation. — The dips of the foliation and the pitches of lineation show local variations (up to $\pm 10°$). In the eastern part of the massif the lineation is in general to the SE and in the western part to the SW. The pitches are steep, never less than 60 degrees.

The bedding of the schist is represented by solid lines on the map. The dip of the bedding is almost vertical, and as shown, the beds are somewhat bent outwards on either side of the granite stock in question. At the northeastern boundary of the granite, the beds are in many places crinkled, and in some cases this effect is fairly intense. A more or less clear cleavage showing some deviation from the strike of the bedding can very commonly be observed. Together with such a cleavage, another one parallel to the bedding is apparent in almost all localities.

As is seen on the map the lineations in the supracrustal series are in general steeply plunging or vertical. In the immediate vicinity of the Värmälä granite, except in the northwest and northeast, they plunge more or less radially away from the granite. In the crinkled beds northwest of Lake Pulasjärvi, the lineation shows some tendency to plunge beneath the granite. On the northwestern side of the massif, it is usually approximately parallel to the boundary and plunges southwest. Near the boundaries the plunge is usually steep, but farther west and southwest of the granite it becomes in some places considerably flatter. A strong steeply-plunging lineation, however, can be observed as far as the southwestern corner of the area, and thus the phenomenon seems to be merely local.



Map of the investigated area. 1 — supracrustal rocks with bedding, 2 — the Värmälä massif, 3 — other plutons, 4 — foliation and cleavage, 5 — lineation, 6 — vertical lineation and 7 — fold axis.

In many cases the linear structures described are well developed and are expressed, for instance, in the elongation of conglomerate pebbles. Another more indistinct lineation with almost vertical plunge is to be observed here and there near Lake Näsijärvi and also in certain places in the vicinity of the western contact of the Värmälä massif. In some cases such a striationlike lineation occurs in slickensides.

CONCLUDING REMARKS

The lineation and the foliation within the granite itself, as well as the lineation in its nearest surroundings, suggest the idea that they have resulted from the rise of the stock. As shown by the lineations plunging exclusively to the SE, S, or SW, the movement in question cannot have been directed vertically upwards, but contemporaneously with this vertical rise another force (E. Cloos 1947) pushing approximately northwards has been operating. Resulting from both the factors mentioned, the granite massif has been tilted to the north. The gradual change of the steeply-plunging lineation to the more gently inclined one, which has been observed on the west side, may be explained also by the movement of the granite inasmuch as this movement presumably has affected the tectonics only in the nearer neighbourhood of the rising stock. During a later stage the plasticity of the rocks having decreased, fissures and faults have resulted from the continued rise of the granite. In connection with these the more indistinct lineation occurs with a steeply inclined or almost vertical plunge.

Farther away from the granite, the beautiful regularity described above is entirely lacking. This is also easy to understand. The rock crust of the area has a very complicated position with three separate intrusive massifs. Probably, the mutual movements of all these intrusives have been of great importance. The comparatively narrow schist belt has apparently been very insignificant between them. The Värmälä massif being small, has acted upon only a narrow zone around itself. It seems, too, that in many places several successive movements have taken place, as may be deduced from different cleavage directions and from lineations of varying strength and attitude, *etc.* Thus the earlier tectonical features have often been replaced by new ones.

REFERENCES

CLOOS, ERNST: Lineation, a Critical Review and Annotated Bibliography. Geol. Soc. of America, Memoir 18. 1946.

—»— Tectonic Transport and Fabric in a Maryland Granite. Bull. Comm. géol. Finl. N:o 140. 1947.

NEUVONEN, K. J. and MATISTO, A. S. I.: Some Observations on the Tectonics in the Tampere Schist Area. Bull. Comm. géol. Finl. N:o 142. 1948.

SEDERHOLM, J. J.: Über eine archäische Sedimentformation im südwestlichen Finnland und ihre Bedeutung für die Erklärung der Entstehungsweise des Grundgebirges. Bull. Comm. géol. Finl. N:o 6. 1897.

3.

A COMPARISON MADE BY MEANS OF CHALCOGRAPHIC INVESTIGATIONS OF SOME ORE-BEARING BOULDERS WITH THE ORES OF OUTOKUMPU AND POLVIJÄRVI

BY

V. MARMO

INTRODUCTION

When the ore-bearing boulders were found in Selkie village in the parish of Kontiolahti in 1919 and in Röksä in the parish of Kiihtelysvaara in 1928, they aroused considerable attention over many years, and in trying to find their sources many attempts were made to solve the question whether or not they were derived from the ore deposit at Outokumpu, discovered in 1910.

These boulders were investigated very closely by Väyrynen (1923), who distinguished two different types in the boulders from Selkie; of these the first contains chrom-bearing minerals, whereas the other has none. According to him they were, however, both derived, if not directly from Outokumpu, at least from some unknown deposit, which contains a very similar ore-type. On the other hand Trüstedt (1926) maintained that they definitely derived from Outokumpu, and Eskola (1935) also held the same opinion.

The investigations of the quaternary geology by Hyyppä in the summer of 1945 raised this question again, and the present author made his investigations of boulders from Selkie and Röksä and also of samples from different outcrops at Outokumpu by the chalcographic method. Besides these he also examined some polished sections of the ore from Kanalampi, the samples of the Kivisalmi boulder (which had led to the discovery of the Outokumpu ore) and also pyrites from the occurrences in Polvijärvi and Karhunsaari.

CHALCOGRAPHIC OBSERVATION

Common to all the samples from Selkie and Röksä is the abundant iron p y r i t e, which is apparently the oldest of all ore-minerals in the samples in question. It occurs as well formed crystals without any other ore-minerals as inclusions. The pyrite grains are somewhat corroded in their edges and often one can see signs of the alteration of pyrite to pyrrhotite. There also occurs another, younger generation of pyrite, as will be seen from the description of pyrrhotite. Often the pyrite grains are surrounded by h y d r o h a e m a t i t e.

P y r r h o t i t e is often primary, but more often as a product of metamorphism of pyrite. It occurs as relatively large, somewhat rounded grains. Palmunen mentions pentlandite among them.

The present author investigated all pyrrhotites in the available samples of the boulders and deposits in question. Very characteristic of all the pyrrhotites is a very distinct lamellar structure, which is seen most distinctly when the polished section is oxidized by H_2O_2. It frequently occurs in consequence of a different crystallographical orientation, but often there are probable differences in the chemical composition also. In the boulders from Selkie there occurs a pyrrhotite, which becomes brownish when treated with H_2O_2, but the colour of the lamellae remains unchanged. Many of the lamellae (as also in boulders from Röksä) are anisotropic, but some of them seem to be isotropic. The latter in many cases resemble pentlandite, but the CrO_3-test was negative. Similar lamellae are also to be found in one of the samples from Outokumpu. On the borders of the pyrrhotite in the Selkie boulders there occurred, however, a mineral of granular habit unchanged by treatment with H_2O_2, which gave with the CrO_3-test a slightly positive result for pentlandite. Therefore the present author made a Ni-test with dimethyl-glyoxime according to Short (1940). After treating the polished section with nitric acid for 5 minutes the mineral became brownish, and after adding dimethyl-glyoxime a very thin but distinct red precipitate was deposited. The mineral consequently is pentlandite. This result was reinforced by a spectrographic determination of nickel in pyrrhotite from Outokumpu made by mr. O. Joensuu. The anisotropic lamellae which remained unchanged also by etching with CrO_3 are probably c u b a n i t e, which will be described later in more detail.

Further, it seems that the pyrrhotite in our samples is composed of two components reacting differently to etching, one of which, when treated with KOH, turns bluish and also seems to be more liable to marcasitization (see below).

The pyrrhotite has in some cases originated chiefly from pyrite. In some boulders from Selkie this can be seen very distinctly. These boulders are apparently different from the boulders described above, for, besides the alteration of pyrite into pyrrhotite (pyrrhotite-pseudomorphs with a well preserved crystal form of pyrite), there also occurs a further alteration of pyrrhotite to marcasite. The grains, with a diameter of about 0,5 cm., are very similar to pyrrhotite, but under the microscope they are obviously marcasite. Here we meet a phenomenon which is very similar to the marcasitization described by Ramdohr (1928) from Rammelsberg in Germany.

Similar marcasitization also occurs often in the specimens collected from the parish of Polvijärvi, where compounds of melnikovite-pyrite have also been found as well as marcasite. On the other hand, the marcasite also occurs here in a way characteristic of some samples from Outokumpu. By treating the sample with KOH all pyrrhotite is coloured brown or bluish, whereas the fissures filled with marcasite appear as a pale coloured net, very similar to a spider's web (Fig. 1). In such cases

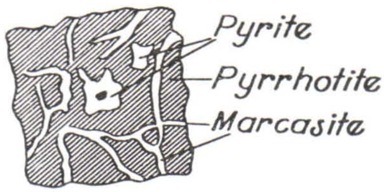


Fig. 1

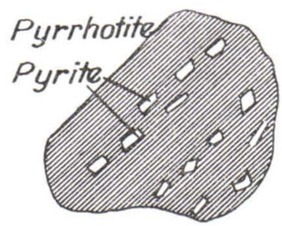


Fig. 2

the marcasite forms very thin needles which lie perpendicular to the fissures. Such a type of marcasite is represented by one specimen from Haaralanniemi in the parish of Polvijärvi. The alteration into this type has consequently followed this order:

(1) pyrite → (2) pyrrhotite → (3) marcasite,

but, particularly in this case, the alteration has stopped at stage (2), whereas it usually has continued over stage (2) wholly to the third stage as is apparent in the ore-impregnations in Polvijärvi and also in some samples from Selkie.

In a few specimens of the deposits of Outokumpu there can be occasionally seen also instances of pyrite originating by alteration from pyrrhotite. Consequently this pyrite belongs to the younger generation of this mineral, and then occurs as small grains in pyrrhotite and the grains are orientated subparallel to the (0001) planes of the pyrrhotite (Fig. 2). Very occasionally the pyrite of the second generation has also been found by the present author in the samples from Röksä, but never in boulders from Selkie.

In the neighbourhood of the chalcopyrite the colour of the pyrrhotite seems to be somewhat deeper than in other parts. The chalcopyrite is younger than the pyrrhotite and in all the samples investigated usually occurs in connection with the pyrrhotite. Further, it seems to be common to all samples that it brecciates the quartzite, or that it occurs together with blende in the fissures of the pyrite. Together they then replace the pyrite according to Laitakari (1931), who states this phenomenon to be common both in Outokumpu and in the Pitkäranta-region.

Very often, but especially in the samples from Röksä, chalcopyrite occurs as a narrow border surrounding the blende or pyrrhotite (Fig. 3). Blende and pyrrhotite only occasionally occur bounded by each other, but usually a very thin strip of chalcopyrite occurs between them, exactly in the same manner as in some copper ores in Alaska, described by Jauwell (1927). In the specimens from Outokumpu this mode of

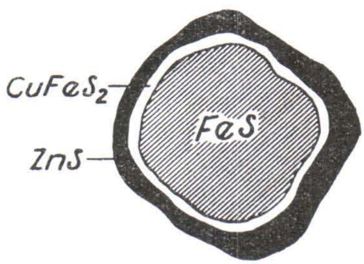


Fig. 3

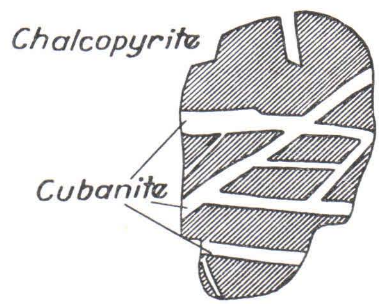


Fig. 4

occurrence is rarer and in the Selät boulders only occasional. Palmunen (1939) mentions, that chalcopyrite from Outokumpu is nonhomogeneous, and that by treating it with $KMnO_4$ a lamellar system is developed, where the lamellae will stay unetched. The present author has found similar lamellae in all the chalcopyrites which he met with in his investigations now in question. However, he used H_2O_2 instead of $KMnO_4$ as means of developing them. These lamellae were especially clear in one of the boulders from Selkie. In this case some parts of the chalcopyrite on the borders remained unchanged under the treatment. This may only mean that these parts of the chalcopyritic crystal were differently orientated but the lamellae of the same crystal were quite different. By a more detailed investigation they were determined as cubanite.

Cubanite is especially well developed in polished sections made of specimens from a small deposit at Kanalampi. In these there are large and compact chalcopyrite grains in which the lamellae mentioned above are already visible without treating with any oxydizing agents (Fig. 4). The interference (xN) of these lamellae changes from greenish blue into deep bluish red. Refringence is slight but visible, changing from pale brown to a darker shade. This is cubanite which occurs in thin lamellae, and appears to have originated from chalcopyrite by unmixing due to the process by which a homogeneous crystal separates (without fusion or solution) into dissimilar parts as a result of instability induced by cooling, as explained also by other authors with regard to cubanites from different occurrences (Schwartz 1923, Geijer 1924, Ramdohr 1928 and Vogt 1925). They have pointed out that the occurrence of cubanite is due to the high original temperature. Above 450°C cubanite and chalcopyrite are miscible, but below this point they remain immiscible. Contemporaneously this unmixing can be accompanied by the alteration of cubanite into pyrrhotite and chalcopyrite. The present author has observed such alteration in samples from Kanalampi, and to a minor extent also in polished sections made of the boulders from Röksä, where lamellae of pyrrhotite in chalcopyrite also occur with the same orientation as in the cubanite lamellae, *i. e.* parallel to (111) of the chalcopyrite. Some of these lamellae are probably identical with the c u b a n i t e II of Schneiderhöhn-Ramdohr (1931), which occurs as nearly anisotropic lamellae in chalcopyrite.

V a l l e r i i t e can also be explained as a product of alteration of cubanite and this occurs both as a mineral filling fissures between other ore minerals in the boulders from Selkie and as small grains on the border of chalcopyrite grains. Both in polished sections of the Selkie boulders and in a few samples from the deposits of Outokumpu the valleriite occurs as a clearly pleochroic mineral (E = brownish gray and O = pale yellowish red), with strong birefringence. All its optical properties are in very good agreement with the description of valleriite by Ramdohr and Ödman (1932).

In the polished section made of the Röksä boulder there occur some very small grains ($<$ 0,03 mm.) distinctly lamellar, and somewhat paler in colour than the chalcopyrite in which they occur. They are also found in pyrrhotite and in this case they are so orientated that the lamellae are lying parallel to (0001) of the pyrrhotite. The refringence is quite weak, but birefringence very strong, with colours of pale grayish blue to pale yellow, with sharp extinction. Its properties and also its paragenesis agree very well with those of m i l l e r i t e. According to Mayer (1926) this mineral should, however, correspond to an origin at a lower temperature, but Schneiderhöhn (1931, p. 348) mentions millerite as present also among the ore-minerals originating under higher temperature conditions.

As products of later alteration of chalcopyrite there is b o r n i t e and c h a l c o s i t e. In some samples from Selkie there occurs c o v e l l i t e, also a product of later alteration. It occurs both as filling matter in fissures and as small grains on the boundary between the chalcopyrite and cubanite, but occasionally also in blende.

B l e n d e occurs in all samples, but as a minor component, and it seems to be of the same age as chalcopyrite, with which it occurs.

In some polished sections made of the Röksä boulders there are in the blende and also in the pyrrhotite very few and extremely small grains of a mineral which greatly resembles magnetite, though it has a strong birefringence. On account of the smallness and rarity of the grains the investigation of this mineral was very difficult. Its colour is somewhat greenish-gray olive. When in chalcopyrite it seems to be a mixture of the colours of the chalcopyrite and of the blende, but when in the pyrrhotite it is light brownish. As mentioned above, its birefringence is very strong and the colours caused by this birefringence can change without extinction between the different colours. Palmunen (1939) mentioned that in one of the polished sections of the Outokumpu ore from the collections of the Geological Survey of Finland he had found a grayish mineral, which occurred in chalcopyrite. Its colour was, according to him, somewhat paler than that of blende, and he mentions the same mineral as also being enclosed in blende. Palmunen did not identify this mineral, but according to his description it can be the same mineral as described above by the present author, who made several etching tests with this mineral and found that all its properties agree with those of s t a n n i t e, which has never been mentioned among the ore minerals of Outokumpu. In this connection it may, however, be mentioned that the tin-content of the ores of Outokumpu is sufficient to admit of the occurrence of small stannite microlites in pyrrhotite and in blende. Also the spectrographic determinations made by Joensuu show a tin-content in the Outokumpu chalcopyrite which can be easily explained by the occurrence of stannite.

The stannite which occurs as microlites must be regarded as a product of unmixing. It seems to have originated under hydrothermal conditions. We have here consequently a miniature of the stannite microlites in the Bolivian zinc-tin ore deposits, where the stannite has unmixed from blende (Ahlfeld 1928).

CONCLUSIONS

In accordance with the chalcographical investigations presented above, all boulders found in Selkie and in Röksä belong to the same ore-type, this type being similar to that represented by the Outokumpu ore. However, among the boulders from Selkie there apparently occur two different kinds of boulders. One kind can indeed have its source in Outokumpu, but this is probably not the case with the other type, which bears plenty of marcasite as a product of alteration of pyrrhotite, and also melnikovite-pyrite. These minerals rather point to the known ore-mineral occurrences in the parish of Polvijärvi, where the pyrites are characterized just by the alteration: pyrite → pyrrhotite → marcasite.

Also Väyrynen (1935) distinctly separated these pyrite impregnations from the Outokumpu ore type. The same alteration series occurs, however, also in the Outokumpu ore, but is not so common as in the parish of Polvijärvi.

HELSINKI, GEOLOGICAL SURVEY, MARCH 1949.

REFERENCES

AHLFELD, F.: Zur Entstehung der Sulfostannate Boliviens. Zeitschr. f. prakt. Geol. pp. 43—4. 1928.

ESKOLA, P.: Malmin etsinnästä ja malmityypeistä. Terra p. 132. 1935.

GEIJER, P.: On cubanite and »chalcopyrrhotite» from Kaveltorp. Geol. För. i St. Förh. p. 2. 1924.

JAUWELL, W. B.: Mineral deposits of the Hyde District, Alaska. Econ. Geol. XXII, pp. 502—3. 1927.

LAITAKARI, A.: Verdrängungen in Sulfidmineralien von Pitkäranta und Outokumpu. Bull. Comm. géol. Finl. N:o 93, p. 55. 1931.

MEYER, E.: Mineralogisch-petrographische Untersuchungen über die Mechernicher Lagerstätte. Diss. Köln. 1926.

PALMUNEN, M. K.: Pitkäranta vv. 1934—1938 suoritettujen vuoriteknillisten tutkimusten valossa. Geotechn. Papers, Comm. géol. Finl. N:o 44. 1939.

RAMDOHR, P.: Über den Mineralbestand und die Strukturen der Erze des Rammelberges. N. Jahrb. f. Min. B.-B. 57, pp. 1013—68. 1928.

—»— und ÖDMAN, H.: Valleriit (= »unbekanntes Ni-Erz» = »fragliches, pleochroistisches Mineral»). Geol. För. i St. Förh. Bd. 54, Heft 1. pp. 89—98. 1932.

SCHWARTZ, G. M.: Chalmersite at Fierro, New Mexico, with a note of its occurrence at Perry Sound, Ontario. Econ. Geol. XVIII, pp. 270—7. 1923.

SCHNEIDERHÖHN, H. und RAMDOHR, P.: Lehrbuch der Erzmikroskopie, Berlin. 1931.

SHORT, M. N.: Microscopic determination of the ore minerals. Bull. U. S. Geol. Surv. 914. 1940.

TRÜSTEDT, O.: Geologisen Toimikunnan Vuosikertomus. 1926.

VOGT, TH.: Ett viktigt, för Norge nytt kobbermineral, Cuban. Norsk Geol. Tidskr. 8. p. 133. 1925.

VÄYRYNEN, H.: Geologisen Toimikunnan Vuosikertomus, pp. 32—5. 1923.

—»— Über die Mineralparagenesis der Kieserze in den Gebieten von Outokumpu und Polvijärvi. Bull. Comm. géol. Finl. N:o 109, pp. 1—24. 1935.

4.

THREE NEW BOULDERS OF ORBICULAR ROCK IN FINLAND

BY

AHTI SIMONEN

INTRODUCTION

Previously, eleven occurrences of orbicular rocks have been reported in the migmatitic Pre-Cambrian rock crust of Finland, and all of these occurrences have been described by Finnish geologists (Frosterus 1892 and 1896, Sederholm 1928, Eskola 1938, Simonen 1941). Many chemical analyses, showing the esboitic (oligoclasitic) composition of the orbicules, have been carried out, and the esboitic crystallization of orbicular rocks (Eskola 1938), the process by which the orbicules have attained this composition, has been discussed.

This investigation deals with three new finds of orbicular rocks made in Finland during the years 1947—48. The new occurrences at Längelmäki, Vilppula and Heinävesi, met with as glacial boulders, will be briefly described. The Vilppula rock, showing clearly the migmatitic character of the matrix, was subjected to chemical analyses. Some conclusions on the origin of orbicular rocks are presented.

THE ORBICULAR ROCK OF LÄNGELMÄKI

Many years ago Mr. Purokoski, M. A., informed me that one of the gravestones in the cemetery of the parish of Längelmäki had been made from orbicular granite. In the summer of 1947 the author visited Längelmäki and obtained the unpolished orbicular rock boulder (60 × 40 × 30 cm) reserved for the gravestone of Mr. Matti Ojanen, the finder of the rock. The local parson informed me that the boulder had been found in the village of Ristijärvi in the parish of Längelmäki, but the exact place of discovery is unknown.

The orbicules of the Längelmäki rock, measuring 8—10 cm in diameter, are esboitic. The non-oriented nuclei of the orbicules contain predominantly medium-grained plagioclase (An_{31}) grains enclosing some small spots of biotite, chlorite and quartz. Xenomorphic quartz grains occur between the plagioclase crystals.

Around the nucleus the plagioclase (An_{29}) assumes a radiating arrangement parallel to the a-axis. The radially arranged plagioclase crystals enclose a number of biotite flakes arranged tangentially, parallel to (001). The biotite flakes are in rows causing a »warp and weft» texture. Many well-developed biotite rows have been observed in the orbicule at my disposal for microscopic study (Fig. 1, Plate I).

Graphic intergrowth of quartz with the radially arranged feldspar is common and the amount of quartz in the orbicule seems to decrease gradually outwards from the nucleus. The biotite shows pleochroism with brown or green for rays vibrating parallel to the cleavage, and chlorite occurs as an alteration product. Some small non-oriented, equidimensional plagioclase grains can be observed among the radially arranged crystals. A narrow biotite-rich zone forms the border of the orbicule against the matrix.

The matrix between the orbicules is heterogeneous containing pegmatitic or aplitic microcline granite and some small biotite-rich spots. Microcline and quartz are the main components of the matrix. Plagioclase (An_{28}) occurs as strongly sericitized grains corroded by the potash feldspar, and some small much altered plagioclase individuals, containing myrmekite quartz, occur as inclusions in the large microcline crystals. The microcline granite contains only a very few flakes of biotite which have been much altered into chlorite. Apatite and sphene have been observed as accessory minerals.

THE ORBICULAR ROCK OF VILPPULA

In the summer of 1947, Mr. Olavi Waldén, student of geology, during prospecting work in the parish of Vilppula in Central-Finland, discovered a new boulder of orbicular rock by the village road along the northeastern side of Lake Löytänäjärvi. During construction of the road the boulder had been blasted into many pieces. Some samples only have been collected for this investigation and the greatest part of the rock is still at the place of discovery.

The orbicules, measuring 7—12 cm in diameter, are esboitic and many of them have suffered strong corrosion by the secondary granitic matrix, as may be seen in Figures 3 and 4 (Plate I).

Coarse-grained, slightly sericitized plagioclase (An_{29-30}) is the main component of the light-coloured nucleus. Small quartz grains occur between the plagioclase crystals. Biotite and chlorite occur occasionally as small flakes. Apatite and iron ore are accessory minerals. In one case a nucleus was quartz dioritic rock similar to the oldest part of the migmatitic matrix. The coarse-grained plagioclase zone, similar to the nuclei of the usual type, has been formed around this isothrausmatic type of nucleus (Loewinson-Lessing and Olga Vorobjeva 1929).

The coarse-grained plagioclase nucleus passes gradually into a finer grained, darker grey zone of plagioclase (An_{33-35}) which is sericitized and contains pigment. Dark-coloured zones of plagioclase alternate with lighter-coloured plagioclase zones causing the concentric structure of the orbicules. Some plagioclase crystals show an inclination to radial arrangement, but on the other hand in some orbicules the plagioclase at the margin assumes a tangential arrangement on its (010) planes. The amount of quartz in the plagioclase zone is lower than in the nucleus, but the amount of biotite and chlorite increases towards the periphery of the orbicule. Some secondary grains of microcline have been observed in the granitized parts of the orbicules.

The matrix between the orbicules is distinctly migmatitic containing quartz diorite and granitic parts.

The medium-grained quartz diorite is the primary component of the matrix. The main minerals are plagioclase (An_{31-33}), biotite and quartz. The plagioclase is sericitized and occasionally zoned. Dark-coloured biotite occurs mainly as aggregates containing grains of sphene. Quartz forms a granulated mass between the plagioclase grains. Epidote, chlorite, apatite and iron ore are accessory minerals. Some secondary grains of microcline occur in the granulated mass.

The primary matrix has been granitized by ichors rich in potash. The granitization has produced microcline porphyroblasts, measuring 1—2 cm in diameter. Transitional forms from the quartz diorite into the porphyritic granite can be observed.

The main component of the matrix is the porphyritic granite, formed by the action of the metasomatic replacement processes upon the pre-existing minerals. The secondary microcline has metasomatically corroded the primary quartz dioritic fabric and small remnants of the altered plagioclase (An_{28-32}) grains occur as inclusions in the large microcline porphyroblasts. Quartz forms the granulated fabric between the potash feldspar grains, and the amount of biotite is very small.

The heterogeneous matrix also contains pegmatitic and aplitic parts of microcline granite poor in mafic components. Some grains of dark blue orthite have been observed in the pegmatitic parts of the matrix.

The granitization has been later than the esboitic crystallization of the orbicules, because it has caused strong corrosion of the orbicules. The esboitic parts of the orbicules are changed by the granitization into red-coloured granite. The fine-grained plagioclase zones of the orbicules have been more resistant to granitization than the coarse-grained nuclei, and in many cases it is possible to observe non-granitized remnants of the fine-grained zone in the secondary, granitic matrix (Fig. 4, Plate I).

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In the slightly granitized parts of the coarse-grained plagioclase nucleus the primary grains of plagioclase contain regularly shaped anthiperthitic inclusions of microcline in homoaxial intergrowth with plagioclase, but these anthiperthitic inclusions have not been observed in the non-granitized parts of the orbicules. This indicates that the origin of the anthiperthitic texture is, in this case, due to metasomatic replacement. The occurrence of the anthiperthitic intergrowth only in the

Table I

Analyses of the orbicular rock from Vilppula.

Anal. H. B. Wiik.

	1	2	3	4
SiO_2	65.85	56.97	61.10	64.38
TiO_2	0.05	0.48	0.65	0.52
Al_2O_3	20.61	23.99	18.68	20.42
Fe_2O_3	0.28	1.77	5.84	0.41
FeO	0.39	1.94	0.07	1.66
MnO	0.01	0.04	0.10	0.04
MgO	0.04	0.15	1.09	0.38
CaO	4.91	6.13	3.98	3.92
Na_2O	6.56	6.63	4.36	4.48
K_2O	0.62	1.05	2.86	3.61
P_2O_5	trace	0.03	0.09	trace
H_2O +	0.40	0.46	0.75	0.50
H_2O —	0.04	0.00	0.05	0.11
	99.76	99.64	99.62	100.43

Norms

	1	2	3	4
q	14.48	0.71	15.24	14.74
or	3.67	6.23	17.01	21.19
ab	55.54	55.80	36.68	37.89
an	24.52	30.24	17.38	19.57
cor	0.13	0.86	2.01	2.00
fs	0.39	1.33	0.18	1.93
en	0.10	0.08	2.72	0.95
mt	0.42	2.64	—	0.60
hm	—	—	5.84	—
il	0.09	0.91	0.15	0.99
ti	—	—	1.39	—
ap	—	0.07	0.20	—

1. Nucleus of orbicule.
2. Fine-grained outer zone of orbicule.
3. Primary matrix.
4. Secondary matrix.

slightly granitized parts of the orbicule shows that the granitization of the plagioclase has started with anthiperthitic replacement, and when the granitization has gone farther the plagioclase occurs as inclusions in the large microcline porphyroblasts.

Chemical investigation of the Vilppula rock (Table I) shows the typical esboitic composition of the nucleus and of the grey-coloured outer part of the orbicule (anal. 1 and 2), characterized by the high values of Al_2O_3, CaO and Na_2O, while the amount of K_2O is very small. The outer part of the orbicule is more basic than the nucleus. This is due to an outward diffusion of the mafic components during the esboitic crystallization (see p. 36). The content of K_2O is higher in the matrix than in the orbicule. This is caused by the later potash metasomatism. The amount of mafic constituents in the primary matrix (anal. 3) is higher than in the orbicule, suggesting the idea that esboitic crystallization is characterized by the impoverishment of the mafic components in the orbicule. The secondary matrix (anal. 4), rich in alkalis and poor in FeO and MgO, shows chemical features typical of granitized rocks.

THE ORBICULAR ROCK OF HEINÄVESI

In the summer of 1948, Mr. Arvo Vesasalo, student of geology, discovered a new boulder of orbicular rock in the village of Varistaipale, situated in the northern part of the parish of Heinävesi, Eastern Finland. Dr. Erkki Aurola has placed at my disposal these specimens of the orbicular rock. The biggest specimen is in the collections of the Geological Institute of the Helsinki University and the greatest part of the rock is still at the place of discovery.

The orbicules of the Heinävesi rock, measuring 6—8 cm in diameter, contain dark-coloured nuclei formed by inclusions of foreign gneiss around which mantles of esboitic composition have grown (Fig. 2, Plate I). The central gneiss shows a schistose structure, owing to a parallel arrangement of the biotite. The longer diameters of the ellipsoidal orbicules are orientated in the direction of schistosity. The main minerals of the central gneiss are plagioclase (An_{43-44}), biotite and quartz. The biotite shows dark brown pleochroism and contains pleochroic halos. Apatite and sphene are accessory minerals.

In some very few cases the amount of plagioclase has secondarily increased in the nucleus causing a gradual alteration of the central gneiss into an esboitic nucleus rich in biotite.

Around the gneiss nucleus the minerals are arranged in regular zones. The innermost light coloured zone contains mainly coarse-grained plagioclase (An_{30-35}) crystals, some of which show an inclination to radial arrangement. Quartz occurs sparely between the plagioclase crystals.

Biotite is as dispersed flakes and there are small hornblende grains especially at the boundary zone against the gneiss nucleus.

The innermost, coarse-grained plagioclase zone passes gradually into the grey-coloured zone of plagioclase (An_{30-33}), which contains chloritized biotite flakes and quartz between the radially arranged plagioclase crystals. The boundary between the orbicule and matrix is not sharp.

The mineralogical composition of the coarse-grained matrix is very similar to that of the plagioclase zones of the orbicules. Plagioclase (An_{27-31}) and quartz are the main components and biotite, containing chloritized parts, occurs as small flakes. This esboitic matrix contains many biotite gneiss inclusions which are similar to the nuclei of the orbicules. Many gneiss inclusions show a gradual change into the esboitic matrix.

DISCUSSION

The orbicules of the new occurrences show an esboitic chemical composition characteristic of which is the high content of Al_2O_3, Na_2O and CaO (see Table I). Esboitic parts of the orbicules are the most common in all the orbicular rocks, while K_2O-rich shells have been met with only in some very few cases. Therefore one of the main problems of the orbicular rocks has been to make clear the process by which the orbicules have attained their esboitic composition.

Sederholm (1928), who was the first to draw attention to the exceptional esboitic composition, considered the orbicules as fractional crystallization products of a viscous, esboitic magma. Eskola (1938) has, however, pointed out in esboites many features contradictory to the laws of magmatic crystallization, and he explained the esboitic crystallization as a metasomatic process which has proceeded outwards from the nuclei of the orbicules. Eskola has laid a special stress on the migmatitic character of the matrix of many orbicular rocks, and he considers that, before the granitization, the orbicules in many cases have been derived by metamorphic differentiation from the material of the primary matrix.

The esboitic composition of the orbicules, compared with that of the primary matrix, indicates enrichment of the orbicules in the salic components, and a corresponding removal of the mafic components involving replacement processes (*e. g.* anal. 1 and 3 in Table I). Furthermore the outer shells of the esboitic orbicules are in many cases more basic than the inner zones (*e. g.* anal. 2 and 1 in Table I). These chemical features contradictory to the laws of magmatic differentiation are due to metamorphic differentiation characterized by an outward diffusion of mafic components during the process of esboitic crystallization.

All the new occurrences show the heterogeneous character of the matrix, and corroborate the idea that the esboitic crystallization has happened metasomatically in the primary matrix, and the granitization, if it has taken place, is later than the origin of the orbicules.

Especially the Vilppula rock, which shows strong corrosion of the orbicules by the secondary granitic matrix, is an elucidative example of the chronological sequence between the esboitic crystallization and the granitization. In the Längelmäki rock the matrix consists of microcline granite, but this matrix contains strongly corroded plagioclase grains, with the same composition as the plagioclase in the orbicules. The corroded plagioclase is the only remnant of the granitized primary matrix the characteristics of which are unknown. In the Heinävesi rock the foreign inclusions have been the centres of esboitic crystallization, and the metasomatic processes have taken place around and between the gneiss fragments, giving rise to the esboitic zones as well as the esboitic matrix. No signs of granitization have been observed.

The esboitic crystallization has been succeeded, in many cases, by later potash metasomatism causing the granitization of the primary matrix and the corrosion of the orbicules. The occurrence of orbicular rocks in migmatitic surroundings indicates, however, that the esboitic crystallization is closely connected with metasomatic processes taking place in an approaching migmatite front. Furthermore some orbicular rocks, containing microcline shells, have originated in close connection with granitization, because the orbicules have been derived from the granitic material added by granitization (Eskola 1938 and Simonen 1941). Therefore to the author it seems that the esboitic crystallization and granitization are closely related and the neighbourhood of the migmatite front has catalytically caused the diffusion and mobilization of the elements in the country rocks giving rise to the peculiar structure of the orbicular rocks.

REFERENCES

ESKOLA, PENTTI: On the Esboitic Crystallization of Orbicular Rocks. Journ. Geol. 46. 1938.

FROSTERUS, B.: Ueber ein neues Vorkomnis von Kugelgranit unfern Wirvik bei Borgå in Finnland nebst Bemerkungen über ähnliche Bildungen. Min. Petr. Mitt. 13. 1892.

—»— Ueber einen neuen Kugelgranit von Kangasniemi in Finnland. Bull. Comm. géol. Finl. 4. 1896.

LOEWINSON-LESSING, F. and VOROBJEVA, OLGA: Contribution to the Knowledge of Orbicular Structure in Igneous Rocks. Compt. Rend. Acad. Sci. U.S.S.R. 1929.

SEDERHOLM, J. J.: On Orbicular Granites, Spotted and Nodular Granites etc. and on the Rapakivi Texture. Bull. Comm. géol. Finl. 83. 1928.

SIMONEN, AHTI: Orbicular Rocks in Kemijärvi and Esbo. Bull. Comm. géol. Finl. 128. 1941.

EXPLANATION OF PLATE I.

Fig. 1. Orbicule of the Längelmäki rock showing the biotite rows. $^4/_3$ natural size.
Fig. 2. Orbicule of the Heinävesi rock. ½ natural size.
Fig. 3. Orbicule of the Vilppula rock. ½ natural size.
Fig. 4. Orbicules of the Vilppula rock in the migmatitic matrix showing non-granitized remnants of the fine-grained plagioclase zone in the secondary matrix .½ natural size.

Photo: Arvo Matisto.

Fig. 1.

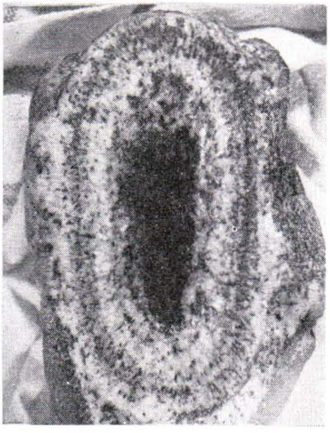


Fig. 2.

Fig. 3.

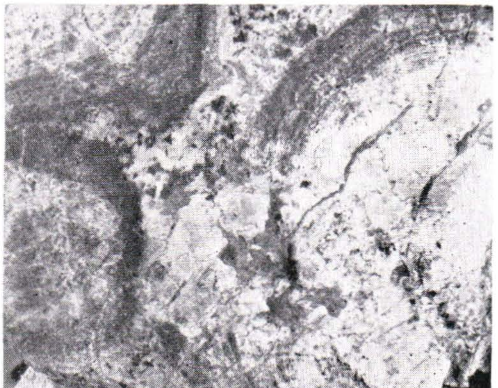


Fig. 4.

Ahti Simonen: Three New Boulders of Orbicular Rock in Finland.

5.

MENEGHINITE FROM AIJALA, SOUTHWESTERN FINLAND

BY

S. KAITARO AND O. VAASJOKI

The sulphide ore occurrences in the village of Aijala in Kisko, Southwestern Finland, have been mentioned in a previous study published by Eskola (1914). The following map shows the area of the Old Mine west of Aijala. The pits, most of which were filled by water, were drained in the summer of 1945 in connection with ore prospecting carried out by Suomen Malmi Oy (Finnish Ore Co.). At that occasion, the first author of this article had the opportunity to map these pits and their surrounding.

The ore-bearing zone consisting of schists and limestone, and the adjacent even-grained leptite and metamorphic quartz porphyry (blastoporphyritic leptite) are shear folded, and the more mobile limestone has »flowed» into the folds. The strike of the cleavage is mainly N 60° E, and the dip vertical or rather steep. The lineation in quartz porphyry as observed specially in the quartz grains is clearly vertical. The quartz porphyry, showing locally breccia-like block structure, has sharp- contacts, while the leptite in some places changes gradually into mica schist. The map shows the structural relationship of the deposits to the steep-plunging drag folds. In the Old Mine, about 23 m deep, a galena quartz vein between coarse-grained crystalline limestone and mica schist has been mined. In the limestone, especially against the quartz vein, diopside occurs as rather large crystals. The schists in the pits east of the mine are very heterogeneous, the most abundant constituents being biotite, sericite, chlorite, talc or hornblende. Anthophyllite aggregates are not rare in the eastern corner of the greatest pit known by the name of »Branched pit.» On the borders of the pits a very siliceous mica schist is predominant. Younger transverse faults are represented by slickensides or by calcite veins. The examined specimens containing meneghinite have been taken from irregular lumps up to 10 cm in diameter. These lumps commonly occur in the southern part of Branched pit in the dark, partly aphanitic host rock. As this mineral, a rare sulphosalt, has not previously been found in Finland and is only known in a few localities elsewhere, the occurrence is worth attention.

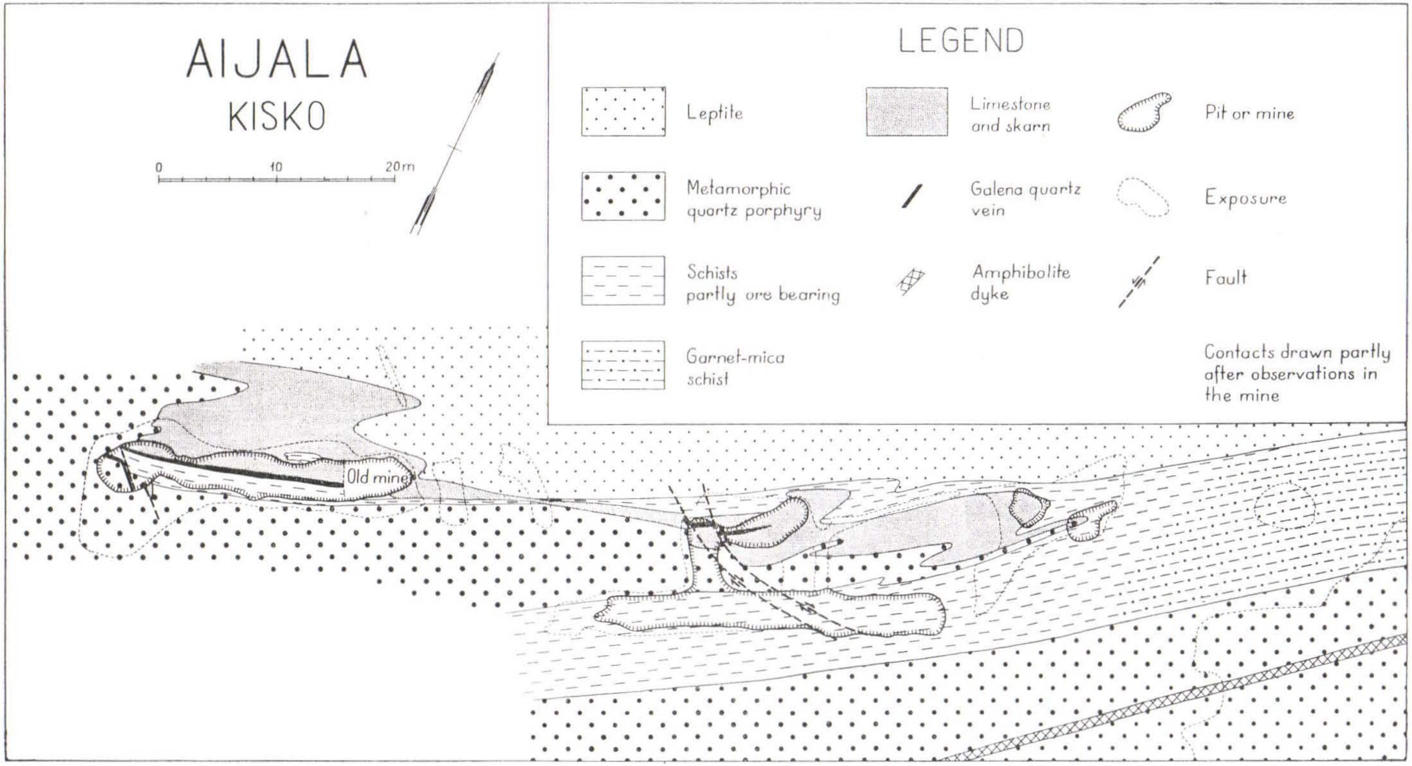
The so-called »Silver Mine», the new mine of Aijala and some other occurrences of sulphides in the neigbourhood of Lapinkylä are situated in the same zone between leptite and quartz porphyry. The deposit first mentioned indicates many paragenetic aspects similar to those in the pits west of Aijala and will, therefore, also be discussed in this paper.

MICROSCOPIC OBSERVATIONS OF THE ORE

Under the microscope the paragenesis of the old Aijala ore is rather complicated. Besides the pyrite with the usual associated sulphides, several sulphosalts have also been met with. Altogether the following ore minerals have been recognized in the specimens investigated: Pyrite, arsenopyrite, pyrrhotite, chalcopyrite, sphalerite, galena, meneghinite, tetrahedrite, native gold and one of the sulphosalts jamesonite, boulangerite or bournonite. It is not possible to distinguish between the three last mentioned minerals due to their small grain size. Similarly it is not possible to identify yellowish grains, which may be bismuthinite. Marcasite is found as a secondary product of pyrrhotite in a specimen from Silver Mine. Previously, Borgström has found (unpublished study) pyragyrite at this last-named locality.

The areal distribution of meneghinite in Aijala seems to be only connected with the particular schist zone in which the Branched pit occurs. There, all the minerals listed above are mostly met with. The predominating ore minerals are pyrite and arsenopyrite, accompanied by galena and sulphosalts in abundance. The native gold occurs as minute grains intergrown with meneghinite, containing small amounts of tetrahedrite (Fig. 3). In the specimens quarried from the Silver Mine no meneghinite was found, but tetrahedrite usually is present as small dots in galena.

In both types of ore the paragenetic relationship of the ore minerals is fairly well developed, and galena with sulphosalts is obviously the youngest of the primary phases. Chalcopyrite is always strongly resorbed as well as pyrite and arsenopyrite, which generally occur as rounded, irregular grains. An example of this typical phenomenon of resorbtion is shown in Fig. 5 illustrating how galena has resorbed pyrrhotite. Simultaneously with resorbtion the galena-sulphosalt material has advanced as vein-like formations along the available cracks or joints in the pyrite or arsenopyrite. In places the galena containing sulphosalts has brecciated the other sulphide minerals (Fig. 2). In relation to the silicate host rock, the galena-sulphosalt material fills the interstices between the silicate minerals (Fig. 1), but the hard minerals, *i. e.* pyrite, pyrrhotite and arsenopyrite, have suffered a cataclastic deformation. This conspicuous difference in behaviour of these mineral groups indicates



Map. 1. Geological map of the area of the Old Mine in Aijala, Kisko, by S. Kaitaro.
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that the hard minerals had crystallized before the last shearing movements took place. The galena-sulphosalt group crystallized chiefly during this phase of tectonic action.

Considering the relationship between the different ore minerals already described, their paragenetic development can be stated as follows:

Phase I Pyrite, arsenopyrite, pyrrhotite, chalcopyrite, sphalerite
Phase II Galena, sulphosalts, gold, bismuthinite
Phase III Marcasite

As shown in Fig. 4 meneghinite occurs associated with galena and it is predominant among the sulphosalts in the Aijala specimens. In places it is present in amounts comparable to that of galena. The chalcographic properties of meneghinite met with in Aijala correspond well to those which have been reported earlier in literature (Ramdohr 1931, Short 1940). In position // c the colour is nearly similar to that of galena, but in position // a and // b the colour is pale greenish grey, being thus darker than the colour of galena. Anisotropy is strong and there is parallel extinction. The etching tests, carried out by means of Short's system, were positive for HNO_3 and HCl. Regarding the hardness, meneghinite belongs to the soft minerals having in polished section no difference in relief in relation to galena. In this connection the absolute hardness was determined by means of Bergsman's micro-hardness tester (Bergsman 1944). The value obtained is 131 stated in Vickers numbers. In a neighbouring grain of galena the corresponding value was 80.

THE CHEMICAL COMPOSITION

The simple formula $Pb_4Sb_2S_7$ well illustrates the composition of meneghinite. According to the published analyses small amounts of copper are mostly present and may be not always due to impurities. In the present case Mr. J. Lounamaa, Technical University, Helsinki, kindly carried out a semiquantitative spectrographic analysis of the material, investigated. According to this analysis, the meneghinite from Aijala is a lead-antimony sulphosalt with about 3 % of copper. This result agrees well with the earlier statements upon the chemical composition of meneghinite.

X-RAY INVESTIGATIONS

For the identification of the mineral x-ray powder study was made using CuKα radiation. The kindness of Prof. E. Norin, Geological Department of the University of Uppsala, made it possible to perform an important part of this work at that department. Pure material was separated by means of micro-drill from polished sections under the microscope. Due to the fabric of the above mentioned ore minerals some galena lying below the plane of the polished surface might have been included as impurity. However, only in one case was a small amount of galena probably present in the material used. Here one must consider that the x-ray interferences given by sulphosalts are relatively weak and therefore the impurities of certain minerals with a simpler structure have a disturbing effect. Galena gives the same or nearly the same lines as meneghinite so that the impurity means, particularly in this case, intensity differences and makes it difficult to resolve some lines. The x-ray data are seen in the Table I, where measurable lines are given by spacing in ångstroms, and the corresponding relative intensity by visual estimation (v v w = very very weak; m = medium; v s = very strong etc.).

Table I

X-ray diffraction data of meneghinite from Aijala, Kisko

I	*d*	*I*	*d*	*I*	*d*
w	3.71	vvw	2.61	vw	1.93
vw	3.42	vvw	2.29	w	1.88
st	3.22	vw	2.23	vw	1.79
wv	3.07	vvw	2.16	vvw	1.71
vst	2.93	st	2.07	vw	1.39
w	2.75	vw	1.97		

Usually x-ray powder photographs provide a reliable identification o ore minerals. Sulphosalts possesing complicated structures often simila to each other show only small differences in the spacing and relative intensity. Therefore it is necessary to make a more detailed comparison for identification. For this purpose the x-ray data of meneghinite from Marble Lake, Ontario, in the collection of Harcourt (1942) and those of meneghinite from Bottino, Tuscany, the primary locality of the species as given by Hiller (1938) were used. The latter has given glancing angles for FeKα radiation, from which the spacing is calculated for comparison.

The comparison of the powder patterns of the meneghinite from Aijala with those of the two meneghinites just mentioned reveals some slight differences, but they are not greater than those between the Marble Lake and Bottino minerals. Some differences are systematic, *e. g.* the high-angle lines being weaker or lacking in the pattern of the meneghinite from Aijala. The Aijala meneghinite resembles in general more that from Bottino, but shows in some respects greater similarities with the Marble Lake mineral. The differences might be caused by the fact that the powder patterns of all three meneghinites have been photographed by different equipment, or they might be caused by absorbtion effects. Some differences in the intensities of the neighbouring lines are due probably to fluctuations in composition. The variation in composition without distortion in the unit cell can be considerable in such a complicated structure. Therefore, it is very reasonable to consider the compared minerals as the same species. So far no further x-ray studies have been made for the determination of the size of the unit cell. This is not possible from the material investigated because no measurable crystals have been found. In this connection it may be pointed out that our knowledge concerning sulphosalts seems to be still insufficient, because some data, *e. g.* the cell constants of meneghinite, given by various authors are not in agreement.

REFERENCES

ESKOLA, P.: On the petrology of the Orijärvi region in Southwestern Finland. Bull. Comm. géol. Finl. 40, 1914.

BERGSMAN, BÖRJE E.: Något om mikrohårdhetsmätning samt beskrivning av ett par nya, enkla prövningsanordningar härför. Järnkont. Ann. 128, 1, 1944.

HARCOURT, G. A.: Tables for the identification of ore minerals by x-ray powder patterns. Am. Min. 27, 1942.

HILLER, J. E.: Röntgenographische Bestimmungsmetoden und Untersuchung der Bleispiessglanze. Zeitschr. Krist. 100, 1938.

SCHNEIDERHÖHN, H.—RAMDOHR, P.: Lehrbuch der Erzmikroskopie. Berlin, 1931.

SHORT, M. N.: Microscopic determination of the ore minerals. Bull. U. S. Geol. Survey 914, 1940.

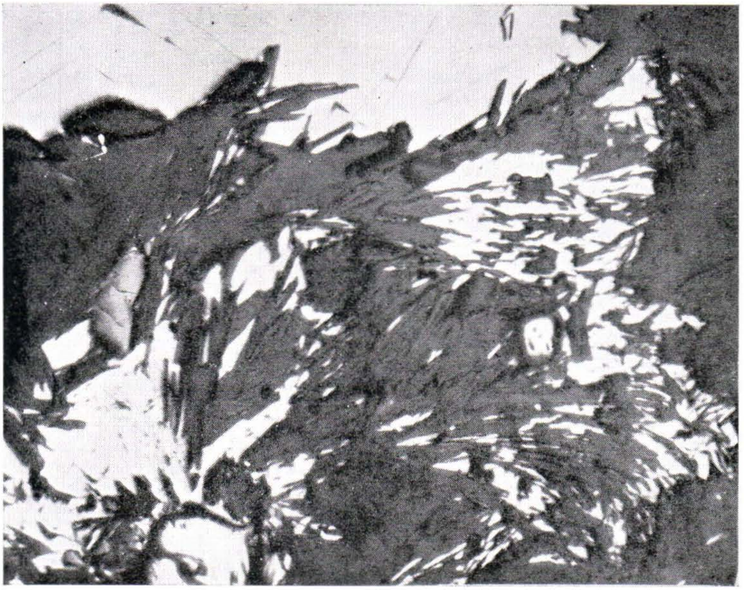

Fig. 1. Galena-sulphosalt material (light) in the interstices between the silicate minerals (black). Magn. 50 ×.

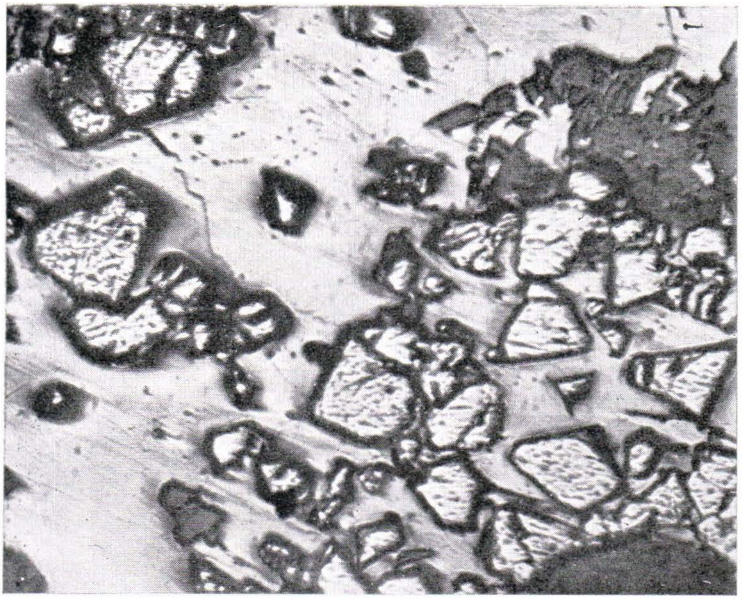

Fig. 2. Brecciated pyrite in galena. Magn. 50 ×.

S. Kaitaro and *O. Vaasjoki:* Meneghinite from Aijala.

Fig. 3. Gold (light) intergrown with meneghinite (dark grey) in the centre of picture, surrounded by galena (light grey). Black = silicate minerals. Magn. 120 ×.

Fig. 4. Meneghinite (slightly darker grey) associated with galena (light grey). Magn. 50 ×.

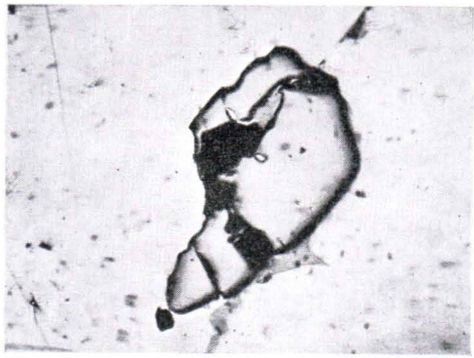

Fig. 5. A grain of pyrrhotite being resorbed by galena-sulphosalt material. Magn 120 ×.

S. Kaitaro and *O. Vaasjoki:* Meneghinite from Aijala.

6.

FRICTION CRACKS IN FINLAND

BY

VEIKKO OKKO

Observations published by Holmström (1867, 1904), Chamberlin (1885), Bøggild (1899), Gilbert (1906), Reck (1911), Lahee (1912) a. o. have already made it evident that cracks lying generally transverse to ice flow are to be found on the surfaces of outcrops in the glaciated areas of Scandinavia, Iceland, and North America. Scientists used various terms for these cracks, until Ljungner (1930) in Sweden and Harris (1943) in U.S.A. treated this problem more profoundly and classified the cracks they had met with into various types. Harris's study is also referred to by Flint (1947).

As our knowledge of transverse cracks in Finland is based on a few separate observations it seems necessary to become acquainted with the theory and grouping of transverse cracks before presenting the Finnish examples.

Harris (1943) divides transverse cracks into two groups: friction cracks and chattermarks. Both of them were formed on the surface of outcrops by over-riding ice.

It has been assumed (Gilbert 1906, Ljungner 1930, Harris 1943) that friction cracks were caused by a local increase in the friction between the flowing ice and the bedrock (by a boulder or a pocket of sand in the basal part of the ice). As the glacier moved forward it tended to carry the bedrock surface with it, especially at the points of greater friction. This relative movement of the bedrock surface involved compression in the front and tension in the rear of the point of friction. When stress exceeded the strength of the rock it caused fractures transverse to the stress. Compression and tension fractures were called by Harris »principal fractures» (Harris 1943, p. 244), and their dips are clearly seen in Fig. 1 (published by Ljungner 1930, p. 290). A fracture with a slight inclination forward

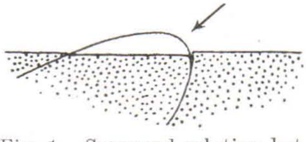

Fig. 1. Supposed relation between the crescentic gouge (left) and the crescentic fracture (right) according to Ljungner 1930, p. 290.

(or downstream) was cracked in front of the point of local friction. The wedge of the bedrock, separated by the principal fracture, has then

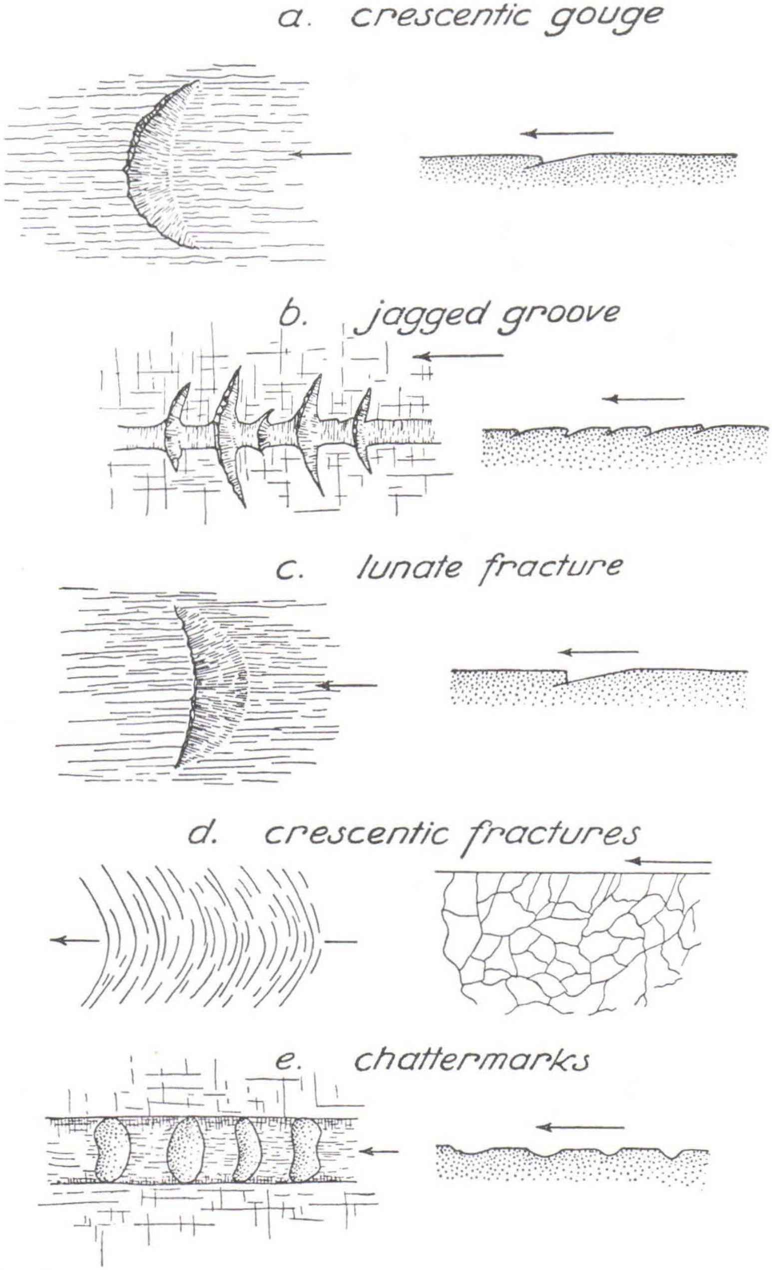

Fig. 2. Crescentic gouge (a), jagged groove (b), lunate fracture (c), crescentic fractures (d), and chattermarks (e) seen from above (left) and from side (right). The direction of movement of the ice indicated by arrows runs from right to left. According to Harris 1943, pp. 245 and 248.

been broken off along a nearly vertical rupture, which is usually concave upstream. This wedge thus left a crescentic gouge (Ljungner's »Sichelbruch») on the bedrock surface with principal fracture dipping slightly downstream. In most cases the horns point upstream (crescentic gouge, a in Fig. 2, and jagged groove, b in Fig. 2), but in two places Harris has also found lunate fractures (c in Fig. 2) with a principal fractures dipping slightly forward, but with horns pointing downstream. Thus the opening direction of crescentic gouges (or the pointing direction of the horns) cannot be always used in determining the direction of ice flow. As the principal fracture seems to dip forward in both cases, it is a useful indicator of the direction of ice movement (Harris 1943 p. 258).

Crescentic gouges occur in rows with the long axes parallel to the direction of movement. Sometimes, they are connected by a groove or by a large stria so forming together a jagged groove, from which the horns of successive crescentic gouges extend beyond the walls of the groove. They seem to be formed by the repeated forward movements of an over-riding boulder. Tension fractures formed beyond the point of greater friction may be counted as crescentic fractures, according to Harris, thus including Ljungner's »Parabelrisse» (1930 p. 286). Crescentic fractures differ from crescentic gouges, so that the fractures are convex upstream (the horns point downstream) and the principal fractures dip more steeply forward (at an angle of 60—80°). As no chip from the bedrock has been broken off, the fractures are to be seen on the surface as thin hyperbolic curves generally occurring in rows. They are also found on surfaces without striations. Consequently it has been assumed (Gilbert 1906) that in this case local friction was caused by a pocket of sand. Crescentic fractures are the most common of the transverse cracks because rock fails more readily under tension than under compression (Harris 1943 p. 249). The shape of crescentic fractures is shown in figure 2 d.

Chattermarks (Fig. 2 e) posses no true principal fracture. They form crescentic or oval-shaped depressions within large striae or grooves, but their size is usually limited by the groove in which they occur. According to Harris's observations, they cannot be used as indicators of the direction of movement.

Harris's study referred to above led to a very interesting conclusion: »The principal fracture has been found to dip forward in the direction of movement of the overriding agent» (Harris 1943 p. 258). So it seems that in every case in which we can correctly determine the direction of inclination of the principal fracture, we can also ascertain the local direction of movement of the ice flow.

The interest in friction cracks in Finland has only arisen in recent years, and only a few observations have hitherto been published. In the Finnish explanation to the superficial map sheet of Nurmes (Virkkala 1948 p. 20) are mentioned crescentic gouges (in Finnish »kaarteet») on the hill Saukkovaara (quartzite) in the parish of Ristijärvi and chattermarks (in Finnish »poikittaisrakennetta leveissä uurteissa») on an outcrop of soapstone (Näätäniemi, Kuhmo). From the northern part of Helsinki, Saksela (1949 p. 38) describes cracks (in Finnish »sirppimurrokset») the horns of which point in opposite directions, both upstream and downstream. The rock is here migmatite granite and some of the crescentic cracks also cut the contacts between the granite and the gneissose parts of the rock. According to the writer's opinion, this observation also agrees with the statements referred to above. The cracks, which open upstream, are true crescentic gouges, while the curves opening downstream, from which no chip has been cracked away, are crescentic fractures with a much steeper, but also forward dipping principal fracture, as the writer could ascertain in the same locality as well as in other outcrops in the northern part of Helsinki. Such an occurrence of various friction cracks can be understood when considering that the point of greater friction moved forward with the ice causing first crescentic gouges and then crescentic fractures on the same surface.

Harris's theory seems to explain also other observations made previously by the writer.

In Middle Ostrobothnia, in the parishes of Pyhäjoki and Rautio (Okko 1949) crescentic gouges (in Finnish »pirstekaarteet») are found on granite (Pyhäjoki, in the village Etelänkylä, mentioned in Mr. L. Heinonen's field reports in 1946) and on medium-grained gabbro (Partala, Rautio).

In North Finland crescentic gouges have been met with on granite in the Marraskoski rapids, Ounasjoki river, in the parish of Rovaniemi (horns point upstream).

In the neighbourhood of Helsinki crescentic gouges are very common on migmatite granite rocks. In every case the gouge is concave upstream (the horns point in the same direction) and the principal fracture dips slightly downstream (Photo 1). As mentioned above in connection with crescentic gouges, crescentic fractures have also been met with (the horns point downstream) but they form thin curves with a steep forward inclination (Photo 2). The span of the arc of crescentic cracks varies from 4 to 70 cm. in length, the sector between 90—160°, and the depth from the surface (the vertical rupture) is 0.5—5 cm. By measuring the trend of the bisector of several sectors, the arithmetical mean of the directions has been proved to be the same as that of the local striae.

A jagged groove is seen on a quartz porphyry rock on the mainroad between Tampere and Aitolahti, Middle Finland. As seen in Photo 3 the horns point upstream and the principal fractures are clear.

In addition some observations made in 1949 in Iceland give support to these statements. Crescentic gouges and jagged grooves are found on the tuffite (softer than the Archaean rocks of Finland) near Lake Hagavatn, 300 metres southeast of the border of the glacier Langjökull (Photos 4 and 5). These friction cracks are concave upstream and they have a principal fracture dipping downstream. The long axis of the rows has the same direction as the striae. In front of the glacier Morsárjökull, an outlet glacier of Vatnajökull in South Iceland, a crescentic gouge is seen on the vertical surface of a hard dolerite rock. This wall makes an angle of 20 degrees to the direction of ice flow and is at the bottom of the southern slope of the Morsár-valley. As the gouge has the same dimensions as the crescentic gouges in Finland it is possible that compression against the dolorite has been of nearly the same magnitude as stress in Finland during the last glaciation.

Crescentic fractures, the horns of which point downstream, are found, as well as in the neighbourhood of Helsinki (Photo 6), on the quartzite in North Finland (Lehmikumpu, Tervola) and on the phyllite in Middle Finland (Tähtinen, Aitolahti). The last mentioned point of observation is known from the discoveries of Corycium enigmaticum (first described by Sederholm in Bull. Comm. géol. Finl. No. 6, 1897), in connection with which the crescentic fractures occur. The thin superficial curves of crescentic fractures are better seen on light, brittle quartzite as the fractures are often filled with dark dust and debris.

Only one observation from the neighbourhood of Helsinki can be added to Virkkala's discovery dealing with chattermarks. The crossroad leading from the Herttoniemi slate quarry to the Helsinki—Porvoo road goes over a flat surface of a biotite-gneiss rock. On this surface can be seen large striae with transverse depressions, which do not extend over the side walls of the striae. As no principal fracture can be observed in the depressions, they may be true chattermarks in Harris's sense.

The instances above include all observations hitherto published in Finland, as well as the observations of the writer. Although the material is so scarce, it is evident that at least *crescentic grooves, jagged grooves, crescentic fractures, and chattermarks can be found on the surfaces of Finnish rocks of different types.* The observations show that the *crescentic grooves and the cracks in jagged grooves open upstream, the crescentic fractures open downstream and, at least in the neighbourhood of Helsinki, they have a principal fracture dipping forward (to the movement direction of ice flow).* Lunate fractures have not as yet been met with. Chattermarks have been found without principal fractures. All friction cracks and chattermarks discovered occur on the polished surfaces of stoss-sides or on the nearly horizontal top planes of outcrops. Thus the observations agree with the theoretical statements and observations cited above.

As friction cracks have commonly cut more deeply down into the bedrock than the glacial striae, they have been preserved still on surfaces where glacial striae have been worn away. For this reason it is possible, that by aid of friction cracks, older movements of ice flow can also be determined. In uncertain cases, *e.g.* in ice divides, the friction cracks can help in determining the direction of movement. Thus the surveying of friction cracks can be of value in tracing the source of ore boulders.

REFERENCES

Bøggild, O. B., 1899, Om Skurestriber i Danmark og beslaegtede Faenomener. Meddel. fra Dansk Geologisk Forening N:o 5.

Chamberlin, T. C., 1885, The Rock Scorings of the Great Ice Invasions. U. S. Geol. Surv. 7th Ann. Rept.

Flint, R. F., 1947, Glacial Geology and the Pleistocene Epoch. John Wiley & Sons, New York.

Gilbert, G. K., 1906, Crescentic Gouges on Glaciated Surfaces. Bull. Geol. Soc. Amer. vol. XVII.

Harris, Stanley E. Jr., 1943, Friction Cracks and the Direction of Glacial Movement. Jour. Geol., vol. 51.

Holmström, L. P., 1867, Iakttagelser öfver istiden i södra Sverige. Lunds universitets årskrift.

—»—, 1904, Öfversikt af den glaciala afslipningen i Sydskandinavien. Geol. Fören. Förhandl. Bd. 26, H. 4.

Lahee, F. H., 1912, Crescentic Fractures of Glacial Origin. Amer. Jour. Sci., vol. 33 (4th ser.).

Ljungner, Erik, 1930, Spaltentektonik und Morphologie der schwedischen Skagerrack-Küste. Teil III. Lieferung I. Bull. Geol. Inst. of Upsala, vol. 21.

Okko, Veikko, 1949, The General Geological Map of Finland. Sheet B 4, Kokkola. Explanation to the Surficial Map. Geological Survey of Finland.

Reck, Hans, 1911, Glazialgeologische Studien über die rezenten und diluvialen Gletschergebiete Islands. Ztschr. f. Gletscherkunde V Bd. H. 4.

Saksela, Martti, 1949, Lohkaretutkimus ja malminetsintä. Terra N:o 1. (Summary in Germany: Geschiebeforschung und Erzsuche).

Virkkala, K., 1948, Suomen geologinen yleiskartta. Lehti D 4, Nurmes. Maalajikartan selitys. Geologinen tutkimuslaitos, Helsinki.

EXPLANATIONS OF THE PLATE I.

Photo 1. The largest of the crescentic gouges met with on the migmatite granite, north of the Tuberculosis Hospital, Helsinki. The span of the arc is about 70 cm. The ice moved upward parallel to the stick.

Photo 2. Crescentic gouges and crescentic fractures on granite. The same locality as in photo 1. The ice moved upward.

Photo 3. Jagged groove on quartz porphyry. The ice moved from right to left. The length of the hammer haft is 30 cm. By the mainroad between Tampere and Aitolahti.

Photo 4. Crescentic gouges and a jagged groove on tuffite. The ice moved upward. The length of the knife 22 cm. About 100 metres N.E. of the present outlet of lake Hagavatn and 300 metres from the glacier Langjökull, Iceland.

Photo 5. Crescentic gouges on tuffite. The ice moved upward. The spade is 17 cm. in breadth. The same locality as in photo 4.

Photo 6. Crescentic fractures on granite. The ice moved upward. The same locality as in photos 1 and 2.

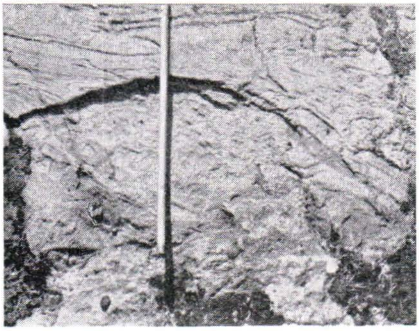

PHOTO 1

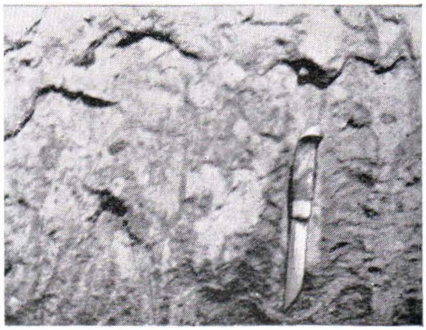

PHOTO 4

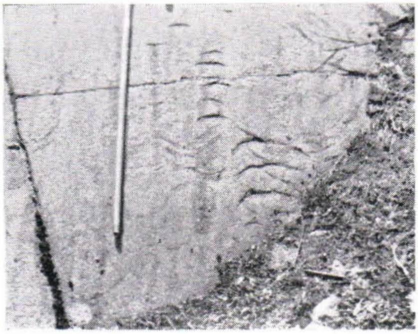

PHOTO 2

PHOTO 5

PHOTO 3

PHOTO 6

Veikko Okko: Friction Cracks in Finland.

7.

PALINGENETIC STRUCTURES IN AUGEN GNEISS OF THE SIERRA DE GUADARRAMA, SPAIN

BY

DIRK DE WAARD
(UTRECHT, HOLLAND)

CONTENTS

ABSTRACT

This paper deals with the nature and origin of a migmatitic structure which is observed in augen gneiss of the central part of the Sierra de Guadarrama. The migmatite, which proved to be a regional phenomenon, is a mixture of gneiss palaeosome and granite metatect in small, flock-like spots, for which the name crocydite is introduced.

Petrographic and structural properties indicate a local recrystallization or rearrangement of the components of the gneiss in a plastic condition. This migmatitic structure, related to the dictyonite of Sederholm, thus completes the palingenetic sequence of the granitization of gneiss, which is recorded by the stages: gneiss — crocydite — dictyonite — nebulite — granite.

The contacts of the intrusive granite show within a short distance this palingenetic transition which is caused by the increase in temperature of the intrusion. Regionally the conditions in a deeper zone will have been favourable in the same way to a palingenesis on a larger scale, which may have been the source of the intrusive granite. This means a petrogenetic cycle within the Variscan period, from granite via orthogneiss into granite.

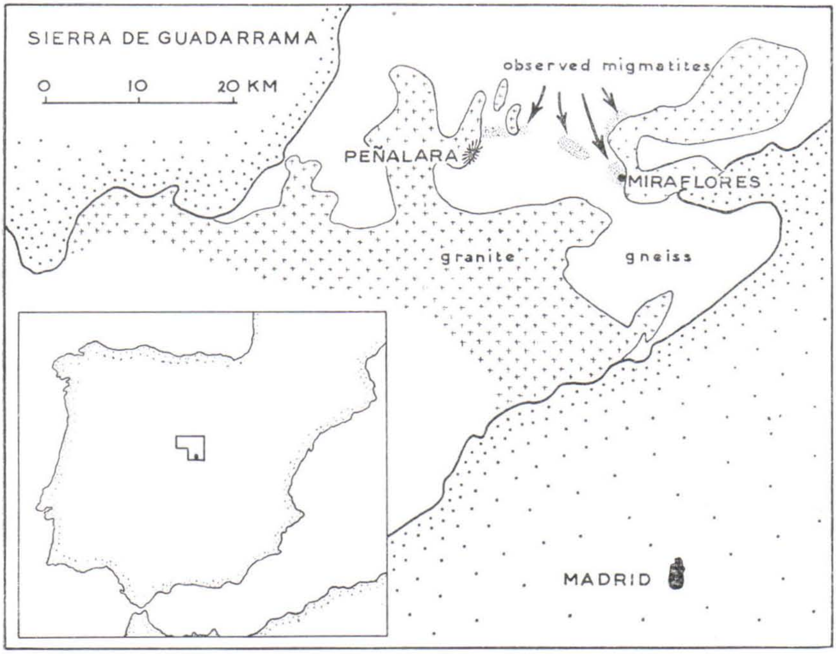

Fig. 1. Geologic map of the investigated area of the Sierra de Guadarrama, according to the Mapa Geológico de España, 1 : 400 000.

INTRODUCTION

During a geologic survey in the autumn of 1948, interesting migmatitic phenomena were found in the mountain range north of Madrid, the Sierra de Guadarrama. The investigated area is situated in the neighbourhood of the highest mountain, Pico de Peñalara (2430 m.) and the village of Miraflores de la Sierra (Fig. 1). Though glacial deposits and hillside waste may be considerable locally, the barren gneiss and granite area is fairly well exposed and river beds in particular facilitated detailed observations.

The field work has been generously supported by a grant of »De Centrale Organisatie voor Zuiver Wetenschappelijk Onderzoek» (Dutch Organization for Scientific Research).

This paper presents the results of the preliminary investigations. The geologic and petrologic survey of this area will be continued by Mr. R. C. Heim (Utrecht).

GEOLOGY

The Sierra de Guadarrama is part of the mountain chain which traverses central Spain in an approx. E-W direction. Most of the investigated area is occupied by augen gneiss and large granite massifs

(Fig. 1). So far, observations have shown the granite to have intrusive contacts. The structure of the massifs indicate a post-tectonic emplacement.

The light-coloured gneiss (Fernández Navarro 1900) contains large augen of orthoclase. As a rule the feldspars are not very strongly rounded; most of them still show remnants of crystal faces. The granite (San Miguel de la Cámara 1936) is generally pale coloured and medium to coarse grained. Though not found everywhere, a porphyritic texture proved to be common.

Most Spanish authors suppose a Pre-Cambrian age for the metamorphic parts of the Sierra de Guadarrama (MacPherson 1883, 1886, 1901, Fernández Navarro 1900, 1915, Mapa Geológico, Hoja 460, 1928). This Archaean orogen would have been a block of resistance to the Variscan folding in which the Palaeozoic strata of the eastern part of the Sierra de Guadarrama are involved (Staub 1926). Later investigations, however, advocate a Lower Palaeozoic age for the crystalline strata, which were metamorphosed and folded during the Upper Carboniferous (Asturian) phase of the Variscan orogeny (Tricalinos 1928, Lotze 1929, Schriel 1930, Schröder 1930).

The gneiss is usually supposed to have originated from sediments by regional metamorphism (MacPherson 1883, Fernández Navarro 1900, 1915, Carandell 1914). In the eastern part of the Sierra de Guadarrama near Hiendelaencina, about 100 km. E of the Peñalara area, transitions from sediments into gneiss, intercalations of sedimentary layers and a gneissose quartz conglomerate in the gneiss together with a lack of injections, in this area, are mentioned as arguments in favour of a para-origin of this gneiss (Lotze 1929, Schröder 1930). The petrogenesis of the gneiss in the eastern Guadarrama is ascribed to a combined action of contact and dynamic metamorphism of Lower Palaeozoic strata by deep-seated syntectonic granite (Lotze 1929).

In the western part of the Sierra de Guadarrama two intrusive actions are supposed. Firstly a deep-seated intrusion at the beginning and during the main orogenic phase, which caused the metamorphic alteration of the Lower Palaeozoic strata to gneiss, and a second of diapiric character at the end of the orogenic phase (Schröder 1930).

An intrusive contact of the gneiss massif, observed in the Peñalara area, points to an ortho-origin of the augen gneiss in this part of the Sierra de Guadarrama. In a small outcrop near Peñalara Mountain, augen gneiss is shown in abrupt contact with spotted schist. The concordant and conformable structure of the contact shows no signs of dislocation. The spotted schist of the country rock is crowded with dark biotite-feldspar spots such as originate by contact metamorphism in slaty rock (*e. g.* de Waard 1950, van der Sijp 1950). Two offshoots of the gneiss massif in the country rock near the contact, an aplitic and a granitic dike, have secondary schistosity and a boudinage structure. Schistose inclusions, probably of slaty origin, with adopted orbicular structure have been observed in the gneiss.

These phenomena demonstrate that the schist is older than the augen gneiss which has been intruded before the tectonic movements. For this part of the Sierra de Guadarrama, an early orogenic or pre-tectonic intrusion (possibly attended with or originated by the granitization of Lower Palaeozoic sediments) of porphyritic granite, is obvious. The subsequent main orogenic phase which caused the alteration to gneiss is followed by the intrusion of post-tectonic granite.

Migmatites have been observed in the gneiss area between the Peñalara and Miraflores de la Sierra. In parts of this region (Fig. 1) the regular schistosity is interrupted by a great many spots of homogeneous, fine to medium-grained granite. As the migmatitic material is connected with the granite at the pluton contacts, its origin must be of about the same age as that of the post-tectonic intrusions.

The geologic history of this part of the Sierra de Guadarrama may be summarized as follows:

1. sedimentation (Lower Palaeozoic?)
2. early orogenic or pre-tectonic intrusions of porphyritic granite (combined with granitization?)
3. main orogenic phase and alteration to gneiss (Upper Carboniferous?)
4. late orogenic or post-tectonic migmatitization and granite intrusions.

DESCRIPTION OF THE MIGMATITE

In all observed localities the migmatite consists of a palaeosome of the normal augen gneiss and a metatect (Scheumann 1936 a) of granite.

As a rule the metatect is not sharply bordered against the gneiss. The shape is irregular and the granitic spots are always strongly interlaced with the palaeosome (Fig. 2). Small veins taper off on all sides into the schistosity of the gneiss. As the dark layers of biotite pass smoothly into the non-oriented metatectic interior, the spots usually show a star-shaped impression. The metatect is always a light coloured, fine to medium-grained homogeneous granite.

The shape and size of the metatects vary from the small star-shaped spots of about 5 cm. diameter, to elongated, more or less straight stripes of about 30 cm. In the polished gneiss outcrops in the river beds near Miraflores 15 to 30 of such dots have been counted per square metre of the surface. By means of various sections no special dike or pipe-like three-dimensional shape could be determined. Most of them are limited bodies surrounded on all sides by gneiss. In only a few cases have dots

Fig. 2. Appearance of crocydite. Gneiss (black) with augen (white) and granitic spots (dotted).

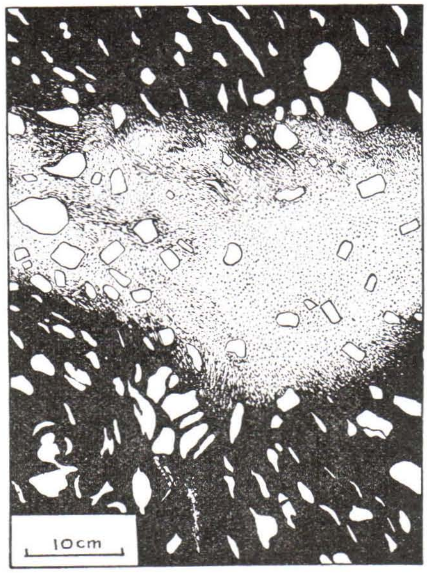

Fig. 3. Appearance of the large variety of crocydite.

been found passing into small irregular veins, connected with larger and more sharply bordered dikes of aplitic granite.

Larger elongated metatects, somewhat different in size but similar in appearance occur in these localities (Fig. 3). These metatects like the dots are not sharply bordered against the augen gneiss, but show always gradual transitions with it. They may be up to 50 cm. wide and transect at any angle the schistosity of the gneiss. The metatect always consists here of fine to medium-grained granite with large crystals of feldspar. The latter very often have an idiomorphic crystal shape (Fig. 5). The crystals are sometimes arranged in the direction of the metatect.

A brief description of these phenomena was given by Fernández Navarro (1915). The migmatites are mentioned as granitic intercalations in the gneiss near granite massifs. They are interpreted as part of the regional metamorphic sequence in the series sediment-schist-gneiss-granite.

As the present nomenclature of migmatites does not cover the type under description, the name crocydite (from *Κροκίς, -ίδος*, fluff, flock) is introduced.

THE PETROLOGIC ORIGIN OF THE CROCYDITE

In principle there are two possibilities for the origin of a migmatite, either by addition of material or by local regeneration. According to the nomenclature of Scheumann (1936 a) the metatect may thus be called an entect when injected into the older rock or an ectect when originated from the surrounding rock. As the origin is usually hard to prove, a decisive answer to this question can be given only in a few evident cases.

The appearance of the crocydite is that of an ectect. The granitic metatect is thus regarded as having originated from the gneiss on the very spot or in its immediate neighbourhood. There still remains a possibility, however, of a little interference by action of material from elsewhere in the origin of the metatect. The indications of the ectectic origin are mentioned as follows.

1. Injection of metatect into the small dots seems hardly possible; they are surrounded on all sides by augen gneiss without any indication of intermediate alteration of the rock. A harmless process as *e. g.* diffusion or percolation, through joints and cracks might be thought feasible, but the pattern and localisation of the phenomenon still remains unexplained.

2. The petrographic composition and even the grain size of the metatect is similar to that of the palaeosome. Both are granitic in composition. In the small dots only finer-grained constituents occur, whilst in the larger crocydite type the large feldspars are also present as in the augen gneiss.

In thin sections there is, apart from the structure, remarkably little difference. In both, large crystals of orthoclase or microcline are embedded in a mass of oligoclase, quartz, brown biotite, muscovite and sometimes sillimanite in parallel acicular aggregates.

Both gneiss and metatect are highly recrystallized, the latter somewhat more strongly than the former. Only some large quartz grains show a slight undulatory extinction and most of the mass is a sutured and dovetailed intergrowth. Many small quartz grains are scattered throughout the rock.

There is also little difference in the quantitative composition of both rocks. Megascopically the gneiss has a darker appearance, probably as a result of the concentration of the biotite into dark bands. Thin sections, however, usually show a more or less equal amount of biotite in both rocks.

3. The smooth merging of the gneiss into the metatect is indicative of an origin ad locum. In the bordering zones of most of them, the gneiss clearly becomes less distinctly foliated and more and more granular. In the larger crocydite the feldspar augen loose themselves from the gneiss and rotate. Most of the biotites are still arranged parallel to the schistosity of the gneiss but the structure already resembles a granitic one. In a further phase the original constituents of the gneiss become rearranged into a granitic texture. Often a dark rim of biotite may still surround the large feldspars, but this is lost and the feldspars reappear with, so it seems, an idiomorphic crystal shape (Fig. 5). All these successive phases in the metamorphism of gneiss into granite can be studied step by step.

Fig. 4. Detail of crocydite, $^3/_5$ of natural size.

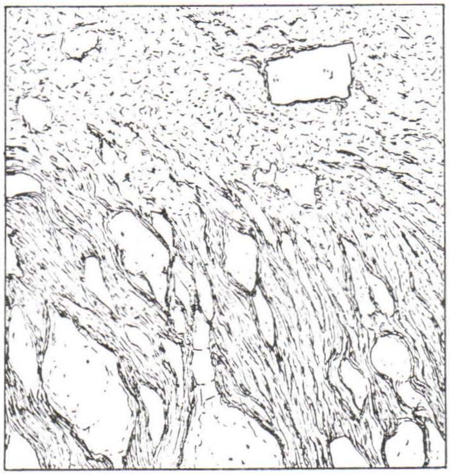

Fig. 5. Detail of the bordering zone of the large variety of crocydite, $^3/_5$ of natural size.

They form together eloquent evidence for an ectectic origin of this migmatite.

The main difference between the palaeosome and metatect seems to be a complete re-arrangement of the structure from a schistose into a massive one, mainly with preservation of the constituents which resulted in a regular distribution of the minerals in these places.

THE STRUCTURAL ORIGIN OF THE CROCYDITE

The structural development of the massive parts may have taken place before or after that of the schistosity. An earlier age implies a mode of origin of the schistosity throughout the rock which did not affect these small spots. Such process is disproved by the presence of schistose parts surrounded by massive granite often observed in larger crocydite occurrences (*e. g.* Fig. 3). Hence the massive parts must have originated after the development of the schistosity, disturbing the latter locally.

Two interesting structural features determine a close tectonic coherence with the origin of the metatect, *viz.* the dragged borders and an obvious parallel arrangement.

The dark and light coloured bands of the gneiss, slightly undulating through the rock, are frequently bent near the metatect. At both sides of the small elongated spots the bands are strongly curved in opposite direction towards the axis of the metatect (Fig. 6). This feature points to drag caused by motion along the axis of the metatect during a very plastic condition of the rock. The zone of movement may be continued

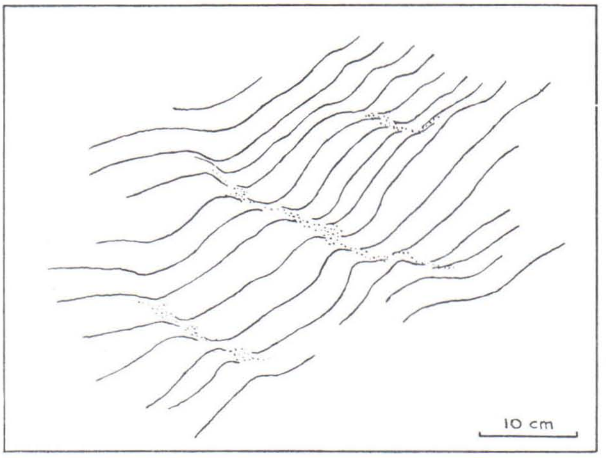

Fig. 6. Elongated metatects in relation to the schistosity of the gneiss.

for some distance at both ends of the metatect, but usually it soon disappears in the schistosity of the gneiss.

The feature is illustrated in outline in Fig. 6. The three zones in which movement occurred are characterized by the presence of metatect, bordered by smoothly curved gneiss bands. The zone is continued at both ends by a flexure which at a short distance fades away.

The smooth bending is shown in detail in Figs. 4, 7 and 8. The position of the feldspar auge in Fig. 7 is not affected by drag. It seems to have

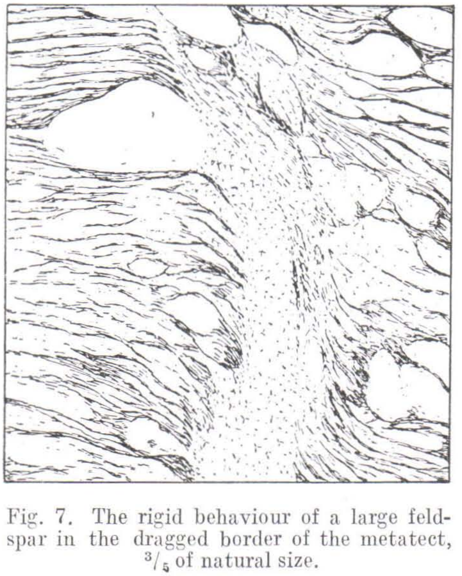

Fig. 7. The rigid behaviour of a large feldspar in the dragged border of the metatect, $^3/_5$ of natural size.

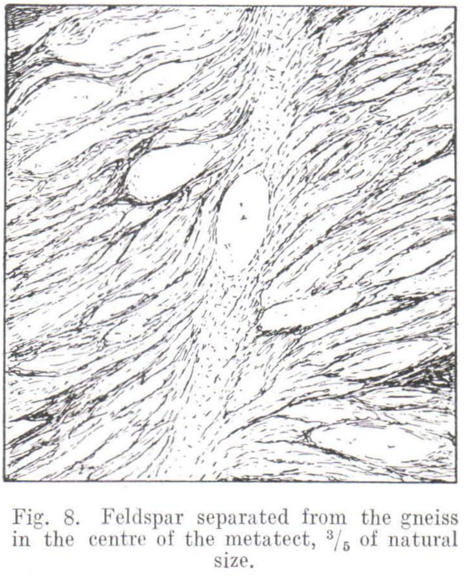

Fig. 8. Feldspar separated from the gneiss in the centre of the metatect, $^3/_5$ of natural size.

been a rigid piece of resistance in a plastic mass of smaller grains. The feldspar in Fig. 8, which was torn from the gneiss and rotated into the direction of the zone must also have been rigid.

Similar features are observed near the larger metatects. Both sides are often dragged and the bending schistosity finds a continuation in the orientation of separated parts of the gneiss and in the longer axes of feldspars within the metatect (Figs. 3 and 5).

The conclusion seems to be justified that movements along local zones are related to the presence of metatect. Either the metatect allowed these movements, or movements have been accompanied by rearrangement of the gneiss minerals. The latter seems to be the only reasonable explanation in accordance with the arrangement of the metatects.

A general idea of the structural pattern of the metatectic parts is given in Fig. 9, as observed near Miraflores. It shows an eloquent parallel arrangement of their longitudinal axes. One direction is strongly dominant, a second might be inferred locally. Thus, motion recorded by drag features has occurred here at a large angle to the schistosity.

At this preliminary stage of research there are too few structural data available to reveal the nature of these movements. It seems, however, probable that movements in a second direction have been effected at the end of, or after the development of the schistosity, in an advanced phase of the orogenic deformation. Small movements occurred in this direction at a certain angle to the schistosity causing disarrangement of the banded

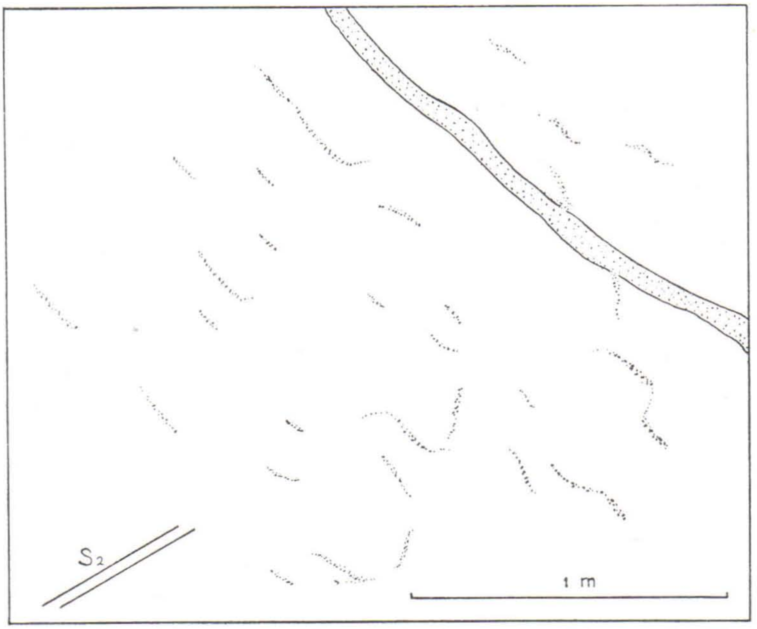

Fig. 9. Mutual arrangement of metatects of crocydite. The irregular dike, containing similar material, is locally connected with metatect.

rock without effecting an obvious parallelism of the gneiss constituents in that direction.

The general appearance of the resulting deformations resembles a step fault in which a system of parallel, undefined shearing zones co-operated in the direction of motion. The zones usually fade away after a short distance. They get lost in the schistosity of the gneiss, reappear in new ones of the same direction or pass into short zones of the obscure second system. These dislocation zones may be closely spaced, locally even at regular distances of about 10 cm.

The shearing process, combined with the development of crocydites, needed a considerable depth in the earth's crust to provide the plastic conditions of the rock, which must have been close to the melting point.

CROCYDITE VARIATIONS

The prototype of crocydite is taken from the characteristic, small, flock-like spots (Figs. 2, 4, 6, 7, 8 and 9, Photo 1). The larger metatects with a similar appearance are provisionally considered as a larger-scale variation of crocydite (Figs. 3 and 5). The regional occurrence, local development, mutual arrangement and relations to the small spots are, however, not yet sufficiently unravelled.

In few cases the metatect is observed to pass into small veins, sometimes communicating with sharper bordered, irregular dikes of fine-grained granite and aplitic granite (Fig. 9). Apparently mobilization as well as transport of material has taken place here. Elsewhere the impression is given of a squeezing out of only the light-coloured components of the gneiss into aplitic veins and dikes; this may be connected with the local occurrence of a darker and schist-like appearance of the gneiss.

THE GRANITIC RELATIONSHIP BETWEEN METATECT AND MASSIF

At present, crocydite is observed in the region between the Peñalara Mountain and Miraflores. The gneiss outcrop in this area is for the greater part surrounded by isolated and united granite massifs (Fig. 1). The granitic structure varies in the diverse localities; coarse-, medium- and fine-grained, homogeneous and porphyritic structures being found.

The alterations of the gneiss structure near the contact proved to be of first importance. Within a few metres of one of the observed contacts the normal augen gneiss changes from banded rock into fine-grained massive granite. Gradually the biotite bands fade and the large feldspar augen dissolve into a fine-grained mass. In this intermediate phase the rock is a typical nebulite, originating as it seems by pure melting of the gneiss.

Another contact shows similar features on a larger scale. Gradually the gneiss adopts a granitic appearance, both in small spots surrounded by gneiss and in larger bodies which are sometimes connected with the granite pluton. A broad zone of the rock near the contact is an intimate mixture of gneiss and granite or a migmatite of nebulitic and crocyditic character. At the pluton side of the contact the homogeneous, fine to medium-grained granite is indistinguishable from the metatect. Further to the centre of the pluton the granite structure becomes coarser-grained and porphyritic.

The contact phenomena show clearly the intermediate position of the crocydite between gneiss and intrusive granite. The higher temperature near the contact intensified the development of migmatites. The zone in which crocydite appears regionally is, as it were, dragged upward near the contact and a deeper petrologic zone is exposed in these places. In these outcrops obviously, the intenser migmatitic structure is representative of a zone in the earth's crust which was regionally deeper seated in this area.

As the metatect is a rearrangement of gneiss components, a rheomorphism with preservation of solid nuclei, or a mobilization of the plastic mass into a crystal mush, the question arises whether the intrusive granite may have been mobilized in a similar way. Crocydite appears regionally in a zone of the earth's crust where the conditions, combined with mechanical structures have been favourable for the development of local palingenetic structures. A still deeper zone would create the necessary conditions for a regional melting or mobilization of the rock into a magma or mush. This zone of palingenesis of orthogneiss may be considered as the source of the granite magma which invaded the upper crust locally by diapiric action (Fig. 10).

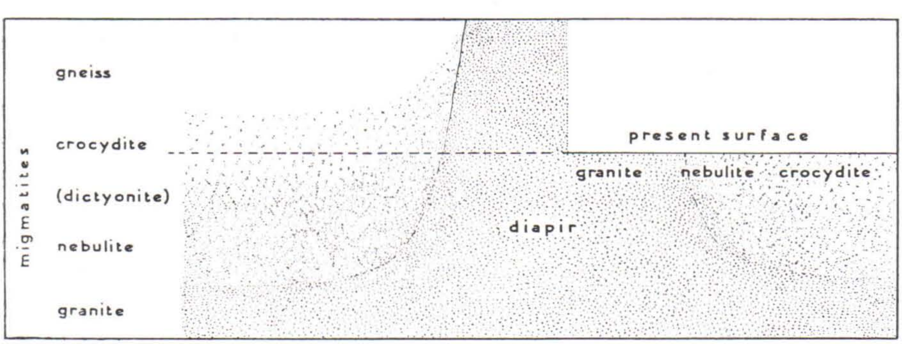

Fig. 10. Ideal section showing the regional transition of gneiss via migmatites into granite, the diapirism of the latter and the upward bending of the petrologic zones near the contact.

In the Huttonian train of thought a short cycle is thus found, *viz.* intrusion (granite) — orogeny (gneiss) — palingenesis (magma) — diapirism (granite).

THE PALINGENETIC SEQUENCE

Crocydite is introduced for the migmatitic type which is characterized by the appearance of numerous small, separated and not sharply defined spots of massive material spread through the original rock. In the case in question the massive material is fine to medium-grained granite, recrystallized from the original augen gneiss. The mutual arrangement of the spots indicate tectonic circumstances which have co-operated with favourable conditions to develop this migmatite.

Closely related to the crocydite is the dictyonite, a migmatite type described by Sederholm (1907, 1912, 1913) from southwestern Finland. The structure is »a network of veins, in which the material is more massive than in the other parts, although not sharply defined from them», representing »the initial stage of the transformation of the gneissose granite into 'younger granite'» (Sederholm 1907). According to his photographs (1907, pl. IV, 1, 2, 1913, pl. VIII, 6) the gneiss often shows dragged borders against the metatect, as observed in the crocydite. The close relation to tectonic movements is emphasized by Wegmann (1931). In southern Finland shear zones of fine-grained material are observed in gneiss which have the appearance of dictyonite. According to Wegmann dictyonitic structures in most cases are due to shearing movements along the planes of the reticular pattern.

Though differing in the structural pattern — a close network in the dictyonite and scattered flakes in crocydite — both forms are very similar in general appearance as well as in origin. In a further stage of migmatitization the crocydite would obviously adopt a veined appearance, in view of the pattern of the spots. This is indeed observed in one locality near Miraflores (Photo 2).

In the same area in SW Finland Sederholm observed the imperceptible grading of the dictyonite structure into nebulite (1907, 1913). In this stage of transition the rock is mainly massive, containing only »ghostly remnants» of fragmental parts with original gneissose structure. The gradual transition towards the homogeneous and massive granite is here almost completed (Fig. 11).

The above-mentioned structures are all stages of the same process, the rebirth of granite from gneissose rock. They are solidified steps in the continuous palingenetic sequence or granitization of gneiss — crocydite — dictyonite — nebulite — granite.

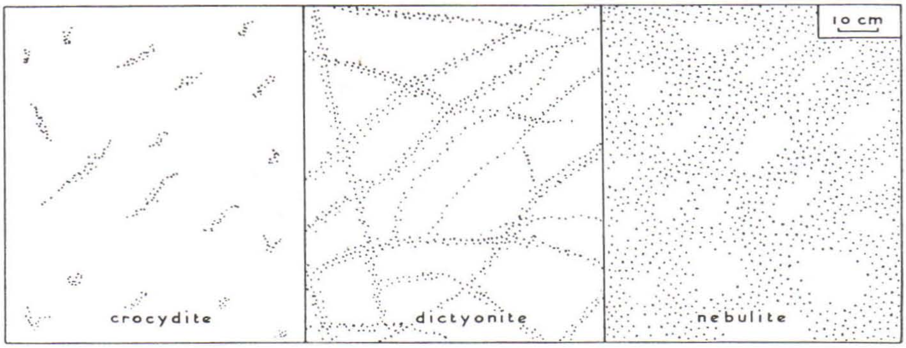

Fig. 11. Comparison of the crocyditic, the dictyonitic and the nebulitic structures.

NOTES ON THE TERMINOLOGY

The very first definition of »migmatite» by Sederholm (1907) is of importance by its direct application to the phenomenon under description: »For the gneisses here in question, characteristic of which are two elements of different genetic value, one, a schistose sediment or foliated eruptive, the other, either formed by the resolution of material like the first or by injection from without, the author proposes the name of migmatites».

In this connection the neutral terms: metatect (ectect and entect) and palaeosome (Scheumann 1936 a, b) are rightly used; they facilitate greatly the descriptions of migmatites.

The misuse and alterations of the definition of migmatite (*e. g.* Sederholm 1926) led in recent years to the endeavour to establish a new and neutral terminology based only on field-geologic appearances (Huber 1943, Niggli 1942, 1948). In this nomenclature »migmatite» is contained in »chorismite» and its subdivisions, which include all possible coarsely mixed rocks. As could be expected the migmatite types of Sederholm occupy a special place in this classification, because of similar properties (usually: a stereogenic cyriosome and a magmatitic chymogenic acyrosome, Niggli 1946).

Crocydite, belonging to the group of vaguely bordered migmatites (dictyonite, nebulite, stictolite), may be genetically defined by the new terminology as an endomerismite with magmatogenic neosome in a palaeosome which is a stereogenic cyriosome.

OUTLINE OF SUGGESTED LOCAL PETROGENESIS

The geologic history of paragraph 3 which is partly based on previous geologic work done in the eastern Sierra de Guadarrama, may be extended with the younger petrogenetic cycle outlined in this paper.

1. Sedimentation of argillaceous and calcareous rocks in Palaeozoic times. The age of the sediments is supposed to go as far back as Cambrian and perhaps still farther.

2. Intrusion of porphyritic granite in a period which may be called early orogenic (comparable with 'older granite' of Sederholm, 1893, synkinematic of Wegmann, 1931 and prim-orogenic of Wahl, 1936) with respect to the sequence of tectonic phases of the orogeny, or pre-tectonic with respect to the (local) main phase. This intrusion may have been attended in some way with granitization of the lower sedimentary series. Strong indications are found in favour of a para-origin of the gneisses in the eastern Sierra de Guadarrama. A local squeezing-out of the mobilized mass, for example, could be supposed to be the origin of the intrusive form.

3. Folding during the main orogenic phase which took place in the Upper Carboniferous (Asturian) time of the Variscan orogeny, according to observations in the eastern Guadarrama; alteration of porphyritic granite to ortho-augen gneiss and the origin of its second orientation.

4. Subsidence of the area into katatype conditions, or emergence of the katatype conditions to this part of the orogen. Shearing movements under plastic circumstances, leaving traces of a third orientation in the gneiss; re-arrangement of the constituents of the gneiss in the shearing zones to a granitic mass. This process caused an ectectic migmatitization of the area, regional granitization, *viz.* palingenesis of the gneiss in a deeper zone and diapirism of palingenetic granite. The intrusion of the latter may be called late orogenic (comparable with 'younger granite' of Sederholm, 1893, ser-orogenic of Wahl, 1936 and late-kinematic, *e. g.* of Simonen, 1948) with respect to the sequence of movements during the orogeny, or post-tectonic, with respect to the main orogenic phase.

THE CONSTRUCTION OF THE DIAPIRIC GRANITE PLUTON

The latter part of the local petrogenesis shows one possibility for the development of the source of an intrusive granite mass.

Granite plutons — especially post-tectonic ones — are of common appearance in the higher zones of orogens. In these epitype surroundings they are usually characterized by a number of structural phenomena, which indicate a diapiric mechanism of their emplacement (De Waard 1949). In the immediate neighbourhood of the pluton, migmatites are found of purely entectic character, *e. g.* arterites, agmatites, lit-par-lit injections.

In katatype surroundings, as exposed in the Peñalara area, the faulting structures of the diapir are superseded by more plastic dislocations. The

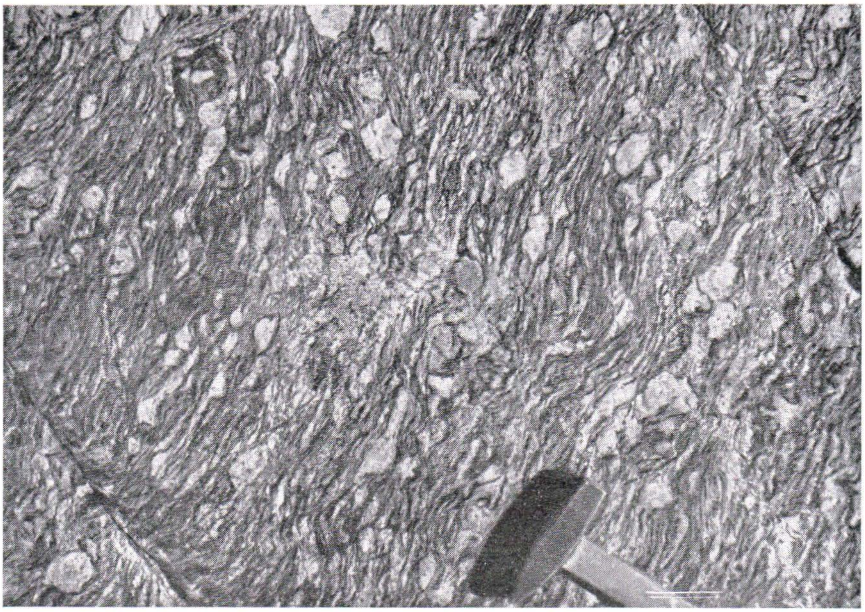

Photo 1. Crocydite. Flock-like metatect of fine-grained granite in the centre of the photograph. (Both photographs have been taken in river beds near Miraflores.)

Photo 2. Dictyonite. Elongated metatects of crocydite grown together in a network (compare Sederholm, 1907, pl. IV, 1).

Dirk de Waard: Palingenetic Structures in Augen Gneiss of the Sierra de Guadarrama.

drag phenomenon around the pluton is well developed, though less by dragging upward of material than by emergence of the zonal conditions from a lower level. The migmatitization of this zone is of ectectic character, *e. g.* crocydites, dictyonites, nebulites, stictolites, venites.

In the deepest part of this zone the granitization of the rock will be completed producing a mobile mass which under favourable conditions will intrude the upper zones.

This completes at least one possibility of the construction of a diapiric granite pluton. A source zone, the root of the diapir, originated by granitization (*e. g.* by palingenesis, anatexis, ultrametamorphism, rheomorphism, metasomatism, migmatism, etc). A lower zone of katatype country rock with chiefly plastic deformation and ectectic migmatitization and an upper zone of epitype country rock with mainly faulting structures and ectectic migmatites.

REFERENCES

CARANDELL, J., 1914: Las calizas cristalinas del Guadarrama. Trabaj. Mus. Nac. Cienc. Nat. ser. geol., N. 8, Madrid.

FERNÁNDEZ NAVARRO, L., 1900: Observaciones sobre el terreno arcáico de la provincia de Guadalajara. An. de la Soc. Esp. de Hist. Nat., 29, 95—123.

—»—, 1915: Monografia geológica del Valle de Lozoya. Trabaj. Mus. Nac. Cienc. Nat. ser. geol., N. 12, Madrid.

HUBER, H. M., 1943: Physiographie und Genesis der Gesteine im südöstlichen Gotthardmassiv. Schweiz. Min. u. Petr. Mitt., XXIII, 72—260.

LOTZE, F., 1929: Stratigraphie und Tektonik des keltiberischen Grundgebirges (Spanien). Beitr. Geol. west. Mediterrangeb., 3, Abh. Gött. Ges. Wiss., Berlin, Math. - Phys. Kl., 16, 1—320.

MACPHERSON, J., 1883: Sucesion estratigráfica de los terrenos arcáicos de España. An. de la Soc. Esp. de Hist. Nat., 12, 341—380.

—»—, 1886: Comparaison des terrains cristallins d'Espagne et du Finistère. Bul. Soc. Géol. France, III série, 14, 828—830.

—»—, 1901: Ensayo evolútico de la peninsula iberica. An. de la Soc. Esp. de Hist. Nat., 30.

MAPA GEOLÓGICO DE ESPAÑA, cuarta edición, hoja 28, Segovia Madrid Guadalajara.

MAPA GEOLÓGICO, Hoja 460, 1928. Memoria explicativa de la hoja no. 460. Inst. Geol. y Min. de España, Madrid.

NIGGLI, P., 1942: Das Problem der Granitbildung. Schweiz. Min. u. Petr. Mitt., XXII, 1—84.

—»—, 1946: Die leukogranitischen, trondhjemitischen und leukosyenitgranitischen Magmen und die Anatexis. Schweiz. Min. u. Petr. Mitt., XXVI, 44—78.

—»—, 1948: Gesteine und Minerallagerstätten. Bd. I. Basel.

SAN MIGUEL DE LA CÁMARA, N., 1936: Estudio de las rocas eruptivas de España. Mem. Ac. de C. Exactas, Fís y Nat. de Madrid, Ser. de C. Nat., vol. VI.

SCHEUMANN, K. H., 1936 a: Zur Nomenklatur migmatitischer und verwandter Gesteine. Zeitschr. f. Kristall., Min. u. Petr., Abt. B, 48, 297—302.

SCHEUMANN, K. H., 1936 b: Metatexis und Metablastesis. Zeitschr. f. Kristall., Min. u. Petr., Abt. B, 48, 402—412.

SCHRIEL, W., 1930: Die Sierra de la Demanda und die Montes Obarenes. Beitr. Geol. west. Mediterrangeb., 4, Abh. Gött. Ges. Wiss., Berlin, Math.-Phys. Kl., II, 16, 1—105.

SCHRÖDER, E., 1930: Das Grenzgebiet von Guadarrama und Hesperischen Ketten (Zentralspanien). Beitr. Geol. west. Mediterrangeb. 5, Abh. Gött. Ges. Wiss., Berlin, Math.-Phys. Kl., II, 16, 119—180.

SEDERHOLM, J. J., 1893: Om berggrunden i södra Finland. Fennia, 8, 1—137.

—»—, 1907: Om granit och gneis. Bull. Comm. géol. Finl. 23, 1—110.

—»—, 1912: Die regionale Umschmelzung (Anatexis) erläutert an typischen Beispielen. C. R., XI Congr. Géol. Int. (Stockholm, 1910), I, 573—586.

—»— 1913: Über die Entstehung der migmatitischen Gesteine. Geol. Rundschau, 4, 174—185.

—»—, 1926: On migmatites and associated pre-Cambrian rocks of southwestern Finland, II. The region around the Barösundsfjärd W. of Helsingfors and neighbouring areas. Bull. Comm. géol. Finl. 77, 1—143.

SIMONEN, A., 1948: On the petrochemistry of the infracrustal rocks in the Svecofennidic territory of Southwestern Finland. Bull. Comm. géol. Finl. 141, 1—18.

STAUB, R., 1926: Gedanken zur Tektonik Spaniens. Vierteljahrschr. der Naturf. Ges. Zürich, 71, 196—261.

VAN DER SIJP, J. W. C. M., 1950: Petrology of the St. Jean du Gard area in the southeastern Cevennes, France. Proc. Kon. Ned. Akad. v. Wetensch., Amsterdam, 53.

TRICALINOS, J., 1928: Untersuchungen über den Bau der Celtiberischen Ketten der nordöstlichen Spaniens. Zeitschr. Deutsch. Geol. Ges., 80, 409—482.

DE WAARD, D., 1949: Diapiric structures. Proc. Kon. Ned. Akad. v. Wetensch., Amsterdam, 52, 1027—1038.

—»—, 1950: Tectonics of a pretectonic orthogneiss massif near St. Jean du Gard in the southeastern Cevennes, France. Proc. Kon. Ned. Akad. v. Wetensch., Amsterdam, 53.

WAHL, W. A., 1936: The granites of the Finnish part of the Svecofennian Archaean mountain chain. Bull. Comm. géol. Finl. 115, Comptes rendus, IX, 27, 489—505.

WEGMANN, C. E., 1931: Übersicht über die Geologie des Felsgrundes im Küstengebiete zwischen Helsingfors und Onas. Bull. Comm. géol. Finl. 89, 1—65.

8.

METAMORPHIC Mg-Fe ENRICHMENT IN THE ORIJÄRVI REGION AS RELATED TO FOLDING *

BY

HEIKKI V. TUOMINEN AND TOIVO MIKKOLA

CONTENTS

ABSTRACT

Some cordierite-anthophyllite-bearing rocks of the Orijärvi region have commonly been regarded as a classic example of Mg metasomatic rocks. A new investigation carried out by the present authors is, however, not in favour of this interpretation.

The rocks in question are, in general, situated along beds of argillaceous rocks intercalated with more competent sandy and volcanic beds. Structurally they occur as phacolithic core fillings in folds.

The authors consider that during the folding, the thick competent beds glided laterally along the relatively thin clayey beds, which were thus subjected to strong penetrative movements and to flowage towards the hinges of the folds. Under the penetrative movements the rock gradually recrystallized into minerals with sheet structure (chlorite etc.) and simultaneously the constituents in excess emigrated, thus causing an enrichment in Mg and Fe within the residue. The process took place under hydrothermal conditions owing to progressive regional metamorphism. The actual mineral composition is the result of a later recrystallization.

* Published by permission of the Director, Finnish Ore Company. Principal conclusions presented 4. 11. 1948 to the Geological Society of Finland.

INTRODUCTION

The hypothesis of Mg metasomatism was first put forward by Eskola (1914) in his excellent study »On the petrology of the Orijärvi region in southwestern Finland», and since then it has been under continuous discussion.

In his paper Eskola suggests that, in the Orijärvi region, certain rocks rich in cordierite and anthophyllite, sometimes also in andalusite (or sillimanite) and quartz, have developed from acid (volcanic) rocks as the result of pneumatolytic introduction of Mg, Fe and some other elements originating from granitic magma. The feldspars were replaced by Mg-Fe silicates, silica and sulphides. In the same process limestones have been transformed into skarn rocks, whilst amphibolites have been changed into cummingtonite-amphibolites.

This hypothesis of magnesia metasomatism has gained much approval particularly in Fennoscandia, and in Sweden there are numerous corresponding examples where granitic magma is regarded as the source of the added magnesia. Also in several textbooks of metamorphic geology (Eskola 1939, Turner 1948, etc.) this hypothesis has been presented as an almost proved fact, illustrated through the classic example from Orijärvi.

As an objection to Eskola's hypothesis, Tilley and Flett (1930) and also Brögger (1934) thought it unlikely that the residual liquids from a granitic magma, very poor in MgO, could furnish a leptite rock with such quantities of magnesia. Eskola (1932 b, p. 74), however, stresses that in spite of the weak Mg concentration of the residual liquids »the large amounts of solution soaking into the leptites would, of course, also carry some amounts of magnesia, which, due to the poor solubility of magnesium metasilicate, could replace the alkalies and lime of the feldspars and crystallize as anthophyllite and cordierite . . . .». He also points out the possibility of siliceous ore solutions and volatiles acting as the carriers of the process (Eskola 1932 c, 1936, 1939).

Concerning somewhat similar rocks at Kenidjack in Cornwall, Tilley and Flett (1930) supposed that they have been derived from extremely weathered portions of doleritic rocks. Later, however, Tilley (1935) regards this idea as untenable, since the recent products of weathering from basic igneous rocks are not chemically similar to the Cornish rocks. He now interprets these rocks as being derived from basic igneous rocks through a contact metasomatism involving »a widespread removal of lime, accession of silica, alkalis, particularly potash, and an i n t e r n a l magnesia metasomatism as contrasted with an accession of magnesia characterizing the Orijärvi and Falun regions».

Some cordierite- or andalusite-bearing rocks in Sweden have also been regarded as products of an internal migration and interchange of magnesia and other constituents between rocks of different composition (*e. g.* skarn and leptite), and a withdrawal of alkalis at once (Magnusson 1930) or in connection with intruding sulphidic solutions within acid volcanic rocks (Gavelin 1939). According to the principles enunciated by Eskola (1932 b) Gavelin regarded the process as a metamorphic differentiation.

Brögger (1934) emphasizes that in the Kongsberg-Bamle formation, cordierite-anthophyllite-bearing rocks of the »Orijärvi type» occur in connection with amphibolites and supposes that they are a special facies of amphibolites or have been formed from amphibolites through a metamorphic removal of calcium and alkalis. He stresses the similar mode of occurrence also in Orijärvi.

J. Bugge (1943), on the contrary, regards the cordierite-anthophyllite-bearing rocks in the Kongsberg-Bamle formation as being developed from acid and basic rocks through Mg metasomatism. This was caused by Mg-rich solutions leached from adjoining gabbros and amphibolites in connection with an advance of disperse solutions during the migmatization. The transportation of magnesia is believed to have taken place only over rather short distances.

According to several geologists Mg and Fe are among the most mobile elements of rocks, and proceed long distances in connection with metamorphism. Wegmann (1931, 1935) and Kranck (1931) seem to have been the first to present the idea that Mg especially will be displaced from rocks undergoing migmatization. This will then bring about an Mg metasomatism in surrounding rocks. Also in respect to the Orijärvi rocks Wegmann (1931, p. 63) suspected a connection with migmatization. He writes: »In Orijärvi sollen diese Bildungen nach Eskola mit der Intrusion der Gneisgranite zusammenhangen. Schon Sander (1914) äusserte gewisse Zweifel. Ohne das Gegenteil behaupten zu wollen, möchten wir empfehlen, bei einer eventuellen Revision den kinetischen Erscheinungen eine gewisse Aufmerksamkeit zu schenken. Vielleicht werden sich auch hier die grossen Cordierite als jünger, vielleicht sogar die ganze Lagerstätte als später metamorphosiert erweisen».

Together with the opinion that granites, in the main, originate through a granitization process, the idea of »basic fronts» has been regarded by some authors as giving the final explanation of the formation of the rocks in question. Reynolds (1947, pp. 34—35) writes in this respect: »Fe-Mg metasomatism is now a well known process, and there is no longer any need to discard the idea because of the "difficulty in believing such magnesia-rich solutions are available in the residual liquids of granitic magma" (Tilley and Flett, 1930, p. 37). Fe and Mg are now known to become displaced from rocks, both igneous and sedimentary, undergoing granitization, and to become fixed in a frontal zone in advance of the main theatre of granitization; granite magma is not their source».

Eskola (1932 a) also, thought it possible that magnesium-silicate-rocks, like cordierite-anthophyllite-rocks may have been produced in connection with granitization, but in an entirely opposite way. They might represent the solid residue after differential refusion (partial anatexis, Eskola 1933), and the squeezing out of the lowest melting portion from different kinds of rocks.

The discussion of magnesia metasomatism has had, for the most part, a purely »petrological» bias, practically without any regard to folding movements. However, at least as far as the Orijärvi region is concerned, folding movements seem to have played a very important rôle in the formation of the rocks under consideration. The purpose of the present paper is to study the problem particularly from this point of view.

The rocks under consideration are often host rocks for sulphide deposits (*e. g.* Falun and Orijärvi), and are as a rule exceptionally rich in ore minerals. For this reason the Finnish Ore Company has been interested in these rocks, and the authors have had the opportunity to study them in the Orijärvi region in connection with the prospecting work carried out by this company. The results are based upon a detailed geological mapping (1 : 2000 or 1 : 4000) made in connection with electrical and magnetic investigations, and covering an area of more than 200 sq. km. In addition many detailed observations have been made in other parts of the »Kisko-Kimito leptite belt» (Eskola 1914, Map I). These investigations are still in progress, and at present no new maps are to be published. If necessary the reader can use the maps by Eskola (1914) for orientation.

As to the petrography and chemical composition of the rocks in question, the authors refer to the detailed analysis presented by Eskola (1914, 1915). The skarns connected with limestones are not discussed in the present paper.

ROCKS OF THE REGION

The Kisko-Kimito leptite belt belongs to the »leptite formations» of SW Finland representing a root zone of the old Svecofennidic range. It consists of a metamorphic series of fine-grained gneisses (leptites), conglomerates, greywackes, diopside-gneisses, diopside-amphibolites, crystalline limestones and abundant amphibolitic rocks. The last named are believed to be partly volcanic (lavas and tuffs) and hypabyssal, and partly of sedimentary origin. Small ore deposits are common. By electrical prospecting some zones of graphite-bearing schists have also been detected.

Two groups of granite occur in connection with these rocks; the older, oligoclase-granite and granodiorite, and the younger, microcline-granite. Furthermore there are more basic infracrustal rocks or metamorphic derivatives of them.

The »Mg metasomatic» rocks, containing cordierite, anthophyllite, occasional almandine, and sometimes andalusite or sillimanite, form a minor but a very conspicuous group owing to their coarsely grained texture. Four areas or separate occurrences of these rocks are mentioned by Eskola (1914). The largest of them, the «Orijärvi aureole», occurs as a belt around the western end of the oligoclase-granite mass of Orijärvi. One of the others also occurs in a somewhat similar geological position, whilst two in contrast lie far from the granites in question. A great number of other occurrences have been detected in the recent investigations, and small bodies are particularly common. As presented by Eskola (1914, p. 168), the following types and mineral combinations, with all transitional varieties, can be observed among these rocks, especially in the »Orijärvi aureole».

Cordierite-anthophyllite-rock: cordierite, anthophyllite (+ quartz and varying amounts of biotite).

Cordierite-anthophyllite-gneiss: cordierite, anthophyllite and plagioclase (+ biotite and quartz).

Quartz-cordierite-rock (»ore-quartzite»): cordierite and quartz (+ biotite).

Cordierite-gneiss: cordierite and plagioclase (+ biotite and quartz).

Andalusite-bearing quartz-mica-rock: andalusite, quartz, sericite, biotite and also plagioclase.

Almandine also is a very common mineral within these rocks. In certain areas sillimanite appears instead of andalusite. In some places the cordierite-bearing rock is extremely rich in biotite and is termed in the present paper cordierite-biotite-schist.

THE MAIN BASIS OF ESKOLA'S HYPOTHESIS

Eskola (1914) regards the leptites of the region as of partly volcanic, and partly sedimentary origin. Some of them are of clayey composition (cordierite-leptites), but for the most part they have a composition characteristic of acid and acid-intermediate igneous rocks without any excess alumina to give rise to andalusite or cordierite. The oligoclase-granite is intrusive in the leptite formation and occurs in the form of anticlinal batholiths. Above the crest of the Orijärvi batholith, in particular, the cordierite-anthophyllite-bearing and related rocks form a characteristic contact-metamorphic aureole (Eskola 1920). Starting with these ideas Eskola (1914, p. 168) finds two possible explanations, »either, that the supercrustal mantle originally consisted of aluminous sediments, in which case the metamorphism would have taken place with unchanged bulk composition, or that the supercrustal mantle-rocks consisted of materials similar to the greater part of the leptite series, but the composition of the rocks was changed at the metamorphism owing to pneumatolytic agencies».

Especially as regards the cordierite-anthophyllite-rock Eskola (1914, p. 254) concludes »that the metamorphism has involved considerable changes in the chemical composition. Iron and magnesium must have replaced calcium, sodium and potassium. For no primary rocks are so rich in iron and magnesium and nearly devoid of the other just named constituents». In some places the replacement was established even on the basis of helicitic relics. Eskola emphasizes also that no potash feldspar occurs within the rocks of the Orijärvi aureole, not even in those devoid of the highly aluminous minerals (biotite-plagioclase-gneisses).

Further Eskola interprets all the cordierite- or andalusite-bearing contact rocks as occurring with gradual transitions towards each other and the surrounding leptites, these transitions frequently taking place »independent of the stratification», this being seen on a larger scale in the eastern end of the cordierite-bearing zone of Orijärvi (Eskola 1914, pp. 203, 255). There »the cordierite-bearing rocks fade away into common leptites, very poor in mafic constituents. In the continuation of the stratigraphical zone to which the cordierite-anthophyllite-rocks belong, no rocks of such a composition were found outside of the aureole, neither east nor west. This fact is doubtless in favour of the supposition that the whole cordierite-bearing zone owes its actual composition to a pneumatolytic metamorphism». In this respect the cordierite-gneisses and cordierite-anthophyllite-gneisses are interpreted as representing »intermediate stages in the alteration of the leptites or other siliceous rocks into cordierite-anthophyllite-rocks». This is, however, presented with some reservation because rocks of a similar composition but clearly of sedimentary origin exist in the same tract (Eskola 1914, pp. 255—256). As important evidence Eskola (1939, p. 386) further states that the cordierite-anthophyllite-rocks occur in the form of schlieren or irregular flecks within the leptites.

Regarding the other occurrences Eskola (1914, 1919, 1920) states that the cordierite-anthophyllite-gneisses SE of the railway station of Koski lie in a corresponding position to the Skogböle batholith; whereas the source of the pneumatolytic metamorphism of those bodies showing no visible connection with oligoclase-granite must have been at a greater depth. These rocks were also believed to lie above the crests of granite batholiths which, however, have not reached the actual erosion surface or have done so far away from the rocks in question. In addition, Eskola (1914) considers that the contact metamorphism has taken place during the folding of the rock complex, but except for the mineral orientation, the folding has had no significant influence upon this contact metamorphism.

MODE OF OCCURRENCE AND RELATION TO MINOR STRUCTURES

CHARACTER OF THE HOST ROCKS

A very great part of the leptitic rocks are characterized by an excess of alumina, which appears as minerals such as sillimanite, andalusite, cordierite, almandine and mica. These rocks are often clearly layered, and in some localities the sequence of strata can also be observed.

A good example of this occurs in an outcrop halfway between the Orijärvi mine and Kisko Church. Between two vertical beds of conglomerate a layered rock occurs. In the different layers the number of porphyroblasts of cordierite, andalusite, or almandine increases as the size of the pebbles in the conglomerate decreases. These layers no doubt originated from a sedimentation of sandy clay, and the increasing amount of aluminous minerals corresponds to a more argillaceous material increasing towards the tops of the strata.

Usually, however, a sequence can not be traced in these rocks. If it ever existed, it was probably destroyed by metamorphism. Yet as these rocks very regularly occur together with conglomerates, greywackes and limestones, they have most likely originated from true argillites, to which also their chemical composition nearly corresponds. This is clearly emphasized also by Eskola (1915, p. 117). The conglomerates, which mainly consist of rounded fragments of various rocks in a cement of sandy composition, however, are interpreted by him as volcanic agglomerates (Eskola 1914, p. 157). This is not surprising as these rocks in general are strongly deformed, and usually only small parts of the various beds are well enough preserved to show the real origin of the beds in question.

On the whole, the amount of acid volcanics, probably existing among the leptites of the region, must be relatively small. Corresponding compositions are, indeed, rather common but in very many cases such compositions obviously have been produced by the metamorphism of ancient sediments or, in some other cases, they may represent sedimentary rocks, even, nearly as they are now. On the other hand it also seems probable that in some rocks the excess of alumina, as well, is the result of metamorphism. At all events, the amount of argillaceous leptites with the above minerals as regular constituents, is many times greater than appears on Eskola's map (1914).

Disregarding the faulting the different constituents of the supracrustal series can be usually followed as long zones, continuous or discontinuous, depending partly upon the variation of the sedimentary facies along the original strata, and partly upon differences in the folding competency. The »metasomatic» cordierite-, anthophyllite- and andalusite- or sillimante-bearing rocks seem to lie almost always within the zones of those leptites containing the same minerals, that means, practically, within the argillaceous rocks.

CORDIERITE-BIOTITE-SCHIST

In the village of Haapaniemi, Kisko, layered rock with dark and light layers occurs. The light layers consist of fine-grained leptitic rock containing somewhat varying amounts of quartz, microcline, plagioclase, mica and accessories. The dark ones, on the other hand, have the composition of a cordierite-biotite-schist with cordierite, biotite, quartz and plagioclase as the chief constituents. Cordierite forms crystals up to 5 mm. in diameter, enclosing small grains of quartz and thin flakes of biotite, and has clearly grown at the expense of the fine-grained ground mass. Much dark brown biotite occurs between the cordierite crystals. It forms intensely distorted scales showing a sub-parallel orientation, and is also of secondary growth. The ground mass consists of the same fine-grained material as the adjacent light layers. Indeed, it is often in too small quantities and too scattered to be called groundmass, and in many cases it is clearly visible that these portions are fragments of the light layers. The thickness of the different layers and also the relation between the amounts of the dark and light materials vary greatly, but apart from reaction zones of some mm. in breadth the boundaries of these layers are quite sharp.

A bed richer in the light material has been distorted into slight flexures (Fig. 1) causing tension cavities, that partly cut the light layers discordantly. The filling of these cavities consists of cordierite-biotite-schist like that in the dark layers. In the vicinity of the cavities the dark layers become narrower and in some places have entirely disappeared. Thus it seems quite obvious that the materials of these layers have been squeezed out from the more compressed parts of the rock and have filled up the tension cavities, and now appear as small dikes of cordierite-biotite-schist.

In another bed, richer in the dark material, the rock has been strongly distorted into small folds and thrusts with rather variable directions. At the hinges of the folds both the light and the dark layers are thicker than in the limbs. However, the dark layers show an essentially higher plasticity, as they have gathered together into masses resembling small igneous bodies, such as sills and phacoliths. On the contrary, the light layers have been deformed in part by bending, in part by faulting and thrusting, or even by brecciation. The broken pieces appear in such positions in relation to the surrounding dark schist that one must suppose that they have rotated in accordance with the flowage of this schist. Also all other structural relations seem to show that this material has moved

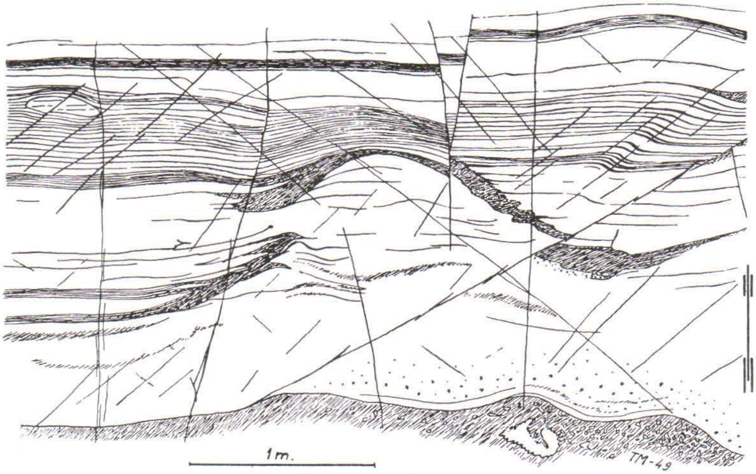

Fig. 1. »Dikes» and »sills» of cordierite-biotite-schist in a layered leptite. White: potash leptite; dark areas and dark horizontal lines: cordierite-biotite-schist; cutting lines: small faults and cracks. Fragments of leptite occur within the schist below. Haapaniemi, Kisko.

as weak plastic masses between the more competent leptitic layers (Pl. I, Photos 2, 3).

The actual habit and mineral composition of the cordierite-biotite-schist has, however, been principally developed in its present positions under quiet kinematic conditions. This is indicated especially by the following facts. 1. In such points where cordierite crystals limit the leptitic layers they have often grown a little into the leptite. 2. The cordierite crystals are idioblastic towards the biotite-mass. 3. There are no traces in the texture of the rock to show that the cordierite crystals could have existed during the flowage of the dark material. They have not rotated and are quite undeformed.

As to the chemical composition, this cordierite-biotite-schist corresponds to some kinds of argillaceous sediments, but, on the other hand, to the »Mg metasomatic» cordierite-anthophyllite-gneisses of the area. In addition even a great part of the evidence presented by Eskola for a metasomatic origin of the gneisses can be applied to the schist also. However, the problem is merely whether this evidence, even in general, is conclusive enough for an Mg metasomatic origin of great bodies. In this relation a short comparison may be profitable.

The dark layers and bodies in question can well be regarded as resembling small schlieren (Eskola 1939, p. 386), but it appears, from what is said above, that such a mode of occurrence can not be considered as evidence of metasomatic origin.

A phenomenon at the contacts of leptitic fragments enclosed in the cordierite-anthophyllite-gneiss of Kurksaari has been described by Eskola

(1914, pp. 208, 256). These fragments are irregular and sharp edged in form and consist of fine-grained leptite, rich in apatite. Crystals of cordierite up to 10 cm. in length appear in the surrounding gneiss. At such points »where a large crystal of cordierite limits the fine-grained rock, there has the cordierite grown two or three mm. into the leptite (Pl. IV, Fig. 2). The minute prisms of apatite and the large quartz grains have been enclosed in the cordierite, but all plagioclase grains of the hornfels mass have been replaced by the cordierite» (Eskola 1914, p. 208).

It is quite evident that in this case the boundary zone of the fragments has been metasomatically changed. Regarding the conditions supposed by Eskola, however, one might ask why these fragments have not been totally converted into cordierite-gneiss. For in comparison even with the size of the cordierite crystals the advance of Mg (2—3 mm.) into the fragments has been rather insignificant.

On the other hand, however, it seems obvious that in all these rocks cordierite has grown by replacing some of the surrounding minerals. In cordierite-gneisses, especially, feldspar may have been replaced. Corresponding examples have been described, *e. g.*, by J. Bugge (1943, p. 92). In a garben-gneiss from Ravneberg, Norway, cordierite is often encircled by an edge of quartz. According to Bugge »this is important evidence to show that cordierite has been formed metasomatically after plagioclase, as quartz is set free from the acid plagioclases during this transformation». A phenomenon like this is, however, no evidence to show that the bulk composition of the rock would have been changed. Such replacement must have taken place even in the normal metamorphosed rocks during the growth of their mineral grains — whether these replacements have left noticeable traces or not (Eskola 1932 b).

The dark and light layers of the Haapaniemi rock most probably originate from clayey and sandy strata of ancient sediments. The deformation may have begun at a very early stage of metamorphism, perhaps before the final consolidation of the sediments. This is indicated by several leptitic fragments and layers with similar »plastic» shapes as are formed by gliding movements within clayey sediments of recent time (van Straaten 1947). Later the sandy layers, after hardening, were broken into angular pieces. On the basis of the small outcrops at Haapaniemi it is not possible to ascertain whether the process in question has taken place in connection with the general folding or not. In the investigated area there are, however, numerous smaller and greater bodies of the same rock type showing quite an analogous mode of occurrence in relation to small folds belonging to the general fold system of the Svecofennidic orogenesis.

Considering the chemical composition of the rocks in question some metasomatic processes must also have been connected with their formation. Analyses 1 and 2 (Table I) represent the composition of the light

Table I.

	Layered leptite Haapaniemi, Kisko Orijärvi region		Varved mica-schist Välimäki, E-Finland		Varved phyllite Ajonokka, Messukylä Tampere region		Varved clay Leppäkoski, S-Finland	
	1 Light layer	2 Dark layer	3 Light layer	4 Dark layer	5 Light layer	6 Dark layer	7 Light layer	8 Dark layer
SiO_2	76.86	57.95	88.36	60.09	63.93	56.63	59.20	50.33
TiO_2	0.16	0.75	0.38	1.56	0.82	1.04	1.20	1.13
Al_2O_3	11.12	20.11	4.13	17.24	16.92	22.41	16.14	19.17
Fe_2O_3	0.69	0.53	0.65	1.47	0.79	0.58	4.36	6.50
FeO	1.40	7.38	2.13	6.75	5.04	5.05	3.24	2.52
MnO	0.02	0.07	0.03	0.09	0.04	0.06	0.09	0.13
MgO	0.42	5.36	1.43	3.88	2.15	2.35	3.14	3.77
CaO	0.24	0.81	0.45	0.95	1.36	1.28	2.52	1.43
BaO	0.10	0.21	—	—	tr.	0.05	—	—
Na_2O	2.68	1.78	1.05	2.08	1.98	2.31	3.82	1.78
K_2O	4.96	2.72	0.72	3.13	4.94	6.15	1.97	4.03
P_2O_5	0.08	0.35	tr.	0.02	0.16	0.12	0.17	0.14
S	0.23	0.44	—	—	0.02	0.08	—	—
H_2O +	1.02	1.99	0.73	2.33	1.43	2.19	1.16	4.78
H_2O —	0.05	0.06	0.79	0.23	0.23	0.18	1.15	3.74
C	—	—	—	—	—	0.31	[1] 1.94	[1] 0.41
	100.13	100.47	100.15	99.82	99.81	100.79	100.10	99.89

Analyses 1 and 2 were made by M. Tavela; 3 and 4 are from Eskola (1932 c), 5 and 6 from Sederholm (1911), 7 and 8 from Sauramo (1923).

and dark layers of the Haapaniemi rock. For comparison, corresponding pairs of analyses of some argillaceous rocks (3—6) and a late-glacial clay (7—8) are also presented in the same table. Although these analyses are not representative statistically they show, however, an apparent correspondence in the distribution of the different elements between the light and dark layers, except, in respect to K. While in clayey rocks and clays the dark layers are characteristically richer in potassium than the light ones, this relation is entirely reversed in the Haapaniemi rock; in addition there occurs an appreciable enrichment in Mg and Fe in the dark layers of the rock. In these circumstances it seems obvious that a considerable interchange of materials has taken place between the different layers of the rock in question.

The phenomenon described is very common within the clayey leptites of the area. There are, however, also many places without any considerable tendency towards such a differentiation, but in these places there are no traces of strong gliding movements to be observed, whereas the gliding surfaces and the zones adjacent to them are regularly enriched in Mg and Fe. Small masses of biotite, frequently occurring in these zones, often show a mode of occurrence quite similar to that of the

[1] Organic substances (humus).

cordierite-biotite-schist at Haapaniemi. Thus it seems very probable that even the chemical alteration in a phenomenon of the Haapaniemi type is essentially connected with gliding movements.

Fig. 2 gives another illustration of the geological mode of occurrence of cordierite-mica-schist. The outcrop is situated near Nygruva about

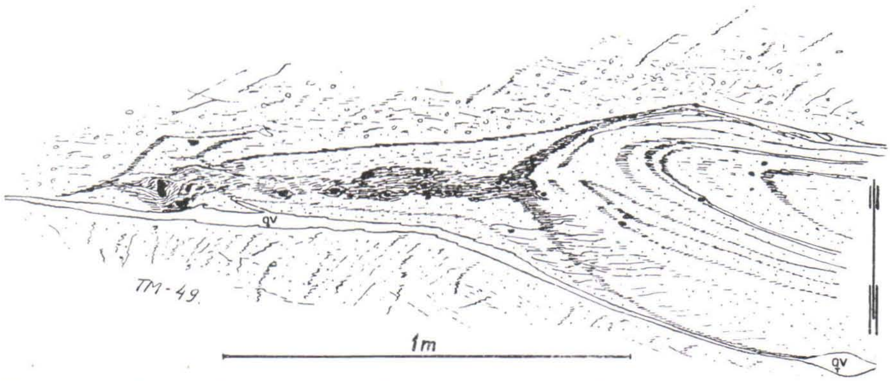

Fig. 2. A combined »phacolith» and »sill» of cordierite-mica-schist (dark) in a small syncline. The surrounding rock consists of cordierite-bearing leptite with phenocrysts of quartz. Black patches: big nodules of cordierite; qv: quartz vein. Nygruva, Orijärvi.

1 km. NW of the Orijärvi mine. A small syncline plunging at about 30° to the east occurs in a »blastoporphyritic leptite» (Eskola 1914) containing much biotite, muscovite and some cordierite as partly pinitized nodules. The very intense vertical schistosity is parallel to the axial plane. An older system of S-planes, probably parallel to the original bedding, is marked by abundant mica and also cordierite, which together with quartz and some oligoclase make a cordierite-mica-schist. The occurrence of this rock ressembles small phacoliths, the greatest one even continuing, like a sill, downwards along the axial plane. Indeed, in a section perpendicular to the fold axis this sill would seem to be 25 % shorter than in the plane of the picture.

Occurrences of this kind, quite similar in principle, are very numerous within the area, even in the immediate vicinity of the Orijärvi mine. As to the composition as well as the size, there are all intermediate stages between them and the »contact-metamorphic» cordierite-bearing rocks to which they very nearly correspond.

CORDIERITE-ANTHOPHYLLITE-BEARING AND ASSOCIATED ROCKS

In discussing the nature of the cordierite-anthophyllite-rock Eskola (1914, pp. 253—255) points out that many features in its geological mode of occurrence »resemble those of igneous bodies: Thus the Träskböle rock mass shows a form of a laccolith. On the island of Vähäholma (p. 187) anthophyllite-cordierite-rock occurs in the form of a sill». Further the other occurrences appear as »lenticular» masses or bodies. He states that the texture of this rock is, however, undoubtedly metamorphic and not that of any igneous rock; *e. g.*, in almandine of the Träskböle rock rounded inclusions of quartz »are arranged in parallel rows, a feature which may be understood as a relic of an earlier structure (helicite). The rock has been foliated or laminated before the crystallization of the garnet». In consequence, Eskola concludes that the rock mass has not crystallized at once from a large mass of solution (or magma) but its minerals have gradually replaced earlier constituents.

The recent investigations also have shown that features resembling those of igneous bodies are exceedingly characteristic of the mode of occurrence of cordierite-anthophyllite-rocks and -gneisses. After concluding that these rocks could not be of igneous origin Eskola, however, makes no further comment on the features in question.

An excellent outcrop for examining the geological occurrence of cordierite-anthophyllite-rock is situated on the western shore of lake Makarlanjärvi in Perniö about 1.5 km. SW of the Träskböle rock mass (Fig. 3). The rock consists of plagioclase-biotite-gneiss rich in almandine and cordierite. These minerals are arranged in parallel rows, in a way which most probably indicates a primary lamination in a sediment. The rock has been distorted into small folds around an axis plunging at 25 degrees to the east. The stratification is transsected by a distinct vertical schistosity. In the anticlines, as well as in the synclines, small bodies of cordierite-almandine-anthophyllite-rock occur. The boundaries against the surrounding rock are rather sharp, and the mode of occurrence greatly resembles that of a phacolith.

The structural features appearing in this shore cliff seem to be very characteristic of that part of the leptite belt lying between the island of Kemiö (Kimito) and the railway station of Koski (Eskola 1914, Map I). The fold axis strikes east-west and usually plunges gently to the east. The nearly vertical cleavage also strikes east-west and intersects the general direction of the stratification. Small bodies of cordierite-anthophyllite-rocks and -gneisses are common and they all appear principally in the same way as the »phacoliths» described above. Neither is the large body in Träskböle an exception in this respect, although for the present, the authors have not had opportunity to investigate this body in detail. Its surface section, as compared with the surrounding structures, gives full evidence for this conclusion (Eskola 1914, fig. 33).

In the other parts of the area investigated (*e. g.* in the »Orijärvi aureole») the general structures may be in part more complicated. However, when the forms and contact relations of the cordierite-anthophyllite-rocks or -gneisses have been investigated, in every case

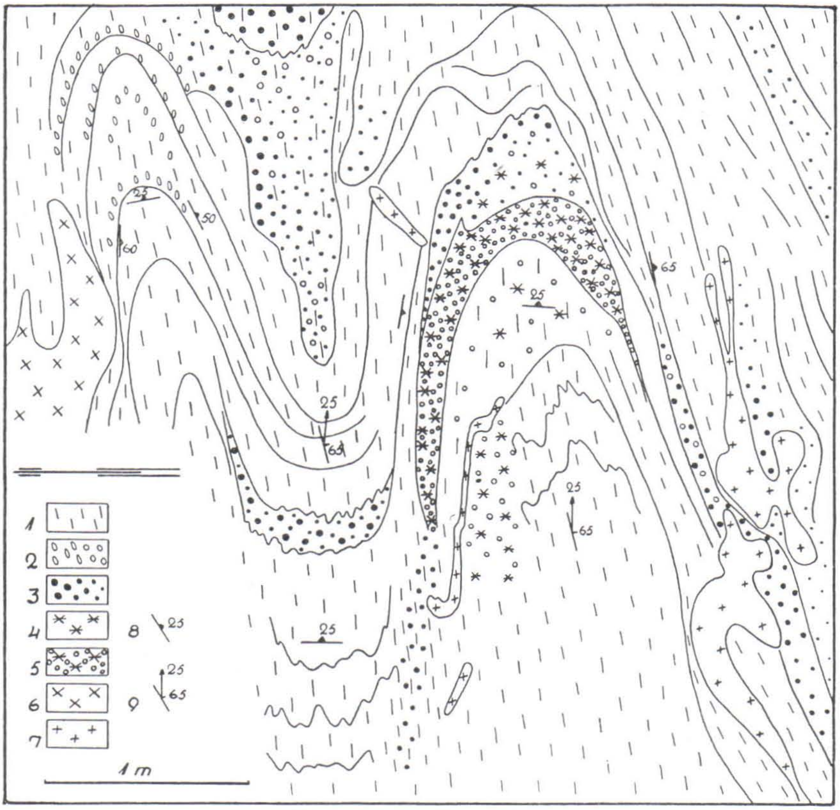

Fig. 3. A »phacolith» of cordierite-antophyllite-rock in almandine-cordierite-leptite. 1. Almandine-cordierite-leptite. 2. Large crystals of cordierite. 3. Large crystals of almandine. 4. Anthophyllite. 5. Anthophyllite-cordierite-rock. 6. Granite-pegmatite. 7. Quartz-veins. 8. Strike and dip of stratification. 9. Strike and dip of foliation and pitch of lineation (arrow). This lineation is parallel to the fold axis. Lake Makarlanjärvi, Perniö. Drawn by J. Tuura.

these rocks occur in a position similar to the occurrences described above. Even the boundaries against the leptites are practically sharp (Photos 1, 4). The gradual boundaries described by Eskola are in most cases only apparent, having been observed in places with acute angles between the contact and the rock surfaces.

Considering the parallel rows of the quartz inclusions appearing in the almandine of the Träskböle rock, there is a great difference in their significance, depending on whether they are relics of a stratification or a secondary foliation. As Eskola (1914, p. 252) points out, the possibility that cordierite-anthophyllite-rock »is of sedimentary origin with its bulk composition unchanged, may be left out of consideration, as no such sediments actually exist». Thus relics of stratification in this rock should prove beyond all doubt that it is the result of extreme metasomatic alteration of earlier sedimentary rocks. The description given by Eskola, however, discloses the fact that the direction of the quartz rows is parallel to the secondary foliation appearing in the surrounding area. Eskola (1914) regards the stratification — »the strike of the leptites» — as parallel to this foliation. In these circumstances the quartz rows only show that the almandine is a product of recrystallization in an older foliated rock, but they do not indicate that the bulk composition of the rock has been changed in connection with this recrystallization.

According to Eskola the contacts of the Träskböle rock are gradual. For instance at the southern boundary of the lens this rock »grades into a typical plagioclase-gneiss, the transition zone being only one metre broad» (Eskola 1914, p. 182). As the orientation of the contact is not known the real thickness of the contact zone can not be estimated; but even supposing the breadth of the surface section (25—100 m.) as corresponding to the real thickness of the body, a metasomatic boundary of one metre broad is rather too narrow to prove that the whole occurrence has developed through metasomatism from material like that of the surrounding rock.

As mentioned by Eskola, there are also transitions between the rocks in question independent of the stratification. For instance in the »Orijärvi aureole» the transition of cordierite-anthophyllite-rocks into andalusite-bearing rocks or leptites occurs in part in the direction of the strata. The same phenomenon can be observed in other places as well. The transition, however, does not seem to be of the kind described by Eskola. The various rock types have acutely zigzag boundaries which are strongly deformed. The transitional zone of this type can resemble in part an injection gneiss, in which the more melanocratic stripes, consisting for example of cordierite-anthophyllite-rock, form the »injected» material.

The contacts between cordierite-bearing rocks and amphibolites or other rocks rich in hornblende are also mostly sharp. As Eskola (1914) describes, amphibolites have, however, been converted into cummingtonite-bearing rocks in a narrow zone along the boundary. Perhaps these zones, which sometimes also contain cordierite or almandine, are to be regarded more as reaction zones between rocks of different compositions than as a phenomenon corresponding to the formation of cordierite-anthophyllite-rocks.

The andalusite-bearing types of the rocks in question frequently occur as bed-like bodies with practically sharp boundaries towards the cordierite-anthophyllite-rocks or gneisses, when interbedded with these. The boundaries towards leptitic rocks, on the contrary, seem more gradual and often there are no visible boundaries, an observation also emphasized by Eskola (1914). In many cases it is difficult to determine, whether their chemical composition is of sedimentary origin or the results of metamorphism. However, in respect to a great part of the andalusite-bearing rocks of the »Orijärvi aureole» and also the sillimanite-gneisses connected with the Träskböle rock (Eskola 1914, fig. 73 and p. 185) a metamorphic origin seems most probable. This is indicated by their exceptional bulk-composition, particularly in Träskböle, and their structural position, as well.

STRUCTURAL RELATIONS TO OLIGOCLASE-GRANITES AND AMPHIBOLITES

At the time when Eskola investigated the Orijärvi region the structura character of the older Pre-Cambrian formations and even the significance of various structural features were for the most part unknown. Thus it is evident that the structural interpretation presented by Eskola (1914) is in need of revision. Some points have been made already in the previous chapter.

Considering the direction of the axis of folding Eskola (1914) writes:
P. 14. — »At all places where smaller folds are seen the axis of folding hitches always to the east, the inclination varying from 10 to 70 degrees. Within the basin of Lake Orijärvi this reversed folding is clearly visible (Fig. 2); here the inclination is only 20 or 30 degrees.»
P. 239. — »As Tigerstedt remarks, the axes of elongation of the lenticular ore-bearing masses incline towards the east, in accordance with the general direction of the folding axis in this region.»

On the other hand, again, Eskola (1914, 1920) states that the crest of the Orijärvi batholith plunges westwards under the leptites. With regard to the easterly plunge of the associated fold, this statement is, however, very difficult to understand because the granite was considered to form a synkinematic anticlinal batholith with conformable boundaries towards the leptites.

In 1949 (p. 468) Eskola writes that in the Svecofennidic zone »the synkinematic dome-like intrusions are diapiric, and the term ,,anticlinal batholith'' assigned to them gives a fairly good idea of their mode of occurrence, as it is shown, for example, in the Orijärvi region in south-western Finland . . . ». He also presents a diagrammatic cross-section of an intrusion of the »Orijärvi» type (p. 469, Fig. 7 II). This illustration corrects the geometrical inaccuracy of the former statement by interpreting the concordance as occurring only in details, and that such a batholith in fact is quite discordant. However, even this interpretation does not seem to be in accordance with the local geology.

According to the recent investigations the axes (b) of the general folding in the country around the Orijärvi granite plunge at 0—30 degrees to the east.[1] This can be concluded, for example, from the fact that

[1] Axial directions plunging gently to the west also occur, but only occasionally and for very short distances.

axes of visible folds occurring in competent (leptitic or amphibolitic) layers, and the dip of these layers when striking north and south, are in this direction. Often also the cordierite crystals and other porphyroblasts have their longest axis in this direction. Furthermore, a distinct Q-jointing appears about normal to this direction.

A certain kind of transverse folding around steeply inclined axes appears besides the general folding. In the competent layers it is mostly seen only as a very gentle undulation. On the contrary, the more plastic or mobile materials have often been arranged into more or less independent bodies along these transverse folds as well as in accordance with the general folds. On account of this *e. g.*, the sulphide and magnetite ores and limestones in the Orijärvi region frequently occur as steeply or vertically plunging »lenticular« masses. In the Orijärvi mine they plunge at about 50 degrees to the east, but also the direction of the general fold axis, plunging locally at 15 degrees to the east, can be established from the folded shapes of the hanging wall of the ore. The very steeply plunging axial directions (70° to the east) mentioned by Eskola obviously belong to the steeper system. This lineation also occurs as mineral orientation in several rocks, for instance in oligoclase-granite. To what extent the cordierite-anthophyllite rocks have been distorted in this direction has not been ascertained for the present.

In accordance with the easterly plunge of the general folding, the north and south striking leptite beds at the western end of the Orijärvi granite dip gently towards the east and obviously slope in this direction under the granite mass. These conditions are illustrated in the sketch map, Fig. 4. It is in the main a simplified combination of the maps made by Eskola (1914, Orijärvi Region) and Erkki Mikkola (Karjalohja region; unpublished), and only small corrections have been made on the basis of the recent investigations. The various rocks of the leptite formation have not been shown separately, and only some amphibolite bodies lying in the immediate vicinity of the Orijärvi granite mass have been marked on this map. In respect to the cordierite-anthophyllite-bearing and andalusite-bearing »contact rocks» only the areas of their occurrence have been indicated, not the separate bodies.

The eastern part of the Orijärvi granite has been strongly re-granitized and secondarily enriched in microcline. Eskola (1914) therefore separates it as microcline-granite. E. Mikkola, on the contrary, included it, together with the oligoclase-granite, among the »gneiss-granites», a classic general name for synkinematic granites of the Svecofennidic zone. He probably stressed the original features of this rock and its geological connection with oligoclase-granite in the west and south-east. Only the eastern marginal part of this body was regarded by him as microcline-granite. As this classification illustrates better the structural relations, it has been applied to the present sketch map also.

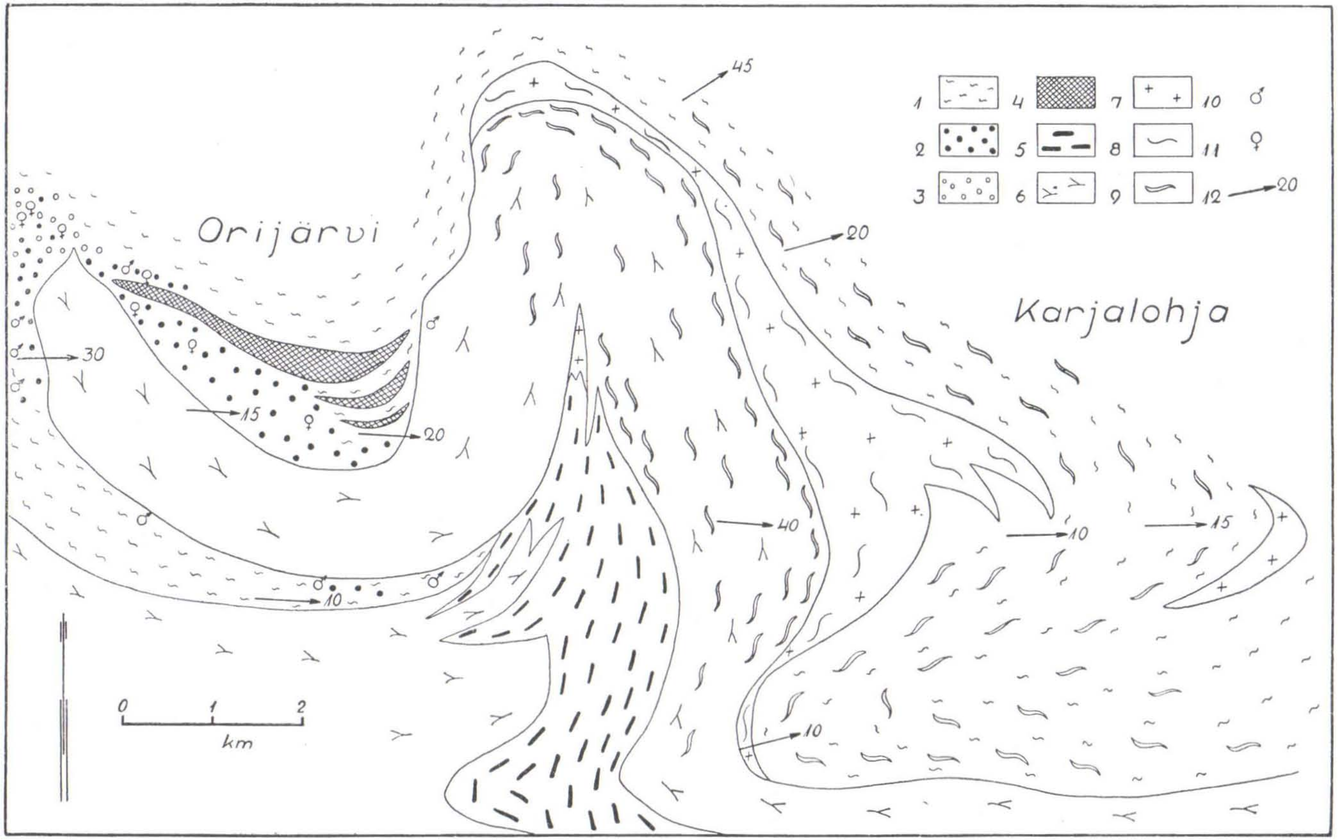

Fig. 4. A sketch map of the area between Orijärvi and Karjalohja. 1. Various rocks of the leptite formation. 2. Cordierite-anthophyllite-bearing rocks. 3. Andalusite-bearing rocks. 4. Amphibolite. 5. Diorite. 6. Oligoclase-granite or »gneiss-granite». 7. Microcline-granite. 8. Inclusions and relics of older rocks in microcline-granite. 9. Schlieren of microcline-granite or migmatized rock. 10. Magnetite deposits. 11. Sulphide deposits. 12. Pitch of the fold axes.

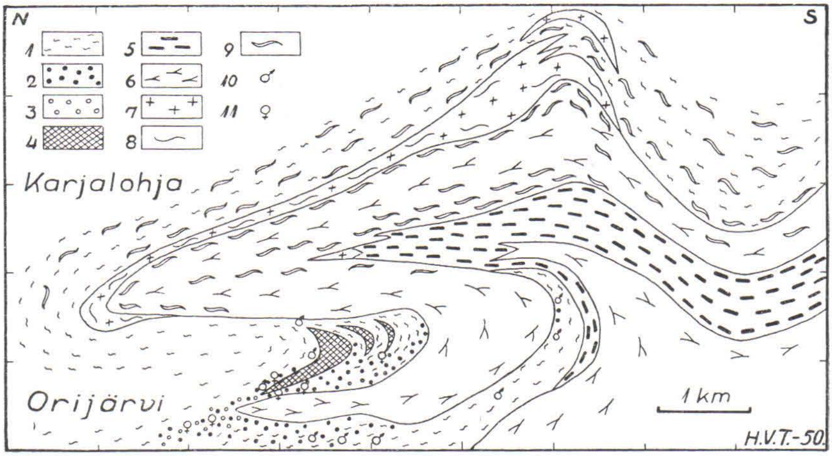

Fig. 5. A diagrammatic cross section normal to fold axis of the area presented in Fig. 4. The keys of both figures are identical.

The directions of the general folding axis have been marked on the map from observations made during the recent investigations. On the average this axis plunges approximately at 20 degrees to the east. To obtain a better illustration of the structural relations the map has been projected into a plane normal to this direction. The result is presented in fig. 5, which thus represents a rough cross section of the folded complex.

According to this cross section the granite mass of Orijärvi is not a batholith, but roughly a concordant body within a large recumbent fold (»Tauchfalte») overturned to the north. The »swarm» of cordierite-anthophyllite-bearing rocks and amphibolites, on the other hand, lie in the trough of the recumbent syncline below. In principle, all the rocks in question show roughly a similar structural position; they can be regarded as core-fillings of anticlines and synclines, a mode of occurrence, which is commonly considered as characteristic of intrusive rocks. A mode of occurrence of this kind is typical also of the other great bodies of oligoclase-granite lying between Karjalohja and the island of Kemiö (Kimito). In some cases these bodies also show simpler phacolithic forms than the granite mass of Orijärvi.

Independent of the neighbourhood of the granite, the cordierite-anthophyllite-bearing rocks of the Orijärvi syncline occur in quite a similar way as the »independent» bodies of these rocks lying far from the bodies of oligoclase-granite. Nor do the amphibolites seem to show any influence in this respect. Considering the structural mode of occurrence of the rocks mentioned above, together with the fact that they frequently occur quite apart from each other, they can in principle be regarded as parallel phenomena from the structural point of view. In general the oligoclase-granites occur as large bodies connected with the major folds.

The amphibolite phacoliths, on the other hand, are associated both with the major and the intermediate folds, and the cordierite-anthophyllite-bearing rocks with the small folds as well. These relations explain the fact that the rocks last mentioned are more often connected with amphibolites than with granites; even in such places, where they occur in contact with the oligoclase-granites (Orijärvi, Skogböle) they are also in contact with the amphibolites. However, with regard to the numerous small occurrences lying even far from amphibolites, this connection can not, in principle, be considered as more significant than that with oligoclase-granite.

As is apparent from the cross section in Fig. 5 the rocks rich in andalusite occur in the lower limb of the Orijärvi syncline and form a direct continuation of the zone of cordierite-anthophyllite-bearing rocks. Also in Träskböle the gneiss extremely rich in sillimanite seems to occur in a similar structural position in respect to the large body of cordierite-anthophyllite-rock. The structural position of the other corresponding occurrences could not be determined due to the small number of outcrops, and thus the observations in this respect are very few in number. However, for reasons presented in the following chapter these structural relations are perhaps to be regarded as a regular phenomenon.

As to the projection presented in Fig. 5, it is quite obvious, that it can not be as exact a picture as an accurately determined cross-section. Such inaccuracy is of course associated with all illustrations of this kind. It is also possible that the effect of the easterly plunge of the folds has been somewhat reversed owing to small faults parallel to the Q-jointing (H. Cloos 1936). That is indicated for example by some shear zones occurring roughly in this direction. Considering the continuity of the leptitic layers these faults can, however, have the character of only very slight flexures. This means that the recumbent fold may be somewhat lower than presented in fig. 5. In spite of all this, the illustration probably corresponds very nearly to the main character of the structure of the Orijärvi region and adjoining areas. The secondary fold, for instance, occurring in the upper limb of the recumbent fold can be traced as a continuous fold with a length of more than 60 km.

The development of this secondary fold has been already connected with the formation of the microcline-granite occurring as core-fillings in it. The nearly vertical, quite intense schistosity striking east and west, very common within the area investigated, has probably originated in the same stages of the folding. This schistosity has also penetrated bodies now existing in the form of cordierite-anthophyllite-rock, but not their actual minerals which, nevertheless, frequently show a slight orientation according to the folding in question. Thus the cordierite, anthophyllite and other porphyroblasts must be later than the vertical schistosity and the corresponding movements; that means they have been formed only after the folding was greatly damped.

The structures of the leptite-formation will be discussed in greater detail when the investigations, still in progress, have been completed. What is presented above may be sufficient to show that the relation of the cordierite-anthophyllite-bearing rocks to the oligoclase-granites is neither that of a contact aureole nor of a basic front.

CONCLUSION AND DISCUSSION

The »Mg metasomatic» cordierite and cordierite-anthophyllite-bearing rocks of the Orijärvi region and adjoining areas have the following features in common.

1. They occur as phacolithic core fillings in anticlines and synclines of folds. Also dike-like bodies are met. The more melanocratic types are »intrusive» in respect to the more leucocratic types of these rocks.
2. They lie mainly within the zones of such leptites which, on the basis of their bulk composition and geological mode of occurrence, are regarded as argillaceous in origin. These leptites are characterized by minerals such as cordierite, almandine, andalusite or sillimanite, and in part also by anthophyllite.
3. Their boundaries against leptites are practically sharp.
4. With regard to their composition they form a series with all intermediate types from cordierite-leptites to melanocratic cordierite-anthophyllite-rocks and even pure anthophyllite-rocks (Eskola 1914, p. 190).
5. Their actual texture is the result of recrystallization from pre-existing foliated rocks.

It follows from points 2 and 4 that the cordierite-(anthophyllite-) bearing rocks most probably originate from argillaceous rocks. With regard to cordierite-(anthophyllite-)gneisses it would even seem unnecessary to suppose a greatly changed bulk composition. In this respect Eskola (1914, p. 256) also points out that »the occurrence of rocks of a similar composition and clearly of a sedimentary origin in this same tract is a fact which must not be disregarded». Thus in the case of the cordierite-(anthophyllite-)gneiss the original clayey rocks, lying between more competent sandy and volcanic beds, could have been squeezed out of the limbs and transported by plastic flow into the hinges of the folds, there recrystallizing (5) into cordierite-(anthophyllite-)gneiss. The leptitic fragments frequently occurring in these rocks probably originate from thin competent beds, which were broken into pieces and carried away by the flowage. This kind of plastic rock transportation seems in general to have been very characteristic of this deep-seated zone.

Particularly the deformation of sedimentary limestone beds into more or less independent bodies of marble gives an excellent illustration in this respect (Metzger 1947, Fig. 1).

However, taking for granted that sediments having a chemical composition of a cordierite-anthophyllite-rock never existed, this rock type can not be explained with equal simplicity, but one must regard the high concentration of Mg and Fe occurring in them to be the result of a metamorphic enrichment. On the other hand, it seems evident that their position as core-fillings in the hinges of folds has been caused during the folding by a transportation of materials rich in Mg and Fe from outside, probably, from the limbs of the same folds. This is indicated, for instance, by the transitions into rocks of lower concentrations in Mg and Fe, these transitions taking place towards the limbs of the folds along the same stratigraphical horizon.

During the folding intense gliding and penetrative movements occur especially in the limbs of the folds. Thus it seems obvious that the loosening of the materials rich in Mg and Fe from their former association has taken place under influence of such movements. This is indicated also by the relations between the gliding movements and the formations of cordierite-biotite-schist (p. 78). In connection with this rock there are also some features indicating that these movements may have begun at a very early stage of the metamorphism; that means, under relatively low temperature conditions and in the presence of much water.

In general, when subjected to a concerted influence of penetrative movements and water, at low temperatures, a silicate rock tends to recrystallize, particularly, into minerals with sheet structure, such as micas, chlorites, talc, kaolin etc., whilst the constituents in excess are lost (Cook 1929, Eskola 1939, Turner 1948 etc.). Considering the composition of the new minerals the rock becomes enriched, in the first hand, in Mg, Fe, and Al, which means a corresponding withdrawal of the other elements: K, Ca, Na and Si. Probably all of the constituents present withdraw to some extent, but with unequal velocity. Thus, under continuous penetrative movements in the supposed conditions, the composition of the rock affected will gradually change in favour of the most stable constituents. At first constituents with intermediate stability will also be enriched, but at a later stage even they will begin to disappear. Also a diffusion of some materials from the environment must be regarded possible, but these materials, as well, will be subjected to the same re-assortment and the end product will be much the same.

Slickenside mylonites and some other foliated rocks of that kind are good examples of rocks obviously formed by the connected influence of strong penetrative movements and water solutions, particularly, as these rocks often have not been greatly influenced by a later metamorphism. In the main consisting of mica minerals of low temperature origin and quartz they commonly show very similar chemical compositions to those of the rocks rich in cordierite or andalusite. Thus it seems evident that, in the case of recrystallization in corresponding conditions, they also produce similar mineral combinations. For instance a type of anthophyllite-cordierite-rock can in this way be derived from a chlorite-quartz-schist:

$$\underset{\text{Clinochlore } Sp_5At_6}{5\ H_4Mg_3Si_2O_9 + 6\ H_4Mg_2Al_2SiO_9} + \underset{\text{Quartz}}{23\ SiO_2}$$

$$\rightarrow \underset{\text{Anthophyllite}}{3\ H_2Mg_7Si_8O_{24}} + \underset{\text{Cordierite}}{3\ Mg_2Al_4Si_5O_{18}} + \underset{\text{Water}}{19\ H_2O}$$

A foliaceous material of this kind obviously possesses a very high gliding capacity and may flow plastically during folding. In these circumstances the consequence will be quite the same as in the case of cordierite-anthophyllite-rock or marble; *i. e.*, the rock will have a mode of occurrence resembling that of an igneous phacolith.

With regard to the discussion above, the »Mg metasomatic» rocks of the Orijärvi region could be interpreted as originated roughly in the following way. During the folding, the relative gliding of the more competent sandy and volcanic beds took place along the rather thin clayey ones, which therefore were brought under strong penetrative movements. This sheared material was adapted to the folding by plastic flow from the limbs towards the hinges of the folds. Owing to the penetrative movements it was subjected to continuous solution, and recrystallization into minerals with sheet structure. Simultaneously a great part of the constituents in excess migrated out and were re-deposited in the layers sheltered from the penetrative movements or, in general, in places where the physical and chemical conditions were favourable for such a re-deposition. In the earlier stages of the process the solution was relatively rich in alkalis, particularly K. In consequence, the probable excess of Al in the competent layers was eliminated and these layers had then a composition typical of potash leptites (Table I, anal. 1). In the course of the process the sheared rock thus became increasingly enriched in Mg, Fe and Al, and in consequence the relative amount of Al in the solution gradually increased, and at a certain point exceeded the amount necessary for the formation of feldspar with the alkalis and lime existing in the same solution. After this the enrichment was, essentially, only in Mg and Fe, while in the environment an Al metasomatism has taken place, producing the rocks which, in the recrystallization that followed, were converted into rocks very rich in andalusite or sillimanite, whilst the residuum formed a cordierite-anthophyllite-rock. In some cases even pure anthophyllite-rock was produced, in some others, again, the process came to a standstill at an earlier stage, the end product being a cordierite-anthophyllite-gneiss or a cordierite-gneiss. Considering that the deformation of all these gneisses of the Orijärvi region has taken place in similar conditions, they rather represent intermediate stages in the alteration in question than sedimentary rocks with quite unaltered bulk composition.

Obviously a great part of the original silica was also transferred along with the other substances removed, but much free SiO_2 remained in the sheared rock. Owing to the flowage the quartzose material was in part segregated into somewhat independent »lenticular» masses which are now represented by the »ore-quartzites»; *i. e.*, the quartz-rich varieties of cordierite-anthophyllite-rocks. It is this rock type, which essentially forms the host rock of the sulphide ores commonly connected with cordierite-anthophyllite-rocks. Considering the very striking association between these ores, »ore-quartzites», and cordierite-anthophyllite-rocks, it seems reasonable to assume, agreeing with Eskola (1914), that the ores, as well, originate by the same process. From the structural point of view it makes no difference whether the sulphidic substances originally existed as syngenetic or epigenetic constituents within the pre-metamorphic argillites, or whether they have been removed from some magmatic source and injected into the flowing layers during the folding. But even in the latter case the sedimentary ore substances, eventually existing within the rocks affected, must have been mobilized, as well. Considering also that clayey sediments are never free from the elements in question, it seems obvious that at least a part of the sulphidic substances originated from the same sediments as the associated rocks.

The water content of the rocks affected may have played an important rôle in the process, and it can be assumed that both the withdrawal of constituents and the continuous recrystallization took place through the medium of an aqueous pore liquid. By facilitating the recrystallization this aqueous liquid must have thus increased the plasticity of the flowing rock. In this respect it is also difficult to say whether the direct, or the indirect componental movements (Sander 1932) have been of greater importance in this process.

The authors regard it as probable that the process has taken place under gradually increasing temperatures and with a continuous loss of water, principally, under hydrothermal conditions. The conditions, producing the actual mineral composition, were first reached in the later stages of the metamorphism when the folding movements were already greatly damped. This recrystallization took place with a further loss of much water (see equation p. 89). In general, it seems probable that the process was essentially caused by progressive regional (dynamothermal) metamorphism. The possibility of some relation to the oligoclase granites cannot, of course, be denied; however, this rock can hardly be the source of the magnesia occurring in the anthophyllite-cordierite-bearing rocks.

Under such circumstances argillaceous rocks are not necessary for the formation of cordierite-anthophyllite-bearing rocks. The fact that these rocks in the Orijärvi region have been derived from clayey rocks is probably due to the relatively thin clayey beds acting as gliding planes in the folding of the thick competent beds, and thus being subjected to strong penetrative movements. The result may be much the same, when a feldspar-bearing rock, of any kind whatever, is subjected to a corresponding metamorphism. On the other hand it seems also possible that even some other rock types, rich in Mg and Fe, can be formed in this way. In respect to a volcanic rock, for instance, the process begins with a retrogressive (hydrothermal) metamorphism (or diapthoresis). Even in a case of this kind, however, the hydrothermal conditions need not be caused by an intruding magma, but by a progressive regional metamorphism caused by crustal movements. This could take place through a continuous sinking of the terrain, or in part, perhaps, through heat generated mechanically.

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REFERENCES

BRÖGGER, W. C., 1934: On several Archaean rocks from the south coast of Norway. The south Norwegian hyperites and their metamorphism. Vidensk. Skr., I, Mat.-Naturv. Kl., Bd I.

BUGGE, J. A. W., 1943: Geological and petrographical investigations in the Kongsberg-Bamle formation. Norges Geol. Undersök., no. 160.

CLOOS, H., 1936: Einführung in die Geologie. Borntraeger, Berlin.

COOK, H. C., 1929: Some chemical changes in rocks, caused by shearing. Bull. Geol. Surv. Canada, no. 46, pp. 22—30.

ESKOLA, PENTTI, 1914: On the petrology of the Orijärvi region in southwestern Finland. Bull. Comm. géol. Finl., no. 40.

—»— 1915: On the relation between chemical and mineralogical composition in the metamorphic rocks of the Orijärvi region. Bull. Comm. géol. Finl., no. 44.

—»— 1919: Antiklinalbatoliterna och malmbildning i Falu- och Orijärvitrakterna. Geol. Fören. Stockholm Förhandl., vol. 41, pp. 205—209. (A comment by Geijer, P. in the same paper, pp. 210—212).

ESKOLA, PENTTI, 1920: Om metasomatiska omvandlingar i silikatbergarter. Norsk geol. tidskr., no. 6.
—»— 1932 a: On the origin of granitic magmas. Min. Petr. Mitt., vol. 42, no. 5/6, pp. 455—481.
—»— 1932 b: On the principles of metamorphic differentiation. Bull. Comm. géol. Finl., no. 97, pp. 68—77.
—»— 1932 c: Conditions during the earliest geological times. Acad. Sci. Fenn., Ser. A, vol. XXXVI, no. 4.
—»— 1933: On the differential anatexis of rocks. Bull. Comm. géol. Finl., no. 103, pp. 12—25.
—»— 1936: Några synpunkter i frågan om magnesiametasomatos. Nordiska (19. skandinaviska) naturforskarmötet i Helsingfors 1936, pp. 1—3.
—»— 1939: Die Entstehung der Gesteine (Barth, T. F. W., Correns, C. W., and Eskola, P.). Springer, Berlin.
—»— 1949: The problem of mantled gneiss domes. Quart. Journ. Geol. Soc. London, vol. CIV, pp. 461—476.
GAVELIN, S., 1939: Geology and ores of the Malånäs district. Westerbotten, Sweden. Sver. Geol. Undersök., ser. C. no. 424.
KRANCK, E. H., 1931: Petrologische Übersicht des Küstengebietes E von Helsingfors. Bull. Comm. géol. Finl., no. 89, pp. 66—104.
MAGNUSSON, N. H., 1930: Långbans malmtrakt. Sver. Geol. Undersök., ser. Ca, no. 23.
METZGER, A. A. T., 1947: Zum tektonischen Stil von Palingengranit und Marmor in den Svekofenniden in Finnland. Bull. Comm. géol. Finl., no. 140, pp. 183—198.
REYNOLDS, DORIS L., 1947: Hercynian Fe-Mg metasomatism in Cornwall, a re-interpretation. Geol. Mag., vol. LXXXIV, pp. 29—50.
SANDER, B., 1914: Studiereisen im Grundgebirge Finnlands. K.-K. Geol. Reichsanstalt. Verhandl., Jahrg. 1914, pp. 82—99.
—»— 1930: Gefügekunde der Gesteine. Springer. Wien.
SAURAMO, M., 1923: Studies on the Quaternary varve sediments in southern Finland. Bull. Comm. géol. Finl., no. 60.
SEDERHOLM, J. J., 1911: Geologisk öfversiktskarta öfver Finland. Sekt. B 2, Tammerfors. Beskrivning till bergartskartan.
STRAATEN, L. M. J. U. v., 1949: Occurrence in Finland of structures due to subaqueous sliding of sediments. Bull. Comm. géol. Finl., no. 144, pp. 9—18.
TILLEY, C. E., 1935: Metasomatism associated with greenstone hornfelses of Kenidjack and Botallack, Cornwall. Mineral. Mag., vol. XXIV, pp. 181—202.
TILLEY, C. E. and FLETT, J. S., 1930: Hornfelses from Kenidjack, Cornwall. Summ. of Progress Geol. Surv. for 1929, Part II, pp. 24—41.
TURNER, F. J., 1948: Mineralogical and structural evolution of metamorphic rocks. Geol. Soc. Am., Mem. 30.
WEGMANN, C. E., 1931: Übersicht über die Geologie des Felsgrundes im Küstengebiet zwischen Helsingfors und Onas. Bull. Comm. géol. Finl., no. 89, pp. 3—65.
—»— 1935: Zur Deutung der Migmatite. Geol. Rundsch., vol. 26, pp. 305—350.

EXPLANATION OF PLATE I.

Photo. 1. Sharp boundary between cordierite-anthophyllite-gneiss (dark) and leptite (light). The pen indicates the direction of fold-axis which plunges very slightly to the left. Liipola, Kisko.

Photo. 2. Rotated leptite fragments in cordierite-biotite-schist. Haapaniemi, Kisko.

Photo. 3. Layered rock. Light layers and fragments: leptite. Dark layers: cordierite-biotite-schist. Haapaniemi, Kisko.

Photo. 4. An »intrusive» contact of cordierite-anthophyllite-gneiss (dark) against leptite (light). Liipola, Kisko.

Photo 1

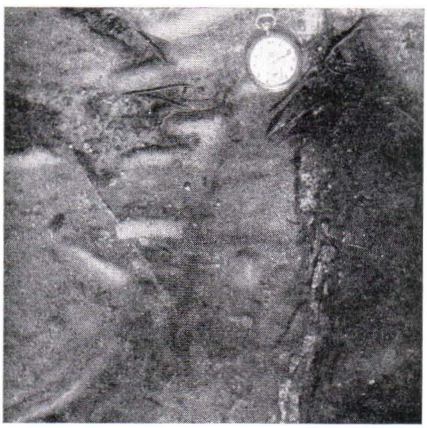

Photo 2

Photo 3

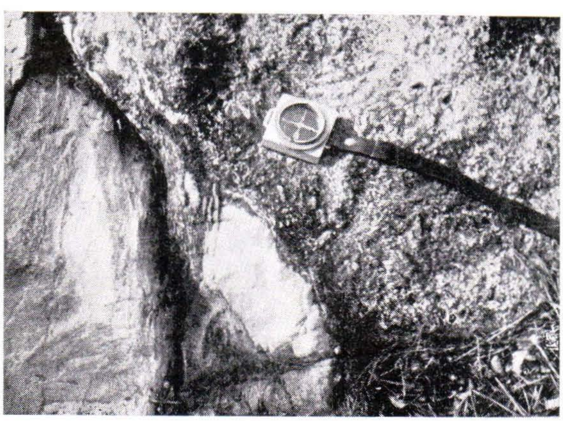

Photo 4

Heikki V. Tuominen and *Toivo Mikkola:* Metamorphic Mg-Fe Enrichment in the Orijärvi Region.

9.

ORIJÄRVI RE-INTERPRETED [1]

BY

PENTTI ESKOLA

INTRODUCTION

42 years have elapsed since I commenced my investigations in the Orijärvi area, mapping in the summer of 1908 the area between Lakes Seljänala and Kiskon Kirkkojärvi. My views expressed in a memoir on the Orijärvi region (Eskola 1914)[2] have since been commented upon by many authors and some of my conclusions have been applied to several other regions without much criticism or amendment, although the stand of general and structural geology has developed enormously. It is fortunate that my views have not restrained the young authors from following new lines of thought in their very thorough re-investigation of the area which they have, with many assistants, mapped to the scale 1 : 2000, whilst my field maps were made to the scale 1 : 21000. Their work has, in fact, brought about important elucidation of many problems of this area. If I feel sceptical concerning some of their conclusions and even believe they are decidedly wrong in certain points, this does not mean that I would deny this first publication by the authors the rank of an important contribution to Archaean petrology. Their new points of view, stressing the kinematic control of metamorphic differentiation, follows a modern trend in petrology and the study of ore deposits and leads to many interesting working hypotheses which certainly will arouse discussion and may lead to real progress.

THE RELATIVE IMPORTANCE OF VOLCANICS AND SEDIMENTS IN THE LEPTITE FORMATION

An important result revealed by the detailed mapping of the area is the insight that, within the Kisko-Kimito leptite belt, sedimentogenous rocks bearing an excess of alumina and containing aluminous silicates, such as cordierite, almandite, and sillimanite, are much more common than I had known. As I have seen during excursions with the authors in the last few years, these rocks are really predominant in many areas.

[1] Remarks to HEIKKI V. TUOMINEN and TOIVO MIKKOLA: Metamorphic Mg-Fe enrichment in the Orijärvi region as related to folding. Bull. Comm. géol. Finl. n:o 150, 1950.

[2] The years refer to the list of references appended to the paper by Tuominen and Mikkola.

The leptite belt thus actually shows features similar to those of the so-called kinzigite areas in Southwestern Finland, the main difference being the absence of granitization in the leptite zone.

However, Tuominen and T. Mikkola exaggerate in their claim that acid volcanics are relatively rare among the leptites. During my field work I had seen many of the outcrops which the authors refer to as conglomerates. I had classed these rocks with volcanic agglomerates, as the pebbles in all cases known to me had shown characteristics of volcanics. Tuominen and T. Mikkola have not presented any evidence that this is not the case. Where the cement of a conglomerate consists of materials of argillaceous composition, the pebbles may nevertheless be of volcanic origin, however, rounded they may be. This is the case also when the conglomerate as a whole shows a graded or varved structure with alternating coarse and fine materials. Of course such rocks can be called conglomerates, but their material nevertheless is of volcanic or half-volcanic origin.

A great part of the agglomerates described in my Orijärvi memoir are of a type that is very common in many other parts of Southern Finland, as *e. g.*, in the neighbourhood of Helsinki and in the Pellinge area. It consists of fragments or more or less well rounded pebbles of leptites embedded in a darker, amphibolitic mass (Fig. 1). The leptitic fragments

Fig. 1. Agglomerate containing leptitic fragments. ¼ nat. size. Saari, Perniö. From the Orijärvi memoir.

mostly show a composition and primary porphyritic texture characteristic of dacites or rhyolites. An analysis of such an agglomerate from Skogböle (Eskola 1914, p. 153) shows a dacitic bulk composition with 14.5 % normative quartz and as much as 7.36 % CaO which I interpreted as due to interaction of the silicates with calcitic amygdules (*l. c.*). Thus the fragments evidently represent the primary material of the agglomerates. They are acid leptites similar to those common Orijärvi leptites that do not contain excessive alumina. Thus these agglomerates represent acid volcanics. Relict textures of primary acid liparitic or rhyolitic lavas are also quite common, whereas there are in Finland no potash nor soda extreme leptites so common in Central Sweden.

TECTONICS OF THE ORIJÄRVI GRANITE PLUTON

I had assumed that the oligoclase granite mass at Orijärvi plunges westward under the leptites. Tuominen and T. Mikkola say this is difficult to understand »with regard to the easterly plunge of the associated fold». The reason for my assumption is stated in my memoir p. 14: The Orijärvi batholith shows marginal quartz porphyritic endo-contact modifications near its western end, whereas eastwards the contacts assume a real deep-seated character with coarse grain up to the contact line. »At its western end rocks are now exposed which originally consolidated at the shallowest depths». I had not thought the easterly axial pitch would imply that large elongated rock masses would be tilted eastwards. This was mainly because I, at that time, did not pay much attention to fold axes. In the present case, however, I still believe that the fold axes do not indicate that large elongated rock masses occupy positions inclined parallel to visible fold axes. This question must be discussed at some length.

The fold axes show, with a few local exceptions, an easterly pitch throughout the Kisko-Kimito leptite belt, and there is no sign of alternation of axial culminations and axial depressions nor any corresponding alternation of the primary sedimentary facies, as is the usual case in many orogenic zones. One might therefore expect to meet higher and higher stratigraphic horizons exposed at the surface when proceeding eastward. The strata exposed, say, at Orijärvi should be some 15 or 20 kilometres higher in the series than those in Kimito. This obviously is an absurdity. Therefore we must assume repeated normal faults, or flexures, effecting a relative rise of the easterly blocks. The net effect of faulting within the whole zone is probably enough to compensate the pitch of the fold axes, or the same as that of folding with a horizontal axis, but locally the effect of faulting may be greater, or there may be parts where the fold axes have a westerly pitch although the reversion of the pitch is not apparent. Tuominen and T. Mikkola (p. 86) have in fact noticed that the easterly pitch may be partly compensated by faulting within the Orijärvi area, but they have not drawn the full consequence of this conclusion.

The authors have assumed an overturned fold pictured in their Fig. 5. According to this profile the leptites east of Lake Orijärvi would plunge eastward under the oligoclase granite mass which here bends towards N. When I first saw this profile during the lecture of Mr. Tuominen in 1948 and remembered the easterly pitch of the axes, it seemed to me acceptable as a construction commonly used. By recollecting my observations from repeated excursions and by studying my field notes from the summer of 1908 I became convinced, however, that the profile must be quite wrong. Nor does it tally with the observations shown on Map II of the Orijärvi memoir. The pronounced foliation in the granite is around Lake Pitkälampi vertical with an almost N-S strike. The dip in the adjacent leptite and limestone layers, striking almost, though not quite, parallel to the granite contact, is 75° or 80°W. In my notes from 1908 I also find a photograph showing a westerly pitch of a fold with the explanation (in translation): »The end of a limestone lens, more correctly the bottom of a small syncline. The pitch of the folds is thus westerly» (Fig. 2). The wider limestone bands which are seen on the map to taper to thin wedges toward E or NE, are apparently also synclines plunging toward W or SW. All this indicates that the granite rather underlies than overlies the leptite series, but as the granite here also cuts the sediment layers, it seems most likely that the contact of the granite here as elsewhere is very steep. The great bend of the granite pluton would thus represent a fold with a steep or vertical axis quite independent of the general folding with an easterly pitch of its axis.

The Orijärvi granite mass is an accordant rather than concordant pluton according to the terminology of H. Cloos [1], although an obvious conformity with the surrounding strata is observable. Geijer [2] classed the Orijärvi granite with his anticlinal batholiths. Like the »urgranites» of the leptite regions in Sweden it is, in fact, a most typical representative of the synkinematic or synorogenic intrusions. But at its contacts the granite intersects the strata of leptites, amphibolites, limestones and skarn in a rather »merciless» manner (»schonungslos durchbrechend» according to H. Cloos), as may be seen from Map II in the Orijärvi memoir. The upward bending of the folds east of Lake Orijärvi thus has a natural explanation: It is a consequence of the diapire-like upward movement of the granite pluton during its intrusion.

[1] Hans Cloos, Zur Terminologie der Plutone, Fennia 50, N:o 2, p. 7. 1928.
[2] Per Geijer, On the intrusion mechanism of the Archean granites of Central Sweden. Bull. Geol. Inst. of Uppsala, vol. XV. 1916.

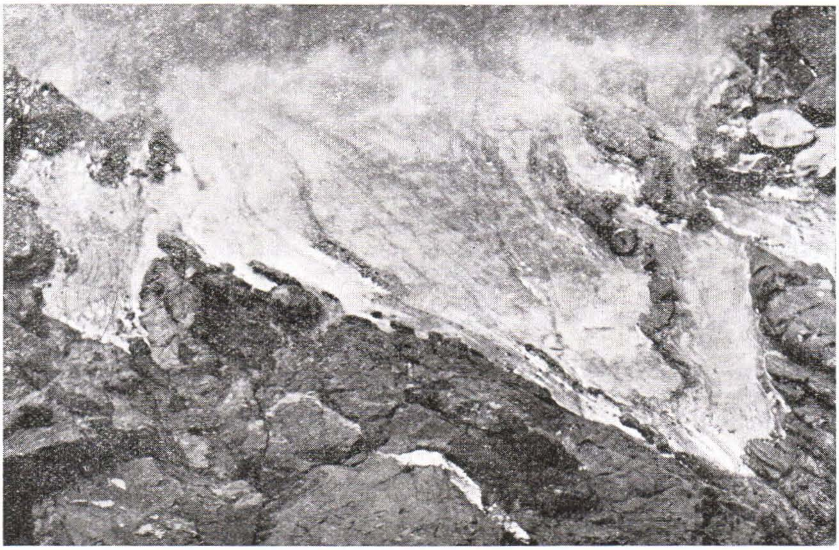

Fig. 2. Westward pitching folds in limestone and adjacent competent leptite on the shore of Lake Orijärvi north of Orjanperä bay. Photo P. E. June 26, 1908.

THE PROBLEM OF MAGNESIA METASOMATISM

The most interesting chapter in the article of Tuominen and T. Mikkola is that dealing with the origin of Mg,Fe-rich rocks which I had interpreted as products of magnesia metasomatism. The authors believe that the composition of the cordierite-anthophyllite gneisses is mainly primary. As it is similar to that of normal argillaceous sediments, and as the authors have found that similar cordierite-bearing leptites do occur in the continuation of the Orijärvi zone, I have no reason to dispute their conclusion in the form presented in their paper.

The cordierite-anthophyllite rocks, on the other hand, present a problem with which I myself and many others have been wrestling ever since 1914. As may be seen from my papers of 1914, 1919, 1932c, 1933, 1936, 1939 I have found it easy to explain the metasomatic replacement of calcium and alkalies by Mg and Fe, but very difficult to find a satisfactory explanation of how magnesium and ferrous iron could be moved to the place of replacement or, in other words, what substances have acted as carriers. I would therefore welcome any hypothesis that could explain the mode of the mobilization of Mg,Fe in a more satisfactory way. As to the source of (Mg,Fe)O, I assumed they had been derived from the granitic magma, not because this explanation was quite satisfactory but because no other source seemed to be available.

Tuominen and T. Mikkola now assume that the enrichment in Mg,Fe has taken place mainly by withdrawal of the other cations. Thereby they, in an elegant way, avoid both last-named difficulties. Of course they can not avoid assuming transport of these cations and metasomatic replacement. Thus their hypothesis also remains unsatisfactory concerning the chemical mechanism of the changes and of the transport of substances.

Another evident objection against this hypothesis is this: The ratio [Mg] : [Mg + Fe] = mg in the anthophyllite-cordierite rocks is higher than in the average leptites from which the cations should have been derived. Perhaps this objection is not very weighty, as the metamorphic differentiation anyhow must be considered as taking place according to the principle of enrichment in the stablest constituents, which might involve a re-adjustment of the proportions between the cations.

The authors present an auxiliary hypothesis, *viz.* that the mobilization of the cations may have begun at an early stage of metamorphism, at low temperatures and in the presence of much water (p. 88 ff). The minerals first to crystallize would be such having sheet structures, like chlorite which, in its content of cations, may be identical with an anthophyllite-cordierite rock. To me this idea sounds very attractive, especially as it is well known that the crystallization of chlorite etc. is favoured by shearing stress. The composition and structure of the rocks in the Orijärvi mine might possibly afford some evidence of a rise of temperature after the crystallization of much chlorite and biotite, in which crystals of tremolite or cummingtonite have grown. Actually, however, no such evidence is available.

It is useful to consider the available information about rocks and ores at the Orijärvi mine in the light of the hypothesis just mentioned. Next to the »Great sköl», or the main slide surface at the contact with amphibolite north of the ore body, the rocks (see 1914, Fig. 54, p. 237), since 1914 entirely mined out, were limestone, skarn and »soft ore». The skarn apparently had been derived from limestone, as was the soft ore which also contained skarn minerals and in which the sulphides enclosed grains of such a typical limestone mineral as chondrodite. The thickness of the skarn layer varied from 15 to 30 metres consisting for the most part exclusively of tremolite, whereas diopside was subordinate. In a considerable part of the tremolite skarn the long tremolite prisms were embedded in a slaty chlorite mass.

Tremolite is stable in association with chlorite. This means that the skarn has originated at temperatures lower than those at which the major part of the rocks of the Orijärvi region have crystallized. This is in good accord with the above hypothesis of Tuominen and T. Mikkola. There is nothing to contradict the assumption that the tremolite and chlorite have both originated together under low temperature conditions, though it seems probable that some diopside, chondrodite etc., still present in the rocks and the ore, had existed prior to the chlorite and the penetrative shear movements to which the slaty habit of the rock is due.

The skarn zone in the mine passes westward along the strike into chlorite-biotite schist containing octahedra of magnetite, slender prisms of anthophyllite and large lumps of brownish cordierite (»hard fahlunite»). The latter might more probably be a relic than a product of later higher temperature metamorphism, as the »fahlunite» is cordierite in incipient process of pinitization. By closer investigation perhaps the question of the metamorphic history of this magnesium silicate rock could be settled. On the whole, it seems probable that some more high grade minerals had existed in the skarn and chlorite schist zone before it was sheared and the present low grade minerals formed. Thus no direct evidence can be found that chlorite had been present before cordierite and anthophyllite, but of course there is nothing to prove the contrary either.

South of the skarn and soft ore zone is a zone of cordierite-anthophyllite rock, cordierite quartzite or »ore quartzite» and »hard ore» with the famous crystals of blue cordierite enclosed in the sulphides or late quartz. In many specimens the cordierite has grown in drusy cavities now filled with chalcopyrite. This zone, which is more than 30 m thick, shows little evidence of shearing, nor is there in it any indication of an earlier presence of chlorite.

Fig. 3. Cordierite-anthophyllite gneiss with rounded holoblasts of cordierite from Kurksaari. $^{1}/_{9}$ nat. size. From the Orijärvi memoir.

Fig. 4. Cordierite-anthophyllite rock with radiating groups, or »suns», of anthophyllite. Träskböle, Perniö. From the Orijärvi memoir.

The cordierite- and anthophyllite-rich rocks in the Orijärvi area are of two principal kinds: 1. Cordierite-anthophyllite gneisses with large rounded cordierite holoblasts surrounded by a mass of anthophyllite and plagioclase (Fig. 3). In this type both cordierite and anthophyllite may be safely assumed to represent the first generation of minerals formed during metamorphism. The cordierite holoblasts have grown like concretions by diffusion of ions from a surrounding sphere and at the expense of innumerable smaller holoblasts which have vanished. 2. Cordierite-anthophyllite rock with radiating »suns» of anthophyllite (Fig. 4). The interstices of the suns and of the diverging prisms of anthophyllite are filled with cordierite. It might be possible that this type has resulted from earlier chlorite, but in the occurrences at Träskböle, at the Orijärvi mine, or other outcrops, no evidence for such an assumption exists so far. But unless chlorite or other sheet-structured minerals have been the first to crystallize, the kinematic hypothesis presented by Tuominen and T. Mikkola is hardly probable. As the authors state, the structure clearly indicates crystallization under quiet conditions and the cordierite is a typical anti-stress mineral.

Occasionally cordierite-anthophyllite rock free of plagioclase may show a nodular appearance like that of the gneiss, with large rounded crystals of cordierite (1914, p. 188). Thus the texture is not determined by the composition but may rather be a consequence of the previous metamorphic history of the rock.

Tuominen and T. Mikkola believe that metasomatism in the common sense of this word has been unimportant in the genesis of the rocks enriched in Mg,Fe. The skarn layer, however, affords an evidence for the contrary opinion: The tremolite skarn could not originate merely by withdrawal of cations from the limestone, but Mg,Fe and silica must have been introduced to replace the carbon dioxide and part of lime.

As to the silicate rocks, surely much of what the authors have said for their hypothesis of a withdrawal of all other cations except Mg,Fe deserves serious consideration. Yet in view of what has obviously happened in the adjacent limestone, addition of Mg,Fe into earlier silicate rocks seems most probable. Direct evidence presented so far is sufficient to prove this beyond any doubt.

The skarn also contradicts the authors' assumption that the silicate minerals, *e. g.* chlorite, might have come to their present positions in a crystalline state by means of gliding. As is well known from the investigations of Sander, W. Schmidt, Fairbairn, E. Cloos and others, crystalline substances do move in many ways at the deformations of rocks. Especially conspicuous is the thickening of incompetent layers at the crests of anticlines of shear folds. The localisation of cordierite-anthophyllite rock described by Tuominen and T. Mikkola from many occurrences is closely related to this phenomenon. But long distance transport of solid materials can not be expected by this means. Nor can the chlorite etc., coating the shear surfaces in slickenside mylonites, have been transported long distances. Most probably in such cases as well the materials have wandered as ions in a disperse state.

The authors assume that the ores, or at least a part of them, also may have been derived from the sedimentogenous leptites. This is a fashionable idea in many circles at present, although nobody can dispute that all metals once have been contained in magmas. It still seems most probable that the sulphidic ores at Orijärvi, at the new Aijala mine etc. have been derived from the oligoclase granites, but I am quite willing to concede that other sources may have existed. Anyway, the source of the metals has most probably not been in the leptites, in which metals like Cu, Zn, Pb, Ag, Au etc. only occur as trace elements n trifling quantities. This agreed, it is evident that other factors except the kinematic ones have been concomitant at the origin of the anthophyllite-cordierite rocks and the sulphidic ores associated with them.

As we found that the position of the Orijärvi ores and anthophyllite-cordierite rock »at the hinge of a fold» most probably is not as visualized in their Fig. 5, I have one more reason to believe that the localization of the Mg,Fe enrichment is not due to the kinematic factors alone. The ore deposit and the Mg,Fe-rich rocks are not located near any crest of an anticline, although their relation to folding and strong penetrative movements is apparent near the Great sköl. They have been formed in the nearest vicinity of the great amphibolite sill which, apparently as an impermeable wall, has controled the path of the ore-bearing fluids.

At Aijala, 10 km southwest of Orijärvi, the recently discovered copper ore deposit is also located at the contact of leptite and amphibolite. Here likewise a shear zone with much chlorite and biotite occurs in the leptite next to the contact wall, but there is no cordierite-anthophyllite rock. Thus it appears that magnesia metasomatism is not indispensable for the genesis of sulphide ores in the Orijärvi region.

Sulphide ores and rocks enriched in Mg and Fe are of common occurrence in the Archaean of Sweden. The Swedish geologists certainly will be interested in the new ideas and it will be easy for them to tell whether the hypothesis set forth by Tuominen and T. Mikkola can find any application in their areas.

The kinematic hypothesis of Tuominen and T. Mikkola appears to me, furthermore, insufficient to explain the origin of the ore quartzites and the andalusite-bearing rocks. I shall postpone the discussion concerning these and many other connected problems. The new hypothesis, however, has many great merits and deserves to be discussed from all possible sides. Above all, it appears from their descriptions that the localization of cordierite-anthophyllite rocks along the limbs and at the crests of folds is a usual case and it can hardly be denied that a kinematic or structural control of the metasomatic changes in one or other way is a reality, whatever the mechanism and whatever the source of the materials may be. Their work affords suggestive ideas and promising working hypotheses, which future investigation has to check, and their work may afford new hints for practical prospecting. It may here be recalled that Mr. Tuominen has acted as chief geologist during the geological and electrical prospecting for ores since 1945, which, certainly by good luck, at the first trial lead to the discovery of the copper ore deposit in which the Aijala copper mine is now operating.

REFERENCE LIST OF THE ARTICLES AND PAPERS PUBLISHED IN THE NUMBERS 1—23 OF THE »COMPTES RENDUS DE LA SOCIÉTÉ GÉOLOGIQUE DE FINLANDE».

AARIO, LEO: Onko Kyrösjärvellä ollut nykyistä vanhempia lasku-uomia. (Deutsches Referat). 5 figs., pp. 145—154, no. 9, 1936.

ANT-WUORINEN, JALO: Der Wiikit und seine chemische Zusammensetzung. Zweite Mitteilung. 4 diagrs., pp. 213—229, no. 9. 1936.

AUROLA, ERKKI: Die postglaziale Entwicklung des südwestlichen Finnlands. 47 figs., 2 maps, pp. 1—166, no. 11, 1938.

—»— and VÄHÄTALO, VEIKKO: The Pyrite Deposit of Hevoskumpu in Tuupovaara. 3 figs., pp. 87—95, no. 13, 1939.

AUROLA, ERKKI: Über die Verbreitung submoräner Sedimente als Widerspiegelung der Bewegungen des Inlandeises. 7 figs., pp. 41—63, no. 22, 1949.

BACKLUND, H. G.: Der »Magmaaufstieg» in Faltengebirgen. 5 figs., pp. 293—347, no. 9, 1936.

BACKMAN, A. L.: Mooruntersuchungen am Lappajärvi-See im mittleren Ostbottnien. 7 figs., pp. 151—165, no. 22, 1949.

BARTH, TOM. F. W.: The Birkeland Granite, a Case of Petroblastesis. 5 figs., pp. 173—182, no. 20, 1948.

BORGSTRÖM, L. H.: Ein Beitrag zur Entwicklung der Immersionsmethode. 3 figs., pp. 58—63, no. 2, 1929.

—»—: The Chemical Formulas of Haüyne and Cancrinite. 2 diagrs., pp. 51—57, no. 3, 1930.

—»—: Beitrag zur Entwicklung der Immersionsmethode. II. Verwendung von Antimonbromid. Versuche mit Selen. pp. 28—29, no. 6, 1933.

—»—: Bestämning av dubbelbrytningen hos optisk enaxliga mineral i konvergent ljus. Pp. 161—164, no. 9, 1936.

—»—: Die Fluoreszenz finnischer Mineralien in ultraviolettem Licht. Pp. 349—355, no. 9, 1936.

—»—: Granite-porphyry from Östersundom II. 4 figs., 1 pl., pp. 121—128, no. 20, 1948.

BOWEN, N. L. vide SCHAIRER-BOWEN.

BRANDER, G.: Über den Dopplerit von Haapamäki in Finland. 1 fig., 2 pls., pp. 98—118, no. 6, 1933.

—»—: Über das Einsammeln von Erdproben und ihre Präparation für die qualitative und quantitative Diatomeenanalyse. Pp. 131—144, no. 9, 1936.

—»—: Zur Deutung der intramoränen Tonablagerung an der Mga, unweit von Leningrad. 2 figs., pp. 93—113, no. 10, 1937.

—»—: Entgegnung auf Dr. E. Hyyppäs Kritik meiner Abhandlung »Ein Interglazialfund bei Rouhiala in Südostfinnland». Pp. 95—107, no. 12, 1938.

—»—: Neue Beiträge zur Kenntnis der interglazialen Bildungen in Finnland. 5 figs., pp. 87—137, no. 15, 1943.

BRENNER, THORD: Die Bodenbildungen des Muhos-Sediments bei Kieksi. 1 fig., pp. 189—196, no. 16, 1944.

BRUCE, E. L.: Geological Relations of the Major Gold Deposits of the Canadian Shield. 6 figs., pp. 165—177, no. 9, 1936.

GLOOS, ERNST: Tectonic Transport and Fabric in a Maryland Granite. 12 figs. pp. 1—14, no. 20, 1948.

EDELMAN, NILS: On the Reaction Quartz Glass-Highcristobalite from the Thermodynamical Point of View. 4 figs., pp. 135—140, no. 20, 1948.

—»—: On the Water Content of Rocks. 9 figs., pp. 53—58, no. 21, 1948.

—»—: Microcline Porphyroblasts with Myrmekite Rims. 1 map., 2 pls., pp. 73—80, no. 22, 1949.

—»—: Some Morphological Details of the Roches Moutannées in the Archipelago of SW Finland. 3 figs., pp. 129—137, no. 22, 1949.

ERÄMETSÄ, OLAVI: Zur Chromatographie seltener Erden. 9 figs., pp. 36—49, no. 14, 1941.

—»—: SAHAMA, TH. G. and KANULA, VILJO: Spektrographische Bestimmungen an Rubidium und Caesium in einigen finnischen Mineralien und Gesteinen. Pp. 80—86, no. 15, 1943.

ESKOLA, PENTTI: On the Occurrence of Orthoclase and Microcline in the Finnish Granites and Pegmatites. Pp. 54—58, no. 1, 1929.

—»—: On the Rôle of Pressure in Rock Crystallization. Pp. 77—88, no. 1, 1929.

—»—: Beobachtungen über die Glazialbildungen in der Gegend der Wasserscheide zwischen dem Bargusin und der oberen Angara in Transbaikalien. 12 figs., pp. 37—57, no. 2, 1929.

—»— and SAHLSTEIN, TH. G.: On Astrophyllite-bearing Nephelite Syenite Gneiss found as a boulder in Kiihtelysvaara, Eastern Finland. 3 figs., pp. 77—88, no. 3, 1930.

—»—: Über die unvollkommene Auslöschung einiger Amphibole. Pp. 89—95 no. 3, 1930.

ESKOLA, PENTTI: On the Disintegration of Rapakivi. 6 figs., pp. 96—105, no. 3 1930.

—»—: On the Rocks of the Upper Bargousin and Namama Regions in Transbaikalia. 5 figs., 2 pls., pp. 106—140, no. 3, 1930.

—»—: On the Principles of Metamorphic Differentiation, pp. 68—77, no. 5, 1932.

—»—: On the Differential Anatexis of Rocks. Pp. 12—25, no. 7, 1933.

—»—: On the Chrome Minerals of Outokumpu. 1 fig., pp. 26—44, no. 7, 1933.

—»—: The term »metamorphic differentiation» first proposed by F. L. Stillwell. Pp. 45—45, no. 7, 1933.

—»—: Eine Bemerkung zur Mineralfazies des Archäicums. Pp. 47—48, no. 7, 1933.

—»—: Über die Bottenmeerporphyre. 3 figs., pp. 111—127, no. 8, 1934.

—»—: Prehnite Amygdaloid from the Bottom of the Baltic. 7 figs., pp. 132—143, no. 8, 1934.

—»—: A Note on Diffusion and Reactions in Solids. Pp. 144—156, no. 8, 1934.

—»—: A Paragenesis of Gedrite and Cummingtonite from Isopää in Kalvola, Finland (with a contribution by Tauno Kervinen). 4 figs., pp. 475—487, no. 9, 1936.

—»—, VUORISTO, URHO and RANKAMA, KALERVO: An Experimental Illustration of the Spilite Reaction. Pp. 61—68, no. 10, 1937.

—»— and NIEMINEN, EERO: The Quartzite Area of Tiirismaa near Lahti. 1 fig., pp. 29—45, no. 12, 1938.

ESKOLA, Pentti: Ein natürliches System der Mineralien. Pp. 179—183, no. 15, 1943.

—»—: The Mica of the Moro. Pp. 113—116, no. 22, 1949.

—»—: Orijärvi re-interpreted. 4 figs., pp. 93—102, no. 23, 1950.

FROSTERUS, BENJ.: Anmerkungen zu einem Vortrage und einem Aufsatze von Dr. H. Väyrynen »Über den Chemismus der finnischen Kaolinvorkommen». Pp. 159—164, no. 2, 1929.

GEVERS, T. W.: Comparative Notes an the Pre-Cambrian of Fennoscandia and South Africa. Pp. 27—59, no. 10. 1937.

HAUSEN, H.: Intryck från en exkursion inom Dalformation (mit deutschem Referat). 3 figs., pp. 23—39, no. 4, 1931.

HELLAAKOSKI, AARO: Das Alter des Vuoksi. 12 figs., pp. 75—106, no. 9, 1936.

—»—: Über das Vuoksi-Delta in Jääski. 5 figs., pp. 51—63, no. 12, 1938.

HIETANEN, ANNA: Über den Rhodonit und andere Manganminerale von Simsiö, Pohjanmaa. 7 figs., pp. 387—400, no. 9, 1936.

HIRSJÄRVI, V. P.: Die Kristallform und optischen Konstanten des 1, 1, 4 - Trimethyl-Cyclohexandiol-3, 5. 3 figs., pp. 119—123, no. 10, 1937.

HOLMES, ARTHUR and REYNOLDS, DORIS L.: A Front of Metasomatic Metamorpphism in the Dalradian of Co. Donegal. 19 figs., pp. 25—65, no. 20, 1948.

HYYPPÄ, ESA: Über die spätquartäre Entwicklung Nordfinnlands mit Ergänzungen zur Kenntnis des spätglazialen Klimas. Vorläufige Mitteilung. 10 figs., 8 pls., pp. 401—465, no. 9, 1936.

—»—: Artesischer Grundwasserausbruch in Terijoki und einige Gesichtspunkte über die Struktur des Karelischen Isthmus. 6 figs., 3 maps., pp. 125—144, no. 10, 1937.

—»—: Bemerkungen über G. Branders Aufsatz »Ein Interglazialfund bei Rouhiala in Südost-Finnland», und zwei neue Tonfunde auf der Karelischen Landenge. 14 figs., pp. 145—170, no. 10, 1937.

—»—: Bemerkungen über Dr. Branders Entgegnung auf meine Kritik über seine Abhandlung »Ein Interglazialfund bei Rouhiala in Südostfinnland». Pp. 111—119, no. 13, 1939.

—»—: Beiträge zur Kenntnis der Ladoga- und Ancylustransgression. 24 figs., pp. 138—177, no. 15, 1943.

—»—: Tracing the Source of the Pyrite-Stones from Vihanti on the Basis of Glacial Geology. 5 figs., pp. 97—122, no. 21, 1948.

HÄRME, MAUNU: On a Pre-Glacial Weathering in Tyrvää, Southwestern Finland. 2 figs., pp. 87—89, no. 22, 1949.

—»— and SEITSAARI, J.: On the Structure of a Tilted Dome near Tampere in southwestern Finland. 1 map, pp. 19—22, no. 23, 1950.

JAANUSSON, V.: Über die postglaziale Entwicklung der Insel Vormsi in Estland. Pp. 86—91, no. 1944.

—»—: Übersicht der Stratigraphie der Lyckholm-Komplexstufe. Pp. 92—100, no. 16, 1944.

JOENSUU, OIVA vide RANKAMA-JOENSUU.

KAHMA, AARNO and MIKKOLA, TOINI: A Statistical Method for the Quantitative Refractive Index Analysis of Minerals in Rocks. 3 figs., pp. 27—40, no. 19, 1946.

KAITARO, SIMO: Über den Charakter der eisenerzführenden Jaspisquartzite von Porkonen-Pahtavaara in Kittilä (Finnisch-Lappland). 1 fig., pp. 139—147, no. 22, 1949.

—»— and VAASJOKI, O.: Meneghinite from Aijala, Southwestern Finland. 1 map, 2 pls., pp. 39—44, no. 23, 1950.

KANULA, VILJO vide ERÄMETSÄ-SAHAMA-KANULA.

KIVINEN, ERKKI: Ein Doppleritfund aus Keuru in Mittelfinnland. 1 fig., pp. 69—73, no. 9, 1936.

—»—: Ein mit Moräne bedecktes Tonvorkommen auf der Karelischen Landenge. Pp. 76—79, no. 15, 1943.

KNORRING, OLEG v.: On a Manganese Garnet Enclosed in Sphalerite from Kimito in S.W. Finland. Pp. 77—87, no. 19, 1946.

KRANCK, E. H.: A Beryl-bearing Pegmatite from Uuksu in Carelia (E. Finland). Pp. 70—77, no. 1, 1929.

—»—: Beiträge zur Kenntnis der Svecofenniden in Finnland. III. Kinetisch-geologische Studien im Schärenhof von Ekenäs (SW-Finnland). 3 figs., 2 pls., pp. 30—53, no. 6, 1933.

—»—: The South Antillean ridge. Pp. 99—103, no. 8, 1934.

—»—: Zur Tektonik der Lappländischen Granulite. 1 fig., pp. 373—386, no. 9, 1936.

—»—: Beiträge zur Kenntnis der Svecofenniden in Finnland. IV. 6 figs., 1 map, pp. 69—91, no. 10, 1937.

—»—: The Rock-Ground of the Coast of Labrador and the Connection between the Pre-Cambrian of Greenland and North-America. 6 figs., pp. 65—86, no. 13, 1939.

—»—: Indications of Movements of the Earth-Crust along the Coast of Newfoundland-Labrador. 3 figs., pp. 89—96, no. 20, 1948.

KUENEN, PH. H.: Observations and Experiments on Ptygmatic Folding. 6 figs., 2 pls., pp. 11—28, no. 12, 1938.

LAITAHARI, AARNE: Über Mineralbildung längs schmalen Spalten. 2 figs., 2 pls., pp. 64—70, no. 2, 1929.

—»—: Verdrängungen in Sulphidmineralien von Pitkäranta und Outokumpu. 6 figs., 2 pls., pp. 55—63, no. 4, 1931.

—»—: The Scapolite Occurrence of Pusunsaari. 3 figs., pp. 115—119, no. 20, 1948.

LEHMANN, WLAD.: Ursus spelaeus rossicus und Ursus spelaeus minor v. Nordmann. 2 figs., pp. 14—22, no. 6, 1933.

LEIVISKÄ, I.: Bemerkungen über Dr. V. Tanner's Aufsatz »Zur Frage der Genesis der Osar». 1 fig., pp. 64—68, no. 4, 1931.

—»—: Über den Kohlengehalt des warvigen Tones. Pp. 149—150, no. 22, 1949.

LUMIALA, O. V.: Zwei Moorprofile aus Siilinjärvi, dem nordlichsten bekannten Fundort fossiler Trapa natans in Finnland. 2 figs., pp. 1—20, no. 15, 1943,

—»—: Über die Beziehung einiger Moorpflanzen zu der Grundwasserhöhe. 1 fig.. pp. 147—164, no. 16, 1944.

LUPANDER, KURT: Sedimentformationen på Fiskarhalvön (with an English Summary). 1 fig., 1 pl., pp. 89—98, no. 8, 1934.

MAGNUSSON, NILS H.: A Short Comparision between the Evolution of the Svecofennides in Finland and Central Sweden. Pp. 179—183, no. 9, 1936.

MALKOWSKI, STANISLAW: On the Analogy between some Polish and Fennoscandian Rocks. 1 fig., 2 pls., pp. 185—193, no. 9, 1936.

MARMO, V.: A Comparison made by Means of Chalcographic Investigations of some Ore-bearing Boulders with the Ores of Outokumpu and Polvijärvi. 4 figs., pp. 23—29, no. 23, 1950.

MATISTO, A. S. I. vide NEUVONEN-MATISTO.

McCALLIEN, W. J.: Metamorphic Diffusion. 2 figs., pp. 11—27, no. 8, 1934.

MELLIS, OTTO: On the Fabric Habit of Fibrous Celestite. 5 figs., pp. 239—246, no. 20, 1948.

METZGER, ADOLF A. TH.: Der Kalksteinbruch von Montola, Geologie und Tektonik. 3 figs., 2 pls., pp. 195—212, no. 9, 1936.

—»—: Über die normative und modale Zusammensetzung einiger Portland- und Brownmillerit-Cemente. 6 figs., 2 pls., pp. 40—75, no. 15, 1943.

—»—: Zum tektonischen Stil von Palingengranit und Marmor in den Svekofenniden in Finnland. 4 figs., pp. 183—192, no. 20, 1948.

METZGER, ADOLF A. TH.: Contributions à l'étude électrique des dépots quaternaires. 3 figs., pp. 3—8, no. 22, 1949.

MIKKOLA, AIMO: The Vähäjoki Iron Ore in Tervola, Northern Finland. 9 figs., pp. 261—280, no. 20, 1948.

MIKKOLA, ERKKI and SAHAMA, TH. G.: The Region to the South-West of the »Granulite Series» in Lapland and its Ultrabasics. 4 figs., pp. 357—371, no. 9, 1936.

MIKKOLA, TOINI: Über die Brauchbarkeit der Projektionsmethoden bei der Untersuchung des sogenannten »Nadelquarzes». 7 figs., pp. 467—474, no. 9, 1936.

—»— and WIIK, H. B.: Petalite, a Mineral New to Finland. 4 figs., pp. 281—286, no. 20, 1948.

—»— vide KAHMA-MIKKOLA, TOINI.

MIKKOLA, TOIVO vide TUOMINEN-MIKKOLA, TOIVO.

MÖLDER, KARL: Die postglaziale Klimaentwicklung im Lichte der fossilen Diatomeenfunde in Südfinnland. 17 diagrs., pp. 15—54, no. 16, 1944.

—»—: Das Karelische Eismeer im Lichte der fossilen Diatomeenfunde. 5 diagrs., 2 pls., pp. 55—85, no. 16, 1944.

—»—: Die Entwicklungsgeschichte des Sees Vieljärvi in Ostkarelien und die Klimaschwankung im Lichte der fossilen Diatomeenfunde aus den Seesedimenten. 9 diagrs., pp. 101—146, no. 16, 1944.

—»—: Entgegnung auf Astrid Cleve-Eulers Aufsatz »Die Diatomeen als quartärgeologische Indikatoren». 3 figs., pp. 1—14, no. 18, 1945.

—»—: Zwei Tonprofile aus Süd-Pohjanmaa. 7 diagrs., pp. 41—76, no. 19, 1946.

—»—: Die Verbreitung der Dacitblöcke in der Moräne in der Umgebung des Sees Lappajärvi. 2 figs., pp. 45—52, no. 21. 1948.

—»—: Wassersedimente unter der Moräne in Süd-Pohjanmaa. 3 figs., pp. 65—71, no. 22, 1949.

—»—: Woher stammen die losen Steinblöcke im Küstengebiet der Stadt Vaasa. 2 figs., 2 maps, pp. 109—111, no. 22, 1949.

NEUVONEN, K. J. and MATISTO, A. S. I: Some Observations on the Tectonics in the Tampere schist area. 1 fig., 2 maps, pp. 79—86, no. 21, 1948.

—»— vide SIMONEN-NEUVONEN.

NIEMINEN, EERO vide ESKOLA-NIEMINEN.

NIGGLI, PAUL: Die Systematik der Gesteine und Minerallagerstätten. Pp. 141—157, no. 20, 1948.

OKKO, VEIKKO: On the Origin of the Alavieska Pyrite Boulder. Pp. 21—24, no. 21, 1948.

—»—: On the Development of the Heposuo Bog near the Town of Kuopio. 3 figs., pp. 33—44, no. 21, 1948.

—»—: Brander's Data of the Littorina Shore-Line in North and Middle Ostrobothnia. 2 figs., pp. 117—127, no. 22, 1949.

—»—: Friction Cracks in Finland. 2 figs., 1 pl., pp. 45—50, no. 23, 1950.

PARRAS, KAUKO: On the Coarse-grained Garnet-Cordierite Gneisses of South and South-West Finland. Pp. 1—7, no. 9, 1936.

PURANEN, MAUNU: The Calculation of the Strength of the Anomaly of a Magnetic Ore at a Given Distance above the Surface of the Earth. 1 fig., pp. 21—26, no. 19, 1946.

RANKAMA, KALERVO: Purifying Methods for the Clerici Solution and for Acetylene Tetrabromide. Pp. 65—67, no. 9, 1936.

—»—: On the Mineralogy of Some Members of the Humite Group found in Finlan. Pp. 81—94, no. 12, 1938.

—»—: On the Composition of the Residue from Silica in Rock-Analysis. 3 figs., pp. 3—35, no. 14, 1941.

RANKAMA, KALERVO: Chalcocite from Merijärvi, Middle Pohjanmaa. 1 pl., pp. 84—89, no. 14, 1941.
—»—: On the Use of the Trace Elements in Some Problems of Practical Geology. 1 pl., pp. 90—106, no. 14, 1941.
—»—: The Niobium and Tantalum Content of three Finnish Archaean Granites. Pp. 34—39, no. 15, 1943.
—»— and JOENSUU, OIVA: A simplified Method of Quantitative Spectrochemical Analysis in the Carbon Arc Cathode Layer, based on the Use of the Logarithmic Wedge Sector. 5 figs., 1 pl., pp. 8—20, no. 19, 1946.

RANKAMA, KALERVO: Some Recent Trends in the Geochemical Investigation of Lithosphere. Pp. 129—133, no. 20, 1948.
—»— vide ESKOLA-VUORISTO-RANKAMA.
—»— vide SAHAMA-RANKAMA.

REYNOLDS, DORIS L. vide HOLMES-REYNOLDS.

SAHAMA, TH. G.: Akzessorische Elemente in den Granuliten von Finnish-Lappland. Pp. 267—274, no. 9, 1936.
—»—: and RANKAMA, KALERVO: Preliminary Notes on the Geochemical Properties of the Maarianvaara Granite. Pp. 5—8, no. 13, 1939.

SAHAMA, TH. G. and VÄHÄTALO, VEIKKO: The Rare-Earth Content of Wiikite. 10 figs., pp. 97—100, no. 13, 1939.
—»— X-ray Spectographic Study of the Rare Earths in Some Finnish Eruptive Rocks and Minerals. 22 figs., pp. 50—83, no. 14, 1941.

SAHAMA, TH, G. RANKAMA, KALERVO and HEINÄSUO, VOITTO: Röntgenspektrographische Bestimmungen des Tantals. 5 figs., pp. 21—33, no. 15, 1943.

SAHAMA, TH. G.: On the Chemistry of the East Fennoscandian Rapakivi Granites. 9 figs., 12 tabls., 2 pls., pp. 15—67, no. 18, 1945.
—»—: On the Chemistry of the Mineral Titanite. 2 figs., pp. 88—120. no. 19, 1946.
—»—: Rapakivi Amphibole from Uuksunjoki, Salmi Area. Pp. 159—162. no. 20, 1948.
—»— vide MIKKOLA-SAHAMA.
—»— vide ERÄMETSÄ-SAHAMA-KANULA.
—»— vide SAHLSTEIN, TH. G.

SAHLSTEIN, TH. G.: Optische Eigenschaften eines Alkaliamphibols aus Feuerland, mit besonderer Berücksichtigung der »Vierachsigkeit». Pp. 23—27, no. 6, 1933.
—»—: Struktur und Bewegungen in der Granulitformation des Finnischen Lapplands. 4 figs., pp. 82—90, no. 6, 1933.
: Ein Wort zur Mikrotektonik besonders im archäischen Grundgebirge. 1 fig.,
—»— pp. 5—11, no. 7, 1933.
—»—: Zur Metamorphose in dem reziproken Salzpaar (Na˙, K˙) — (Cl', JO'_3). 2 figs., pp. 104—110, no. 8, 1934.
—»— vide ESKOLA-SAHLSTEIN.

SAKSELA, MARTTI: Tektonische und stratigraphische Studien im mittleren Ostbothnien, mit einigen Vergleichspunkten aus anderen Gebieten. 8 figs., pp. 16—39, no. 5, 1932.
—»—: Über die geologische Kartierung und die Einteilung der Granite im finnischen Grundgebirge. 3 figs., 1 pl., pp. 275—292, no. 9, 1936.
—»—: Über einige Eisenerze im Jussaarigebiet, SW-Finnland. 17 figs., pp. 9—38, no. 13, 1939.
—»—: Über eine antimonreiche Paragenese in Ylöjärvi, SW-Finnland. 15 figs., 2 pls., pp. 199—222, no. 20, 1948.

SAKSELA, MARTTI: Das pyroklastische Gestein von Lappajärvi und seine Verbreitung als Geschiebe. 6 figs., 1 map, pp. 19—30, no. 22, 1949.

—»—: Über Erzpropaganda und ihre Ergebnisse. 2 figs., pp. 99—107, no. 22 1949.

SALMI, MARTTI: Ein Seehundfund aus Ruukki und die Salzwasserkonzentrationsschwankungen des Wassers in dieser Gegend während der Postglazialzeit auf Grund fossilen Diatomeenfloren. 10 diagrs., pp. 165—187, no. 16, 1944.

—»—: Die Ancylustransgression in dem Moore Hangassuo im Süd-Finnland. 10 figs., pp. 1—20, no. 21, 1948.

—»—: Zwei subfossile Tierknochenfunde aus Pohjanmaa. 1 fig., pp. 25—32, no. 21, 1948.

—»—: The Hekla Ashfalls in Finland. 2 figs., pp. 87—96, no. 21, 1948.

—»—: Die Litorinagrenze in der Umgebung von Alajärvi in Süd-Ostbottnien. 5 figs., pp. 31—40, no. 22, 1949.

—»—: Geologische Altersbestimmung des Tümmlerfundes von Närpiö und des Seehundfundes von Ylistaro. 3 figs., pp. 91—93, no. 22, 1949.

SALMINEN, ANTTI: The Influence of Exposure upon Temperature Differences in Rocks. 2 figs., pp. 52—62. no. 5, 1932.

—»—: On the Chemical Composition of Clays in a Vertical Profile through Layers of Different Ages. Pp. 79—81, no. 6, 1933.

SAURAMO, MATTI: Zur Kenntnis der Geologie von Worms und Nuckö, Estland. 3 figs., 2 pls., pp. 17—36, no. 2, 1929.

—»—: Zur spätquartären Geschichte der Ostsee. Vorläufige Mitteilung. 18 figs., 6 tabls., pp. 8—87, no. 8, 1934.

—»—: The Mode of the Land Upheavel in Fennoscandia during Latequaternary Time. 9 figs., pp. 39—63, no. 13, 1939.

SCHAIRER, J. F. and BOWEN, N. L.: The System Anorthite-Leusite-Silica. 6 figs., pp. 67—87, no. 20. 1948.

SEDERHOLM, J. J.: Sur une nouvelle espéce de granite nodulaire. 1 fig., pp. 63—76, no. 5, 1932.

SEITSAARI, J. vide HÄRME-SEITSAARI.

SIMONEN, AHTI: Chemical Study of the Orbicular Rock in Kemijärvi (Preliminary Report). Pp. 47—49, no. 12, 1938.

—»—: Orbicular Rocks in Kemijärvi and Esbo. 20 figs., 2 maps. pp. 107—142, no. 14, 1941.

—»—: On the gradual Development of the Basaltic Parent Magma during the Course of the Geological Periods. Pp. 193—198, no. 20. 1948.

—»— and NEUVONEN, K. J.: On the Metamorphism of the Schists in the Ylöjärvi Area. 2 figs., 2 maps, pp. 247—260. no. 20, 1948.

SIMONEN, AHTI: Three New Boulders of Orbicular Rock in Finland. 1 pl., pp. 31—38, no. 23, 1950.

SIRÉN, ARNE: Zur synthetischen Darstellung des Analcims. Pp. 115—118, no. 10, 1937.

STIGZELIUS, HERMAN: Über die Erzgeologie des Viljakkalagebietes im südwestlichen Finnland. 59 figs., 1 map, pp. 1—91, no. 17, 1944.

STRAATEN, L. M. J. U. v.: Occurrence in Finland of Structures due to Subaqueous Sliding of Sediments. 10 figs., pp. 9—18, no. 22, 1949.

SUNDELL, I. G.: Fineness and Composition of Alluvial Gold from the Ivalojoki, Finnish Lapland. Pp. 155—160, no. 9, 1936.

TANNER, V.: Zur Frage der Genesis der Osar. Einige Bemerkungen. 2 pls., pp 165—175, no. 2. 1929.

—»—: The Problems of the Eskers. II. The Vačer Esker. Inari, Lapland. 5 figs., pp. 33—39, n:o 3, 1930.

TANNER, V.: Zur Deutung der Genesis des ausgeebneten Reliefs der Hochflächen und »Widden» in Fennoskandia. 4 figs., pp. 40—51. no. 5, 1932.

—»—: Tre visten i Petsamo från den epipaleolitiska stenåldern på Varangerfjordens södra strand samt några supplerande iakttagelser beträffande de postglaciala nivåförändringarna (Résumé en français). Pp. 128—131, no. 8, 1934.

—»—: Det senglaciala havets utbredning i Lutto och Suomu älvars dalgångar ovanför sammanflödet samt några ord om morfologin i denna trakt. Résumé en français: L'extension de la mer senglaciaire dans les vallées des riviéres Lutto et Suomu en Laponie en amont de leur confluent. 1 fig., pp. 107—119, no. 9, 1936.

TILLEY, C. E.: The Cabbro-Limestone Contact Zone of Camas Mor, Muck, Inverness-Shire. 2 figs., 2 pls., pp. 97—105, no. 20, 1948.

TUOMINEN, HEIKKI V. and MIKKOLA, TOIVO: Metamorphic Mg-Fe Enrichment in the Orijärvi Region as related to Folding. 5 figs., 1 pl., pp. 67—92, no. 23, 1950.

DE WAARD, DIRK: Palingenetic Structures in Augen Gneiss of the Sierra de Guadarrama, Spain. 11 figs., 1 pl., pp. 51—66, no. 23, 1950.

VAASJOKI, O.: On the Microstructure of Titaniferous Iron Ore at Otanmäki. 1 pl., pp. 107—114, no. 20, 1948.

—»— vide KAITARO-VAASJOKI.

WAHL, WALTER: Contributions to the Chemistry of Igneous Rocks II. Eutectics and the Crystallization of Igneous Rocks. 8 figs., pp. 78—95, no. 2, 1929.

—»—: Note on the Bearing of Eutectic Surfaces on Crystallization-Differentiation. Pp. 96—97, no. 2, 1929.

—»—: The Granites of the Finnish Part of the Svecofennian Archaean Mountain Chain. 1 fig., pp. 489—505, no. 9, 1936.

—»—: A Composite Lava Flow from Lounatkorkia, Hogland. Pp. 287—302, no. 20, 1948.

—»— and WIIK, H. B.: The Meteorite from Varpaisjärvi. 1 fig., 1 pl., pp. 5—18, no. 23, 1950.

WEGMANN, C. E.: Stereogramm des Gebietes von Soanlahti-Suistamo. 1 pl., pp. 58—66, no. 1, 1929.

—»—: Note sur la dépression axiale d'Åland. 1 fig., pp. 71—77, no. 2, 1929.

—»—: Beispiele tektonischer Analysen des Grundgebietes in Finnland. 9 figs., 2 pls., pp. 98—127, no. 2, 1929.

—»—: Über Diapirismus (besonders im Grundgebirge). 4 figs., pp. 58—76, no. 3, 1930.

—»—: Über einige Deformations- und Bewegungstypen kristalliner Schiefer. 1 fig., 4 pls., pp. 40—54, no. 4, 1931.

—»—: Note sur quelques problémes de la tectonique superposée. Pp. 223—238, no. 20, 1948.

WIIK, H. B. vide MIKKOLA, TOINI,-WIIK.

—»— vide WAHL-WIIK.

WILKMAN, W. W.: Übersicht der Gesteine im Gebiet des Kartenblattes Kajaani. 1 fig., pp. 40—50. no. 3, 1930.

—»—: Über zwei Syenitvorkommen in Nilsiä, nördl. von Kuopio. 3 figs., pp. 91—97, no. 6, 1933.

—»—: Über Archäische vulkanische Gesteine in Saarijärvi im mittleren Finnland. 2 figs., 1 pl., pp. 121—130, no. 9, 1936.

VIRKKALA, K.: Late-Glacial Development of Shore-Lines in Southern Kainuu and Northern Karelia. 9 figs., pp. 59—78, no. 21, 1948.

—»—: Ein Profil aus dem Grunde des Sees Pyhäjärvi südlich Tampere. 3 figs., pp. 81—85, no. 22, 1949.

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