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THE STRUCTURE AND STRATIGRAPHY OF THE YLIVIESKA-HIMANKA SCHIST AREA, FINLAND

BY

ILMARI SALLI

WITH 28 FIGURES AND 4 TABLES IN TEXT AND 3 MAPS

HELSINKI 1964

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Helsink 1964. Valtioneuvoston kirjapaino

PREFACE

The field observations of the Ylivieska—Himanka portion of this study were made during the geological mapping program of the Geological Survey in the summers of 1950—1953. During that time and afterward until 1956 I carried out revisional investigations in the area.

The field material was processed at the Geological Survey in the years 1952—1958, at which work I was assisted by many persons. Preliminary notes have been published in Finnish (Salli 1955 a, 1956) and part of the research material served to meet the requirements for my licentiate examination (1962).

Professor Martti Saksela encouraged me with kind counsel and showed continued interest in all phases of my work. Professor Ahti Simonen likewise helped me with much advice and constructive criticism of the manuscript.

Mr. P. Ojanperä, Mag. Phil., and Mr. A. Heikkinen, Mag. Phil., performed the chemical analyses.

Messrs. P. Ilola and R. Aromaa prepared the thin sections, Miss Thyra Åberg drew the graphical figures and maps, and Mr. E. Halme, research assistant, took most of the photographs.

Professor Vladi Marmo, Director of the Geological Survey of Finland, kindly accepted my paper for publication in the series Bulletin de la Commission géologique de Finlande.

Mrs. Toini Mikkola, Mag. Phil., did the translation into English and Mr. Paul Sjöblom, M. A., corrected the manuscript in part.

To all the persons that assisted me in my work, I sincerely wish to express my appreciation.

Geological Survey of Finland, Otaniemi, February 1963.

Ilmari Salli

ABSTRACT

Lithological and petrographical descriptions are given of the sedimentary formations of the Ylivieska-Himanka area, and chemical analyses clarify their composition. On this basis these formations are classified into conglomerates, graywacke-like schists, quartz-feldspar schists (leptites) and mica schists. The problems of structure and stratigraphy of different zones are discussed in the light of field observations, and geological maps are presented. Volcanogeneous rocks are petrographically described and their composition chemically analysed. Infracrustal rocks are likewise petrographically described and their relations to supracrustal rocks are compared on the basis of the field observations and the conception given by the geological map.

CONTENTS

INTRODUCTION

The purpose of the present study is primarily to analyze the structure and stratigraphy of the Archean bedrock of the area investigated. Chief emphasis is laid on the schist formations. Other rocks are considered to the extent needed to make matters understandable. Mineralogical, petrologic, petrographic and lithologic data are introduced for further elucidation of the main problem.

The geology of this area was investigated earlier by Eero Mäkinen (1916), Martti Saksela (1932, 1933, 1935) and W. W. Wilkman (1930, 1931). Eero Mäkinen's investigations took in the entire area now studied and his research was of great value to the present writer. Martti Saksela devoted his attention to the western part, and W. W. Wilkman to the eastern part of the area. Their investigations have further aided the author in compiling the present study.

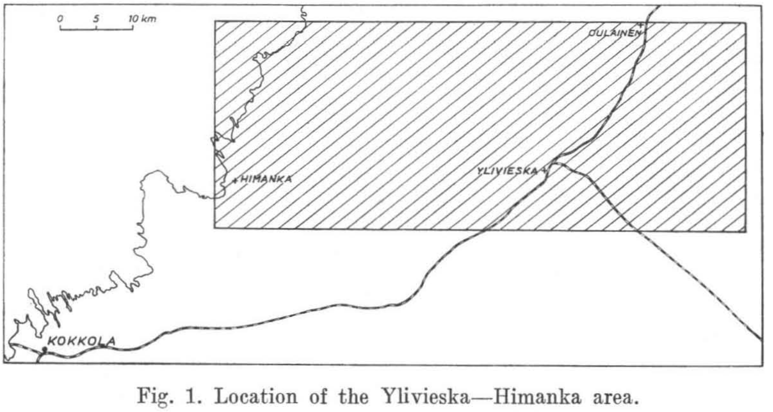

Fig. 1. Location of the Ylivieska—Himanka area.

The area investigated is shown in the sketch map of Fig. 1. It includes parts of the map sheets of pre-Quaternary rocks already published: Kalajoki (Salli 1955 b), Ylivieska (Salli 1955 c) and Haapavesi (Salli 1958). A simplified petrological map (1:200 000) of the whole area is included at the end of this paper (Map 1). In addition, use has been made of pictorial material from the area covered by the map sheet of Pyhäjoki (Salli 1957), in the commune of Merijärvi.

Textbooks by Pettijohn (1949), Shrock (1948), Krumbein and Sloss (1951), Twenhofel (1950) and De Sitter (1956) were consulted for the description of supracrustal rocks.

STRUCTURAL REVIEW

The geological map shows how the schists of the area investigated readily form many separate lenticular parts. Many of these are oval in shape and taper towards the ends while some other ones are forked and irregularly shaped. Plutonites occur between them in diverse forms. As early as the mapping stage it was noted that these schists possess various well-preserved relict forms, by which it was possible to classify them into different groups and to determine the sequence and thickness of their layers and the top and base of the strata (*cf.* Salli 1955a, 1956).

These observations enabled the structure and stratigraphy of each separate schist zone to be worked out. The bases of the beds were determined by different methods: Cross-bedding, differences in the grain size of various beds, differences in weathering and denudation in various parts of the beds (*cf.* Salli 1953), differences in the enrichment of porphyroblasts within beds of mica schist. All these data are compiled on a special map at the end of this study (Map 2).

Tectonical observations were much harder to carry out than the stratigraphical ones. Only a few directions of the fold axes were determinable, even then not in every case the directions of the main folding axis. Particularly the axial directions of minor foldings were determined to a comparatively greater extent. The lineation seen in the foliation plane has been measured, on the other hand, quite abundantly.

The main folding is considered to have taken place around a gently sloping axis with a NW-SE direction. This result is suggested by the few true axial measurements and the fact that schist beds only a few hundred meters thick extend for tens of kilometers. This would scarcely have been possible if the culmination and depression areas had sloped steeply. The folding has been intensive and comparable to an isoclinal one, also nearly symmetrical. In addition to the main folding, secondary folding is noticeable, too, with its b-axis nearly at right angles to that of the main folding. This is best seen at the border parts of the isoclines, where transversal schistosity accordingly occurs.

In view of the field determinations mentioned the clarification of the structure and sequence of beds of separate schist zones proved successful and no contrary determinations existed. Consequently the different schist belts divide into synclines and anticlines, as is shown in the map at the end of this paper (Map 2).

Many of the synclines and anticlines have developed into isoclines. Among them the syncline of Himanka has formed an isocline. Similarly, there is an isocline in Rautio, although not so clearly defined as in Himanka. It still shows some syncline-like parts with open shapes. An anticline, to some extent deformed to an isocline, is to be found in Alavieska. It comprises distinctly isoclinal and still anticlinal parts. There is a syncline in Ylivieska which has also in places developed into an isocline. In the region of Kangas—Oulainen there occurs a fairly large syncline.

SUPRACRUSTAL GROUP

THE HIMANKA SCHISTS

The SW corner of the investigation area is covered by the Himanka schist zone. Its NE border, which runs NW—SE, is situated in the islands off Kalajoki and continues southeastward from there across the village of Mutkalampi, in the commune of Kannus, and crosses the southern border of the area. At its NE border the zone is bounded by a broad plutonic massif while its NW end plunges into the sea. It mainly comprises bedded sedimentogeneous schists but also considerable amounts of volcanogeneous rocks. The composition of the rocks varies within small features and the determination of the exact limits between schists of varying composition is difficult. This is due to the fact that alternating layers are common and also the different material apparently was greatly mixed at the time of sedimentation. Fine-grained, bedded quartz-feldspar schist (leptite) occurs principally in the vicinity of the border of the plutonic massif at the northern border of the schist zone, as, for example, in the village of Mutkalampi. In addition to quartz-feldspar schist, amphibolitic and hornblende-gneiss-like rocks occur here and there at the northern border of the schist zone. Toward the center of the zone they pass into a graywacke-like schist, which contains conglomerate intercalations and further passes into a mica schist containing porphyroblasts. Toward the center a volcanogeneous schist is met with, occurring as a clearly defined belt, a few hundred meters broad, basaltic composition and with pillow-lava and agglomerate structures. This zone comprises, particularly at its S end, also uralite and plagioclase porphyrites. Toward SW from the volcanogeneous rock belt, schists occur symmetrically, as they do NE of this belt.

The twelve reliable measurements of the base of the beds made in the Himanka schist zone prove that it is an isocline developed from a syncline. The zone is vertical and symmetric. The determinations were made both in the porphyroblastic mica schist and the graywacke-like schist with cross-bedding. At the NE border of the zone in the village of Mutkalampi there is an outcrop along the road showing graywacke-like schist with cross-bedding. Fig. 2 (p. 12) represents a specimen taken of this rock. Determination No. 1, marked on Map 2, was made at this outcrop.

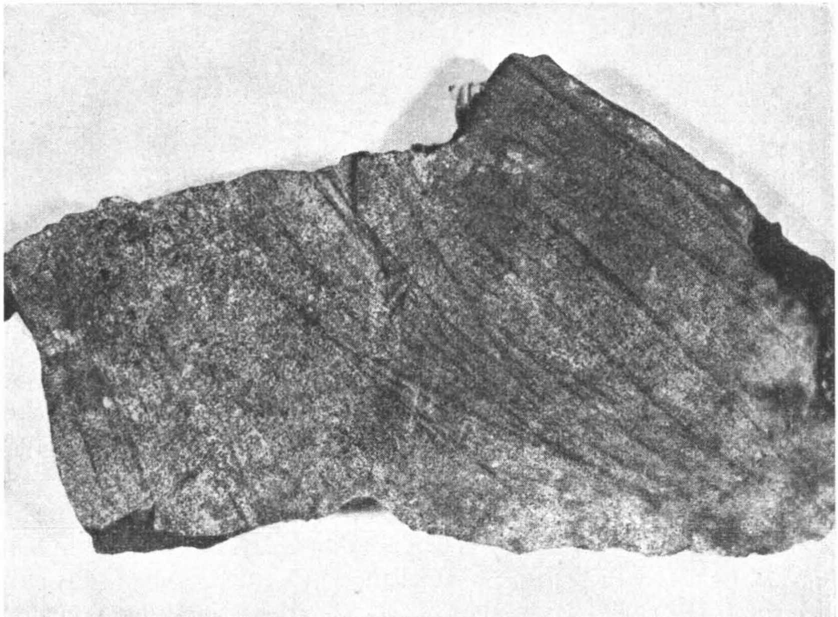

Fig. 2. Graywacke-like schist with cross-bedding. 1: 2. Mutkalampi.

Determination No. 2 was made at an outcrop of graywacke-like schist with cross-bedding, shown in Fig. 3 (p. 13). Determinations 3 and 4 were made of similar graywacke like schists with cross-bedding. About 2 km NW from Hanni and about 200 m NE from the road near the brook, there occurs a porphyroblastic mica schist which has given the result of determination No. 5. In this rock staurolite-cordierite porphyroblasts had formed at the upper limit of the bed, from which the lower border, being richer in sandy material, differs sharply. Later (p. 32, in Fig. 13) the determination of the base of the beds was made after similar principles. Determinations 6—9 were also performed from porphyroblastic mica schists along the same lines as determination 5, while determination 10 involved graywacke-like schist with cross-bedding. Determinations 11 and 12 were made from the graywacke-like intercalation of porphyroblastic mica schist.

The longitudinal direction of the Himanka isocline is the direction of the b-axis of the main folding. Its dip is rather gentle. As the fold does not yield the measurement of axial direction, the dip is determined from the fact that thin packs of schists extend unbroken for tens of kilometers in the longitudinal direction of the isocline. For example, the volcanogeneous schist, only 100 to 300 m thick, located in the center of the isocline, is observed to continue nearly the whole distance the isocline is visible in the area investigated.

Fig. 3. Graywacke-like schist with cross-bedding. 1:5. Himanka.

Both flanks of the isocline are divided into several different schist horizons, the most important and most clearly discernible of them are as follows, from the youngest to the oldest:

I. Basic volcanogeneous rocks, which comprise pillow lavas, agglomerates and porphyrites;
II. Arkose-like schist;
III. Mica schist containing abundant staurolite, andalusite or cordierite as porphyroblasts;
IV. Graywacke-like schist containing, in part, fine-grained quartz-feldspar schist as fragments and showing cross-bedding;
V. Fine-grained slightly bedded quartz-feldspar schist (leptite).

I. The basic volcanogeneous pillow lava-agglomerate-porphyrite sequence can be followed in the center of the isocline from the S border of the area investigated to the vicinity of the sea-shore in Himanka.

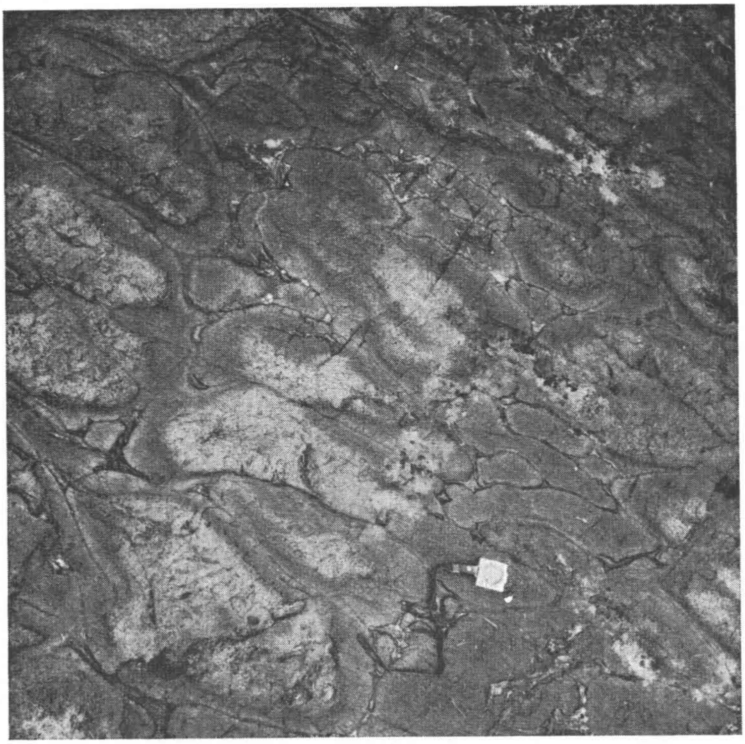

Fig. 4. Pillow lava. Settling direction of pillows is clearly seen. Hanni.

The primary structure of the pillow lava is clear, the diameter of the pillows varying between 10 and 50 cm. They are fairly rounded and display their settling direction as is to be seen in Fig. 4. Pillows formed of mass-like amphibole contain amygdules filled with quartz, which occur most abundantly in the upper part of the pillow and are largely lacking in the lower part.

The ejecta of the agglomerate are fragmentary. They are basic in composition with amphibole predominating. The matrix is of the same material.

Particularly at the southern end of this volcanic belt, coarse uralite and plagioclase porphyrites are to be found. They occur in varying amounts associated with agglomerates and belong to the same volcanic group with them.

II. West of the village of Hanni there occurs an arkose-like schist which contains mainly quartz and feldspars and is markedly coarser than the quartz-feldspar schist to be described more closely in the following. Distinctly bedded schist seems to lie upon the mica schist horizon. It is not, however, possible to follow this horizon further, because this outcrop is the only one where it is visible.

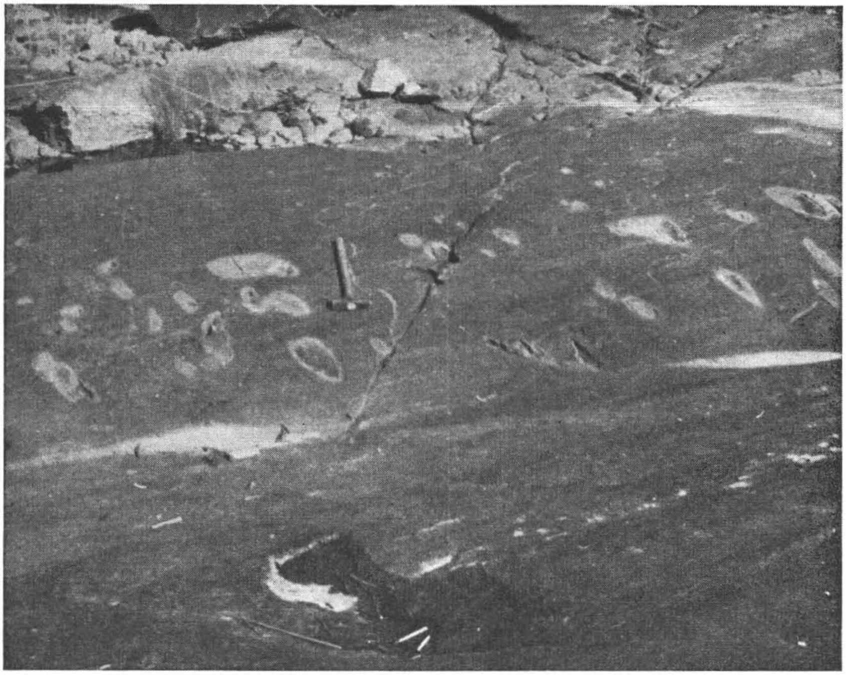

Fig. 5. Porphyroblastic mica schist containing globes rich in epidote. The porphyroblasts are pseudomorphs after andalusite. The globes probably originated as boudinaged lime-rich intercalations. They partly conform to the transverse schistosity nearly perpendicular to the layers. Himanka.

III. The best exposed outcrops of the porphyroblastic mica schist are found in the village of Hanni. All these mica schists are stratified. Porphyroblasts are in places so abundant that stratification is only dimly visible as if in the background. This makes it difficult to determine the base of the beds. Staurolite, cordierite and andalusite occur as porphyroblasts. Among the other minerals, quartz and biotite are most prominently present. In some instances the porphyroblastic mica schist contains globes rich in epidote. They are seen to be arranged in rows after the strata of the mica schist. Fig. 5 represents porphyroblastic mica schist containing such globes. The porphyroblasts are of andalusite. The mica schist displays transversal schistosity and the globes are seen to follow this schistosity conformably.

The staurolite porphyroblasts are crossed twins or single crystals. Their crystal form is always clearly evident. Most often they are small (Ø about 0.5 cm) and densely scattered.

The cordierite porphyroblasts are on the whole irregularly shaped lumps larger than the staurolite. Their Ø varies from 1 to 5 cm. A staurolite crystal may occur inside a cordierite porphyroblast and it looks corroded under the

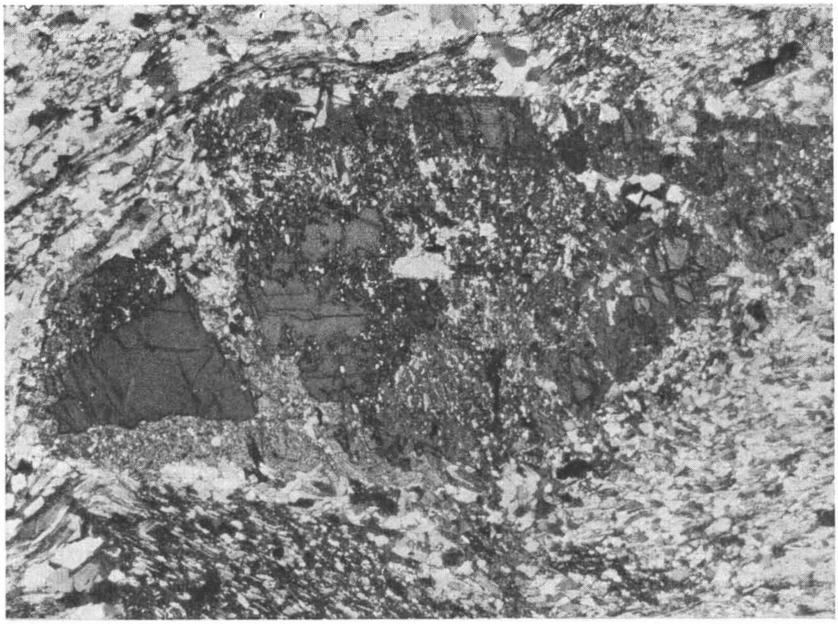

Fig. 6. Staurolite porphyroblasts partly passed into cordierite. Nic. +; 1:10. Hanni.

microscope, although the staurolite's crystal form still remains. The surrounding cordierite occupies a considerable part of its volume. A cordierite porphyroblast may even display the crystal form of staurolite, although the latter has completely disappeared. Fig. 6 shows such a staurolite-cordierite porphyroblast. The dark parts in the rhomb are remains of a staurolite individual, optically showing a parallel orientation, and the lighter parts are cordierite particles. In the lower part of the figure there is a cordierite porphyroblast resembling the crystal form of staurolite and being in fact a pseudomorph of staurolite.

Andalusite porphyroblasts are also fairly common. In reddish porphyroblasts with an andalusite crystal form, the andalusite could no longer be found either by means of an X-ray investigation or microscopically. The andalusite pseudomorph almost exclusively contains quartz-sericite particles, which replace the former andalusite. It is apparent that this is the alteration product of andalusite that originated as soon as the andalusite became unstable. Fig. 14 on p. 33 presents such an andalusite pseudomorph. It was taken of the sample from the village of Kantokylä, Ylivieska.

Porphyroblastic mica schists are rocks with an Al excess, the bedded structure of which bears evidence of a sedimentogeneous origin. In many places the enrichment of porphyroblasts in the Al-richer upper part of the beds bears witness to the sorting of material in the upper and lower part of the stratum. Most often the material was strongly argillaceous and the formation of porphyroblasts intense, thus leaving for the matrix scarcely 2/3 of the total volume of the rock. It is difficult to decide which material belongs to typical porphyroblastic mica schist as an intercalation or which to the graywacke-like schist in the alteration zones, where the graywacke-like schist still forms more than half of the total composition. In places where the porphyroblastic mica schist appears in its most typical habitus, about one-half of the stratum contains mainly sandy material. Here and there, the mica schist contains evenly distributed porphyroblasts to such an extent that the rock is homogeneous. In these cases the primary argillaceous material was so evenly distributed that the borders of the beds are not discernible. The mineral assemblage of the porphyroblastic mica schist is quite simple, including only a few grains of feldspar in addition to biotite, quartz and porphyroblasts. Its chemical composition is shown in analysis No. 22 on p. 64 made from andalusite mica schist.

IV. Graywacke-like schist is met with at both flanks of the isocline. Well exposed, it is seen in the village of Mutkalampi.

The minerals of the graywacke-like schist are mainly quartz, oligoclase, biotite, hornblende and, in rare cases, chlorite. Further, fine-grained quartz-feldspar schist occurs as fragments. The diameter of the fragments is less than 2 mm. Chemical analyses 10 and 11 (p. 63) show the composition of the graywacke-like schists of the Himanka isocline.

The graywacke-like schist seldom contains plain rock fragments, although there occur sharply broken quartz and oligoclase. Both kinds of mineral fragments are markedly larger than the clastic quartz-oligoclase matrix proper, with its Ø ~ 0.3 mm grain size. Biotite and hornblende occur recrystallized as somewhat larger individual crystals than the quartz-oligoclase mass. Chlorite is rarely present and occurs associated with biotite. Also epidote appears here and there. The conglomerate occurs associated with graywacke schist as intercalations. These layers are usually thin, mainly forming only one row of pebbles. The pebbles are of fine-grained, quartz-feldspar schist met with toward the plutonic massif at the NE border of the isocline. The thicknesses of the beds of graywacke-like schist vary from some millimeters to some centimeters. The bedding is remarkably distinct graded bedding and cross-bedding (Figs. 2 and 3, pp. 12—13). Several reliable determinations of the base of the beds were made of these schists. Determinations of the direction of current were also carried out. In a bed as thin as 0.5 m 3 to 8 different directions were measured.

V. Fine-grained quartz-feldspar schist (leptite) is best exposed in the village of Mutkalampi. The minerals of the quartz-feldspar schist are principally quartz and oligoclase. The amount of biotite varies but is always small. At the borders of the layers the dark line, which is clearly visible particularly on weathered surfaces, is caused by biotite. The colour is reddish grey on weathered surfaces but dark grey in a fresh break. The stratification is in some places clear, in other places so slight as to be scarcely visible. The quartz-feldspar schist is blastoclastic in its texture. Its chemical composition approaches the average of the arkose (Pettijohn 1949, p. 259). Analysis 16, on p. 64, was made from the Mutkalampi quartz-feldspar schist.

THE ALAVIESKA SCHISTS

The Alavieska schist zone is longish and tapers at both ends about 10 km NNW and SSE of the Alavieska church. At its broadest it is only a few kilometers. Its most characteristic rock type is fine-grained quartz-feldspar schist, which lies in the center of the zone and extends at both ends across its total length, thus giving the zone its elongated shape. Symmetrically at both sides of the quartz-feldspar schist, there occur graywacke-like schists with conglomerate intercalations. Outermost in the zone are pure mica schists, which contain as porphyroblasts Al-rich minerals like andalusite, almandine and staurolite.

Determinations of the base of the beds were successful in many places in the Alavieska schist zone. They were made of both the graywacke-like and quartz-feldspar schists with cross-bedding and of the porphyroblastic mica schist. Determination 33 (Map 2) was made of graywacke-like schist in which the cross-bedding and the gradation of the material show the base. There the border of the beds is sharp between the coarser basal material of a bed and the fine-grained top material of the underlying bed. Determination 34 derives from the lamellar-bedded quartz-feldspar schist, where the borders between the beds are similarly distinct. Determinations 35 and 36 were made from quartz-feldspar schist with slight cross-bedding. They are as reliable as the determinations just described, although the cross-bedding in these rocks appears sporadically and in smaller features than in graywacke-like schist. Bedded conglomerates are also met with here, their stratification revealing top and base. In them the tops of the beds usually consist of graywacke-like material. Downward the matrix gradually becomes coarser and the pebbles increase in size and number. Hence a sharp demarcation line is formed between the bottom of a bed and the top part of the next layer. Determination 37 was carried out with such conglomerate.

In the light of these determinations, the conclusion may be drawn that the Alavieska schist zone is structurally an anticline. In its main portion the anticline is closed to the extent that it has developed to the stage of an isocline, although more open portions do occur in it. Hence it will be referred to as the Alavieska isocline. The dips of its schist packs are 20—80° NE on

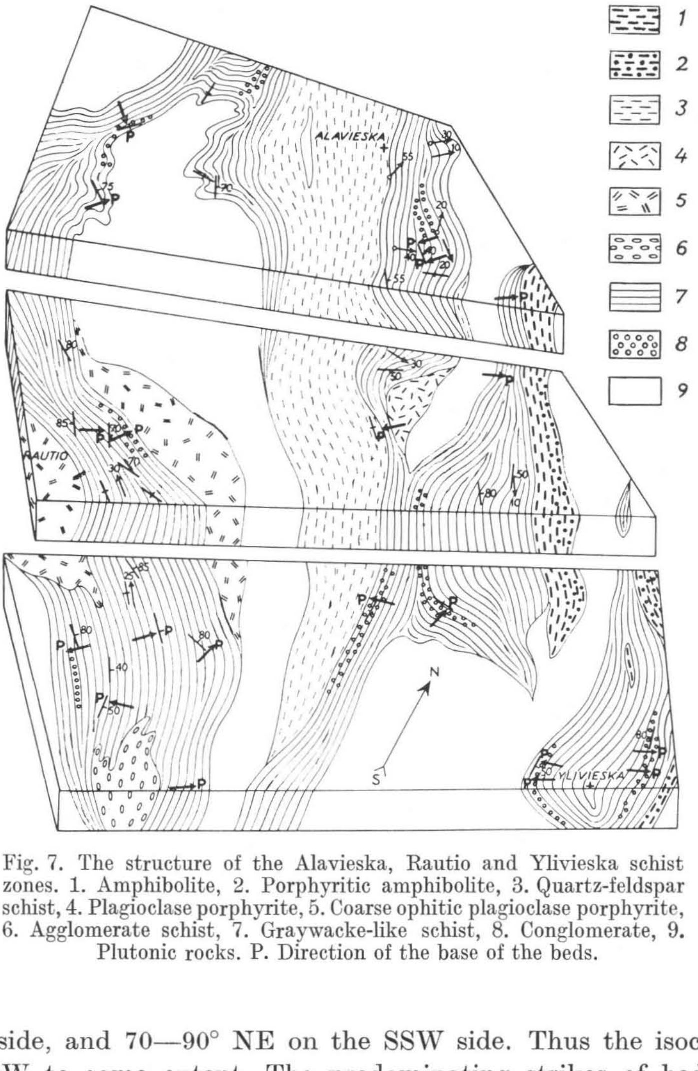

Fig. 7. The structure of the Alavieska, Rautio and Ylivieska schist zones. 1. Amphibolite, 2. Porphyritic amphibolite, 3. Quartz-feldspar schist, 4. Plagioclase porphyrite, 5. Coarse ophitic plagioclase porphyrite, 6. Agglomerate schist, 7. Graywacke-like schist, 8. Conglomerate, 9. Plutonic rocks. P. Direction of the base of the beds.

the NNE side, and 70—90° NE on the SSW side. Thus the isocline leans toward SSW to some extent. The predominating strikes of bedding and schistosity coincide with the trend of the long axis of the zone. The b-axis of folding could not be measured from the folds but, in view of the longitudinal form and symmetrical structure of the zone, the trend of the b-axis coincides with the longitudinal direction of the zone and its dip is fairly gentle at both ends of the isocline. The quartz-feldspar schist represents here a local culmination. The axial plane of the folding lies conformably with the long axis of the zone and the plane of bedding and schistosity. The bedding, which in the middle of the isocline closely adheres to the long axis of the zone, is disturbed along the borders in many places. Miniature cross-folding is often to be observed. For this reason, determination 38, which was made from the layer of the conglomerate, differs from the other directions of base in the isocline. The schistosity, on the other hand, remains fairly constant throughout the whole isocline and conforms to the axial plane of the main folding. The structure of the isocline is graphically demonstrated in Fig. 7. Included in the profile are the determinations of the base of the beds, presented on Map 2.

The quartz-feldspar schist in the middle of the isocline represents stratigraphically the lowermost horizon of the sedimentary rocks of the area. Upon it there lies graywacke-like schist, which includes conglomerate beds as intercalations. The uppermost layer in this isocline is noted to consist of porphyroblastic mica schist, which, particularly in the vicinity of the graywacke-like schist, becomes feldspar-bearing and includes oligoclase. In such cases, however, the formation of porphyroblasts is weak, and only garnet porphyroblasts appear. Oligoclase is lacking when the mica schist contains andalusite or staurolite porphyroblasts.

The stratigraphic sequence of the supracrustal rocks in the Alavieska isocline is thus from the youngest to the oldest:

I. Porphyroblastic mica schist;
II. Graywacke-like schist, which contains in its upper parts mica schist-like varieties and conglomerate beds as intercalations throughout the entire horizon;
III. Fine-grained quartz-feldspar schist.

I. Mica schist which contains remarkable amounts of different Al-rich minerals as porphyroblasts occurs as numerous outcrops toward E and SE of the Alavieska church (along the Kalajoki river). Similarly, such schist is met with correspondingly on the other side of the isocline about 4 km W of the Alavieska church S of the river, on the road leading to Kalajoki. Garnet and andalusite were observed with certainty as porphyroblasts in the mica schist of the eastern flank. The western mica schist contains staurolite as porphyroblasts. Andalusite occurs here, as in the Himanka schists, as pseudomorphs. Also in other respects the Alavieska mica schists resemble those of Himanka.

II. Graywacke-like schist represents the next sequence in the isocline. It is quite heterogeneous owing to changes in its structure and mineral composition. On the whole, the description of the graywacke-like schist of the Himanka isocline applies likewise to this rock. Noteworthy differences are to be seen in the conglomerate intercalations included in the graywacke-like schist of Alavieska, which are considerably thicker than in the graywacke-like schist of Himanka. A detailed description of these conglomerates is given in the corresponding chapter (see pp. 34—42).

III. The fine-grained quartz-feldspar schist lies in a zone 20 km long, at its center about 2 km broad, which tapers at both ends NNW and SSE of the Alavieska church. It is slightly stratified. The beds vary in thickness on the average from 0.5 to 5 cm. The borders of the strata are indistinct. Thus the determination of the base is impeded. The bedding is usually lamellar but in places cross-bedding is to be observed, indicating the base of the beds. The schistosity is weak and in the main runs conformably to the bedding of the zone; and the dips are vertical or steep NE, being 35—75° NE at the E border and 65—85° NE at the W border.

Measurement of the lineation is impeded by the small grain size of the material and the results are therefore unreliable. The lineation of the biotite and the hornblende seems to have a gentle dip.

The colour of the schist is usually somewhat reddish grey on the weathered surface, but it looks nearly black in a fresh break. Mineralogically the schist is a mica-bearing quartz-feldspar schist. The minerals are quartz, oligoclase, biotite; there are sporadic occurrences of chlorite, epidote, hornblende, muscovite and apatite; ore pigmentation also occurs, presumably causing the blackish-gray colour of breaks. The texture of the rock is granoblastic.

Quartz occurs (Ø=0.5—0.05 mm) as irregular grains comprising over 50 % of the total composition of the rock. Oligoclase appears as larger grains than the quartz and forms about 30 % of the total. In some cases it equals the quartz in amount. Biotite occurs as small scales without any noticeable orientation.

In many thin sections chlorite occurs at the borders of the biotite scales, sometimes also as separate grains. Epidote forms dim masses around the biotite and chlorite grains as may be seen in some thin sections. Hornblende is rare. Ore grains (sulphide ore) were found in a couple of sections, and muscovite in only one. Apatite appears here and there as small grains (Ø about 0.05 mm).

The proportions of different minerals vary markedly in different places and different beds. Plagioclase is rather abundant in some samples at the expense of quartz, in certain others the amount of biotite approaches that of the biotite of mica schist, while other samples have only traces of it. In such cases the other dark constituents are nearly lacking and the rock is very acid. The central part of the schist zone is noted to be in general more acid than the border parts. The latter begin to include more and more hornblende in their mineral assemblage. This phenomenon is visible particularly at the E border of the zone, which is well exposed. The primary material looks rather weathered in the central parts of the zone, while the border parts begin more and more to resemble a volcanogeneous ash sediment. In reality one may assume that the volcanic ash was here mixed with a material of far-advanced weathering. It is also possible that the graywacke-like schist, the next sequence, merges as intercalations into the lower horizon and causes the material to pass into another type.

THE RAUTIO SCHISTS

To the west of the Alavieska isocline lies a schist sequence with NNW—SSE trend. It is several dozens of kilometers long and 3 to 10 km broad. Its NW end is forked into two parts and its south end passes over the southern border of the map area. Called the Rautio schist zone it leans at its eastern border toward a longish granodiorite which protrudes from the Alavieska isocline. Its western side is similarly bordered by plutonic massifs. The predominating rock types of this zone are graywacke-like schists and porphyroblastic mica schists, which are symmetrically located with respect to the central part of the zone. This symmetry is most evident at the southern end of the zone. Agglomerate and porphyrite schists form the core there and symmetrically on both sides of them are mica schists and graywacke-like schists. At the NW end of the zone, quartz-feldspar schist occurs symmetrically against the granodiorite and it measures 1 km in thickness. Conglomerate intercalations occur particularly at the south end of the zone in the graywacke-like schist. Distinct basal directions can be seen in the outermost quartz-feldspar schists and conglomerates of the west side and in porphyroblastic mica schists. These directions are so unmistakable that it seems safe to assume that the formation has the structure of a syncline. It leans slightly toward the west. Since the beds dip on both sides as much as 80°, the synclines may be regarded as having in places the structure of an isocline. This can be verified especially at the southern end of the zone.

Determination 13 (Map 2) of the base at the NW end of the zone was done of a quartz-feldspar schist displaying slight cross-bedding. Numbers 14—18 represent graywacke-like schists with cross-bedding. Determinations 19 and 20, located at the east border of the zone, were obtained from porphyroblastic mica schists containing graywacke-like intercalations. Determination 21 is from a bedded conglomerate. Determinations 22—24 are from a graywacke-like schist with cross-bedding. Determination 25 was obtained from clearly graded quartz-feldspar schist. Number 26 is from porphyroblastic mica schist. Number 27 is bedded quartz-feldspar schist. Determinations 28—32 were carried out from porphyroblastic mica schist.

As far as the fold axes could be measured they were gently sloping. Thus the formation represents a slight depression of the main folding. Characteristic of the fold axis is its winding trend. It turns about 90° along a distance of 20 km, starting N-S and ending approximately E-W.

On the basis of the determinations just mentioned, the sequences of the syncline of Rautio, partly developed into an isocline, can be listed from the youngest to the oldest as follows:

I. Volcanogeneous schists comprising andesitic agglomerate and plagioclase porphyrite;

II. Porphyroblastic mica schist;
III. Graywacke-like schist;
IV. Graywacke schist with conglomerate intercalations;
V. Quartz-feldspar schist (leptite).

I. The agglomerate and plagioclase porphyrite sequence met with uppermost is most distinctly evident at the center of the south end of the syncline. The ejecta of agglomerate are epidotized to a great extent. In places the schist is metamorphosed to the extent that relict structures are no longer visible and the rock thus is amphibolite. In general this volcanogeneous belt is more metamorphosed than, e.g., the metavolcanics of the Himanka syncline.

II. Porphyroblastic mica schists occur most abundantly in the western parts of the syncline. Conspicuous is the great number of cordierite porphyroblasts, while staurolite porphyroblasts are rare, as is also andalusite. At the south border of the syncline, again, sillimanite porphyroblasts appear. They are found to have passed nearly completely into quartz-sericite particles.

III. The graywacke-like schist horizon proper underlies the mica schist. It occurs mainly in the southern parts of the syncline, where it forms several clearly defined beds. Cross-bedding is observed in many outcrops indicating the base of the beds. Lithologically this graywacke-like schist resembles that of the Himanka syncline and in all probability belongs with the latter to the same horizon.

IV. Downward the graywacke-like schist merges into graywacke with intercalated conglomerate beds. This conglomerate is particularly prominent in numerous outcrops on the NE border of the syncline a few km SE of the Rautio church. These conglomerates are described in greater detail on pp. 34—42.

V. The quartz-feldspar schist of the Rautio syncline is fairly much the same at both the northern and southern borders of the syncline. It differs from the Alavieska quartz-feldspar schist chiefly by its more marked bedding structure and homogeneity. Particularly at the SW border of the syncline, where the schist occurs as numerous outcrops, its bedding is so distinct that the base of the beds are easily and reliably measured. Also the north border of the syncline shows reliable primary structures. The construction of the Rautio syncline is largely revealed by these determinations. With regard to its mineral assemblage this schist resembles the acid parts of the Alavieska quartz-feldspar schist. The main minerals in it are quartz, oligoclase and biotite. Its chemical composition appears in analyses 12 and 15, p. 63.

THE YLIVIESKA SCHISTS

The separate schist belt E of the Alavieska schist anticline is here referred to as the Ylivieska schists. It is mainly composed of conglomerates with intercalated graywacke beds and of quartz-feldspar schist. Symmetrically along the lateral boundaries of the belt lie the Ylivieska conglomerates. Intercalated in them is a graywacke-like schist, which contains quite distinct cross-bedding structures. In the central part of the belt graywacke and quartz-feldspar schist beds predominate. Conglomerate exposures proper do not occur there. However, certain observations indicate the presence there of sparse mica schist beds with porphyroblasts.

Numerous reliable observations point to a synclinal structure (Map 2). Determinations 38—43 were made both from the conglomerates and the graywacke schists with cross-bedding and determination 45 from the porphyroblastic mica schist. In places, at the borders of the syncline, the graywacke schist seems to border directly on intrusive granodiorite the contact resembling veined gneiss. The conglomerates start from on top of this comparatively thin bed, and extend across wide areas as beds several meters thick containing intercalated graywacke schist.

Acid quartz-feldspar schists and graywacke schists alternate. This syncline is cut by a granodiorite "isthmus" 1 km broad, which lies west of the church of Ylivieska. The northwestern part, NW of the granodiorite, contains the same schists as occur to the SE of it. Evidently the fault cut the syncline in the NE-direction. The fault extends several kilometers, also horizontally. And indeed, if fault lines are sought in the aerial photograph, they may be seen here.

The schists at the Ylivieska end of the syncline, the form of which is well preserved, have a more gentle dip than the isoclines described earlier. The schists at its west border are less steep than the corresponding beds at the east border, where they are almost vertical. Dips of 50° W are common in the west border wall. Thus the syncline is not quite upright here but has a tendency to lean westwards. The direction of the b-axis of the main fold is here rather slightly inclined, because all the axial dips measured are less than 30°. Also the extension of the schists for dozens of kilometers supports the assumption that only a slight depression of the main fold axis occurs here.

The stratigraphic succession of the Ylivieska syncline is from the youngest to the oldest:

I. Volcanogeneous amphibolite;
II. Porphyroblastic mica schist;
III. Graywacke-conglomerate and quartz-feldspar schist.

I. It is not clear whether the smallish amphibolite belt, regionally associated with the central part of the syncline, belongs to the bed series of this syncline at all. As it is nowhere seen to cut the rocks of the syncline, it may be assumed to belong to the corresponding horizon with the volcanogeneous schists of the afore-described isoclines.

II. Porphyroblastic mica schist appears in the outcrops north of the large gabbro massif of Ylivieska. On good grounds they can be connected with the Al-rich mica schists met with elsewhere in the area (*cf.* pp. 15—17). Andalusite occurs as porphyroblasts in the village of Niemelä, but in Ylivieska also garnet and sillimanite are to be found. These porphyroblasts of different minerals do not, however, appear together in the same rock, but separately in different places.

III. About 2 km south of the Ylivieska church, graywacke schist occurs under the conglomerate beds near the boundary of the granodiorite. The contact with granodiorite is indistinctly intrusive. The appearance of the granodiorite becomes progressively more plutonic, both with regard to its texture and general structure, the farther one moves away from the contact, but it remains schistose against the border of the schist, with no distinct demarcation line. Characteristic of the contact are the conformable schistosity and regionally conformable bedding. The corresponding graywacke horizon is met with on the east border of the syncline against the volcanogeneous schists. It is difficult to determine precisely where the graywacke horizon passes into plagioclase porphyritic schist (amphibolite). The contact is indistinct and the transition seems to be a gradual one. These graywacke schists indeed show quite many features peculiar to porphyrite, for instance, zoned oligoclase occurs as fragments on both sides of the syncline. The main material of the rock is composed, furthermore, of crushed quartz and oligoclase with a scattering of rock fragments. It seems to represent a very ash-rich »sediment», or a graywacke containing very immature material.

The graywacke with conglomerate beds, the predominating bed on both sides of the syncline, is composed of Ylivieska conglomerates and a rather dense graywacke, whose composition and appearance in many places resemble those of arkose. The conglomerates will be treated in detail in a special chapter, being applicable to the conglomerates of all the isoclines described in the foregoing.

The schist zones of Alavieska, Rautio and Ylivieska constitute a unified totality in the center of the area investigated. Its structure is shown in Fig. 7, p. 19.

THE SCHISTS OF KANGAS-OULAINEN

A large schist field lies in the Kangas—Oulainen area. Its north end extends over the boundary of the area investigated, and its SE end sweeps in a wide curve as far as the village of Kantokylä in the commune of Ylivieska. The most significant part of this field is a large occurrence of volcanogeneous schists in the vicinity of the railway station of Kangas.

Particularly at the north border of the occurrence, many well-exposed outcrops bear witness to the reliability of the map. Gently sloping (20—45°) beds lie conformably on both sides of the elliptical zone. Thus the synclinal structure of the formation appears substantiated although the base of the beds could not be determined. The long axis of the ellipse, which coincides with the trend of the b-axis of the main folding, runs NW—SE, and it has a prominent depression at the site of the syncline. The SE end of the synclinal basin is more distinct than the corresponding NW end, where the lack of outcrops to some extent hampers the forming of a true map picture.

This synclinal belt, which is not more than about 20 km^2 wide, proves upon closer examination to be only part of a larger zone, also having a synclinal structure. About 10 km SE of Oulainen, various sedimentary schists are abundantly met with. Their comparatively thin beds follow in a wide curve the volcanogeneous schists through the village of Kantokylä as far as the north side of Raudaskylä, continuing from there due west to a point near Ylivieska. These schists belong to the lower horizon of the extensive syncline formation. The observations made of the primary structures from the SE side of Oulainen along the entire length of this great sedimentary curve enable one to obtain a reliable picture of the structure of this formation. It is true that, owing to the lacking determinations of the base of the beds SW and W of the Kangas railway station, the syncline remains undetermined. Determinations 44, 46, 49 and 50 were obtained from porphyroblastic mica schist and 47, 48, 51—54 from graded quartz-feldspar schists.

The special features of the Kangas—Oulainen volcanite syncline reveal it to be an open syncline. The dipping angles of the schist packs are gentle, particularly in the uppermost part of the syncline in the environs of the Kangas railway station (25—40°). The sketch (Fig. 8) on p. 27 demonstrates the structure of this syncline.

The best idea about the stratigraphy of the Kangas—Oulainen syncline may be obtained by following its extreme NE border about 10 km SE of the church of Oulainen. Porphyroblastic mica schist of the same type as the mica schist of the Ylivieska syncline here underlies the volcanogeneous schists. Below it is a horizon comprising conglomerates and graywacke schist corresponding to the Ylivieska conglomerate-graywacke schist. Here it includes additional quartz-feldspar schists. Immediately overlying the mica schist are coarse uralite and plagioclase porphyrites, which evidently represent beds of lava rocks. These are further observed to contain alternating acid beds of lava rocks and bedded acid tuffites (pp. 27-31). Higher up the bed series

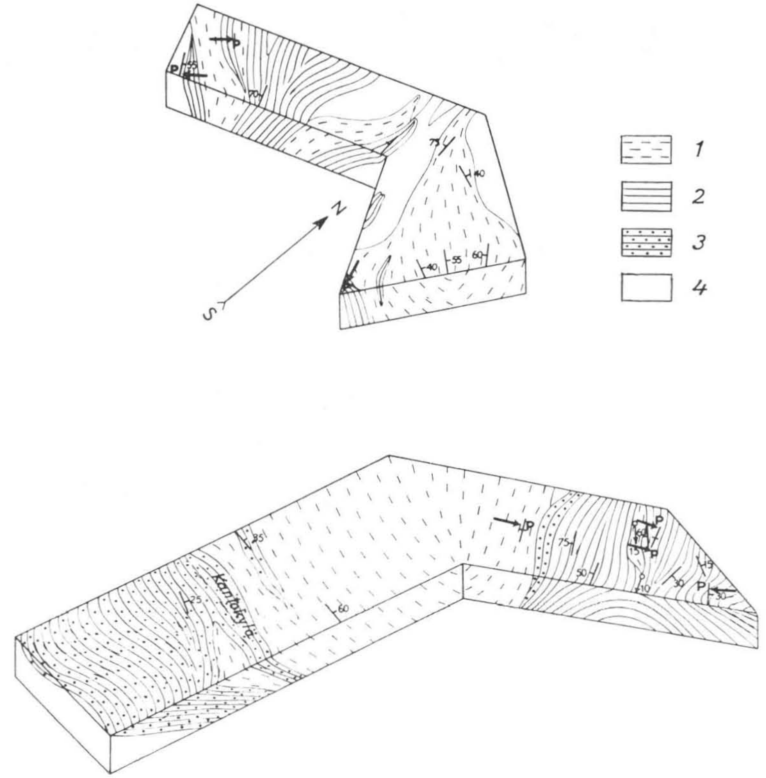

Fig. 8. Sketch of the structure of the Kangas—Oulainen syncline. 1. Volcanic schists, 2. Graywacke-like schists, 3. Porphyroblastic mica schist, 4. Plutonic rocks.

becomes increasingly dominated by tuffites. Included to some extent are small-grained porphyrites containing hornblende phenocrysts and, uppermost, stratified intermediary and acid pyroclasts.

Two excellent examples of outcrops where determination of the base is easy are shown in Figs. 9 and 10. Both are from the area outside the northern border of the map used in this paper, but they do lie within the northern limit of the Kangas—Oulainen syncline.

The sequence of the Kangas—Oulainen syncline from the youngest to the oldest is as follows:

I. Volcanogeneous schists;
II. Porphyroblastic mica schist;
III. Conglomerate-graywacke schist;
IV. Arkose-like bedded quartz-feldspar schist.

I. As already mentioned the uppermost horizon of the Kangas—Oulainen syncline contains a varied assortment of volcanics. Next above the mica schist there seems to be coarse uralite and plagioclase porphyrite beds. The

Fig. 9. Graywacke-like schist with cross-bedding, which readily yields the direction of the base. 1: 4. Merijärvi.

texture of these porphyrites is ophitic in many places or the rocks resemble plutonites. Starting from this bed is a more varied volcanogeneous one made up of more acid components and rocks with an andesitic-basaltic composition. Dense acid tuffites and porphyrites lie as quite narrow intercalations between basic, nearly amphibolitic, yet small-grained schists with plagioclase or hornblende phenocrysts. Even if the rather gentle dip of the beds is taken into consideration, these volcanic schists are altogether about 1 km thick.

The uralite porphyrite contains uralite as well-preserved phenocrysts (Ø = 0.5—1.0 cm). Its best outcrops are met with to the east of the Kangas railway station. The crystal forms of augite are here detectable with the naked eye and microscopically it can be seen that the uralite crystals still contain some unchanged augite at their centers. The majority of the uralite porphyrites are fairly coarse. The grain size of the ground mass is of the order of

Fig. 10. Graywacke-like intercalations with cross-bedding in conglomerate. The conglomerate cobbles turn gradually larger in size from top toward the base of the layers. 1: 4. Merijärvi.

Ø—0.5 mm, and the texture is markedly ophitic. The chemical composition of the rock is shown by analysis 1 on p. 63. The uralite porphyrites are located in the proximity of gabbros. Often an ophitic transition variety may be observed at the borders between the uralite porphyrite and the gabbro.

Plagioclase porphyrite occurs as two main types: ordinary plagioclase porphyrite and — ophitic plagioclase porphyrite.

Both plagioclase porphyrites appear side by side and they are seen to pass into each other without any sharp contacts. The chemical composition of both porphyrites are principally alike (anal. 2—4, p. 63).

Also the mineral composition is alike. They contain mainly andesine, hornblende, biotite and small amounts of quartz. The principal difference is in the texture. The ophitic plagioclase porphyrite also has an ophitic ground mass. Andesine phenocrysts are frequently present. They are clearly visible in the weathered surface, and the length of the longitudinal section of the laths is 1—2 cm. Sometimes the phenocrysts appear orientated in a certain direction in which case the rock is slightly schistose.

The ground mass of the ordinary plagioclase porphyrite is almost granoblastic. Andesine phenocrysts are abundant. Their longitudinal sections are short and prismatic, a feature peculiar to them (Ø about 0.5 cm). The ground mass of both porphyrites is fairly small-grained (Ø about 0.5 mm).

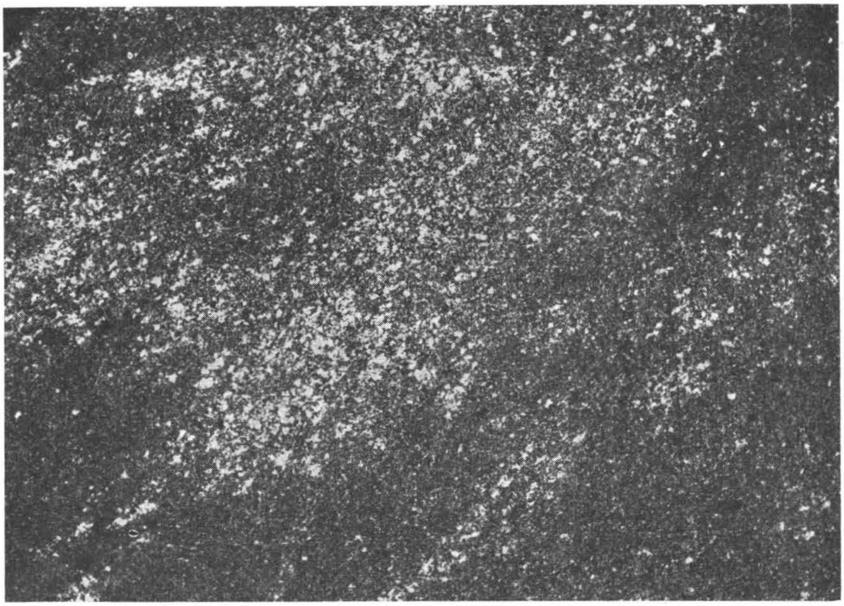

Fig. 11. Dense tuffite. Nic. +, 1: 10. Oulainen.

The field of volcanogeneous rocks includes a widely distributed, slightly banded rock with hornblende phenocrysts. It occurs as an elongated area, which lies to the west of the Kangas railway station and continues across the whole volcanogeneous field. This rock is markedly paler on the weathered surface than are the uralite porphyrites proper. The rock contains abundant biotite, which nearly equals the hornblende in amount. Also quartz occurs in considerable abundance, and the composition of the plagioclase is between that of andesine and oligoclase. The rock in all probability originated as a dacitic ash sediment.

Particularly at the north and south ends of the volcanogeneous field, there occur hornblende-rich schists, amphibolites, in which relict textures are completely lacking.

About 7 km NNE of the Kangas railway station there occur dense, acid volcanics as longish portions conforming to the general trend. Individual minerals or textural relicts cannot be detected with the naked eye. Microscopically the texture of the rocks gives a rather confusing picture, owing chiefly to the ore pigmentation. A crystalline, granoblastic texture looms as a dimly visible background. The grain size is roughly in the Ø ~ 0.03 mm class, thus rendering recognition of individual minerals microscopically difficult (Fig. 11). Yet quartz, potash feldspar and biotite can be identified. To the

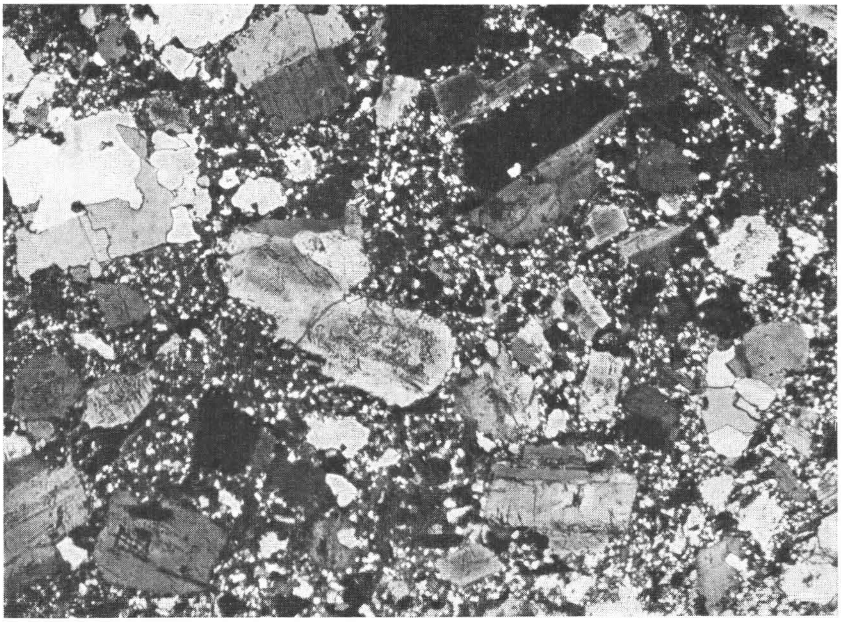

Fig. 12. Porphyrite from the contact zone between the volcanogeneous and sedimentary schist. Nic. +, 1: 10. Ylivieska.

SE of these schists, there occurs a dense feldspar porphyry with quartz and potassium feldspar present as phenocrysts (Ø about 0.5 mm). The form of the phenocrysts is irregular, and the ground mass is of the same order of grain size as in the dense schist described in the foregoing. Both of these dense schists are associated regionally with the other volcanogenenous rocks of the Kangas area, and are, in all probability, comparable in age with them.

In the contact zone between the volcanogeneous schists and graywacke schists in Ylivieska there occurs a homogeneous rock similar to plagioclase porphyrite (Fig. 12), which contains oligoclase and quartz as phenocrysts. Oligoclase and quartz predominate in its ground mass. The mafic constituents include both hornblende and biotite. The composition of the rock corresponds most nearly to that of dacite. Some relict clasticity is, however, to be seen in the ground mass. Hence, it remains undecided whether the rock belongs among true volcanogeneous schists or whether the volcanogeneous ash material has partly mixed with disintegration products.

II. Porphyroblastic mica schist is an essential part of this syncline. Andalusite, garnet, cordierite, and staurolite are the porphyroblasts. Thick beds are met with particularly in the southern part of the syncline. The lack of exposures makes it difficult to determine the borders of the schist on the

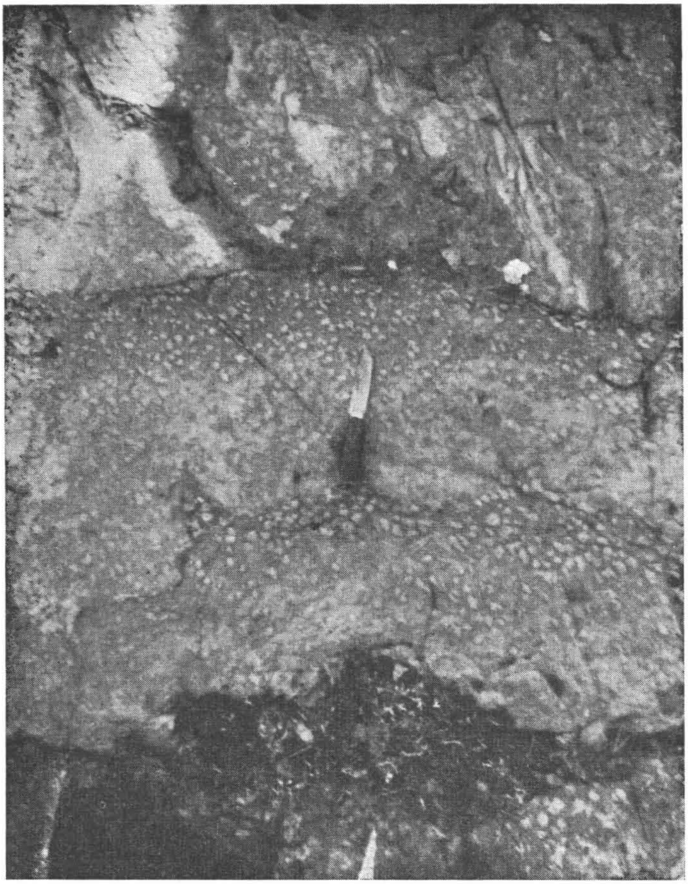

Fig. 13. Porphyroblastic mica schist. The porphyroblasts, andalusite pseudomorphs, are more densely scattered in the upper part of the layers. Transverse schistosity nearly perpendicular to the layers has caused the borders of the layers to wind. Kantokylä, Ylivieska.

map. The schist outcrops on the SE side of the syncline readily yield the base of the beds (Fig. 13). The thickness of the beds and the marked differences between the sandy and clayey parts of the strata make it possible.

The reddish colour peculiar to andalusite is visible in these porphyroblasts, as is the relict crystal form, too (Fig. 14). Yet the original mineral is seldom. to be observed in them, for they are filled mainly with quartz and sericite Garnet porphyroblasts, almost entirely lacking in the other schist zones of the area, are here quite common. Garnet (almandine) occurs as comparatively small porphyroblasts, the diameter of which seldom exceeds 0.5 mm. Also staurolite occurs here as porphyroblasts, which are not as distinct as the beautiful cross twins of the Himanka zone. Cross-bedding and schistosity

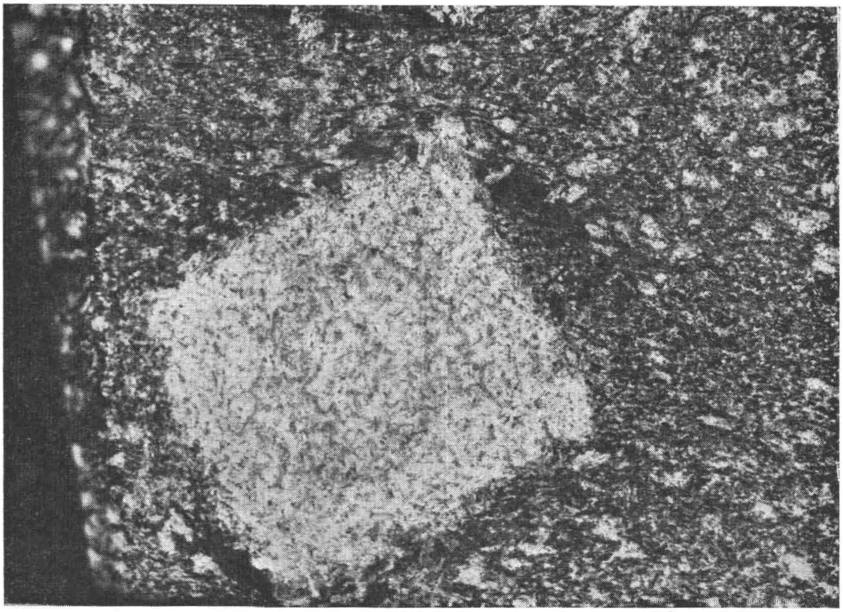

Fig. 14. Andalusite pseudomorph in mica schist. The circular dark band visible in the center of the crystal is due to the primary hour glass structure of andalusite. Andalusite has passed into a mixture of quartz and sericite. 1: 4. Kantokylä, Ylivieska.

are characteristic of the sandy parts. The mica schist on the south side of the syncline, on the other hand, occurs as thin beds with frequent cordierite porphyroblasts. Sillimanite porphyroblasts are also present. The vagueness of the beds here impedes determination of the base. These mica schists resemble the cordierite-bearing mica schists of the Himanka and Rautio synclines.

III. Conglomerate-graywacke schist underlies immediately the porphyroblastic mica schist just mentioned. This conglomerate is entirely comparable with other conglomerates within the formation (see pp. 34—42). Far-advanced schistosity renders determination of its lithological composition more difficult than is the case with the better preserved Ylivieska conglomerates.

Particularly at the east and south borders of the volcanic schist field there are graywacke schists which resemble the graywackes of Rautio and Himanka. In places, conglomerates, to be described later, are associated with them (see pp. 34—42).

IV. The arkose-like bedded quartz-feldspar schist, which is found in many places in the widely curving SE end of the syncline, is best visible about 10 km SE of Oulainen. It can next be connected with the quartz-feldspar schist, which occurs as the lowermost horizon in the afore-described Alavieska anticline and in the Rautio syncline. It represents the total composition of the arkose, and is a distinctly schistose rock which readily yields determinations of the base.

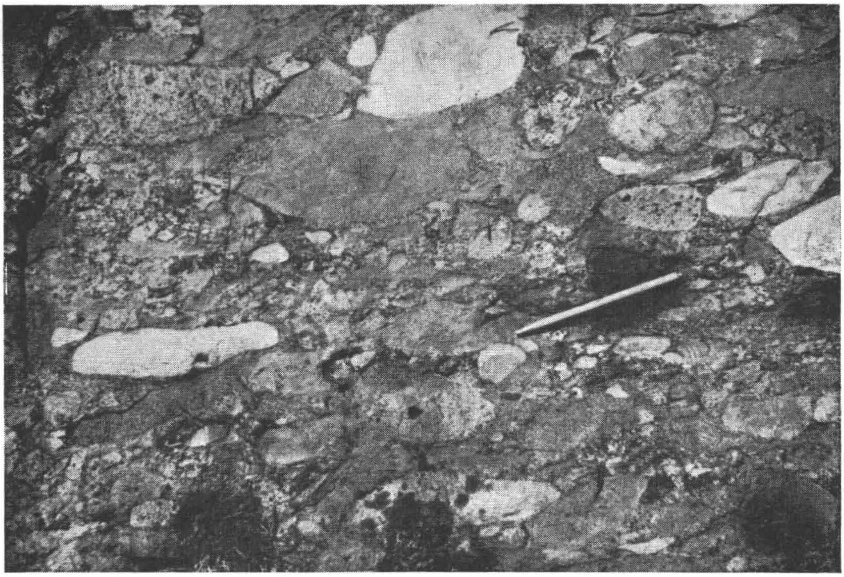

Fig. 15. Ylivieska conglomerate. Pebbles mainly volcanics and quartz-feldspar schist.

THE CONGLOMERATES

In addition to the two conglomerate belts of Ylivieska described by Mäkinen (1916), several other occurrences have been found in connection with new geological mapping operations.

In the vicinity of the village of Niemelä, Ylivieska, a conglomerate is exposed in many outcrops, which appear on the map as three different occurrences north of the large gabbro massif in Ylivieska. Similarly, west of the Alavieska schist zone, two main conglomerate occurrences are to be seen following the border of the schist zone. The eastern one has a westerly extension, which is known from earlier maps. There are small occurrences between Oulainen and Ylivieska east of the railway and about one kilometer SE of the Alavieska church and in the commune of Himanka.

Lithologically, both of the Ylivieska conglomerate deposits belong to the same type. In both, similar volcanogeneous rocks occur as pebbles, although the main material of the pebbles in both cases is an acid quartz-feldspar schist, which is arkose in composition and entirely granoblastic (Fig. 15).

Marks of stratification are to be seen there and consequently it must have originated as a sedimentary rock. Especially the plagioclase porphyrite and hornblende porphyrite pebbles are easily recognizable as volcanogeneous rocks. Both vary in degree of coarseness and in type. Plagioclase porphyrite also

Fig. 16. Intercalated conglomerate in graywacke-like schist. The pebbles of quartz-feldspar schist are cemented to resemble graywacke schist. Ylivieska.

occurs as a coarse ophitic variety, which is always easy to recognize and is well preserved. In all probability the majority of the hornblende porphyrites may be referred to the genuine uralite porphyrites. Mica schist pebbles are met with seldom. Quartz pebbles are here found in places.

Generally the conglomerate is rather unhomogeneous. Intercalated are ɛrkose-like schist and graywacke-like schist.

The matrix corresponds in its composition mainly to graywacke, in which the part played by hornblende is considerable. The texture is blastoclastic and the amount of quartz is quite large. The chemical composition is shown by analysis 26 on p. 64.

Among the conglomerate occurrences found west of the village of Niemelä in Ylivieska, the middle one differs remarkably, owing to the lithology of its pebbles, from the conglomerates just described. There the quartz pebbles account for the great majority. Ranking second in amount are quartz-feldspar pebbles similar to those in the Ylivieska conglomerates, and volcanogeneous pebbles form a minority. The pebble calculation below (1552 specimens) shows these relations:

— quartz	58.7 %
— quartz-feldspar schist	32.7 %
— plagioclase porphyrite and other porphyrites	8.6 %
	100.0 %

Also in this conglomerate the matrix is graywacke, which is hornblende-bearing and contains mainly plagioclase and quartz. Hornblende has accumulated as a cluster-like aggregate. Some relict clasticity is seen in the pale-coloured mass, and the stratification of the rock is distinct. Intercalated between the conglomerate beds is some graywacke with cross-bedding.

Conglomerates occurring on both sides of that of Niemelä resemble more closely those of Ylivieska than the ones described in the foregoing. The lithology of the pebbles is more complicated and the matrix contains noteworthy amounts of hornblende.

West of the quartz-feldspar schist zone of Alavieska the pebbles of the conglomerates closely resemble those of the Ylivieska conglomerates. Most often the numerical superiority of the quartz pebbles is striking. According to a calculation made with respect to an occurrence on the south side, the pebbles (222 specimens) occur in the following proportions:

— quartz	30.5 %
— quartz-feldspar schist	15.5 %
— plagioclase porphyrite	14.0 %
— uralite porphyrite	12.0 %
— amphibolite	25.0 %
— quartz pebbles rich in epidote	3.0 %
	100.0 %

Another calculation (199 specimens) some kilometers to the north of the former place:

— quartz	17.5 %
— quartz-feldspar schist	64.5 %
— plagioclase porphyrite	2.5 %
— uralite porphyrite	2.5 %
— amphibolite	10.0 %
— quartz pebbles rich in epidote	1.0 %
	100.0 %

The matrix in both these rocks is clearly a clastic schist resembling graywacke.

Of these two conglomerate occurrences, the north end of the southern one has turned E—W. This is to be observed on the roadside about 5 kilometers from the Rautio church in the direction of Kalajoki. It contains the most acid combination of pebbles ever seen in the conglomerates of the

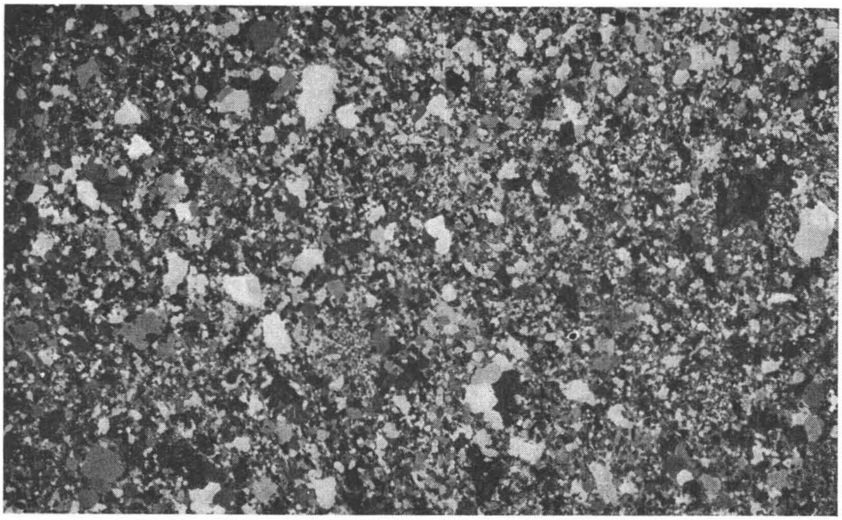

Fig. 17. Arkosite pebble of conglomerate. Nic. +, 1: 10. Ylivieska.

district. On good grounds it can be designated as a quartzite conglomerate. The majority of the pebbles are quartz pebbles and only a very small number are quartz-feldspar schist pebbles. Also the matrix is quartzite.

Between Oulainen and Ylivieska, E of the railway there occurs a conglomerate which resembles those of Ylivieska in every way.

The conglomerate occurrence about 1 km south of the Alavieska church is most nearly comparable to the one towards the SE and to the aforedescribed middle occurrence of Niemelä village.

Many graywacke schists show quartz-feldspar schist pebbles in the intercalated layers. Such conglomerates occur at the north border of the Himanka and Ylivieska schist zones and in some other places in the graywacke schists of the district (Fig. 16).

The pebbles of the conglomerates described include only supracrustal rocks and granulated quartz. The diameters of the pebbles vary from 2 mm to 10 cm. Occasionally even larger pebbles are found in the Ylivieska zone, with Ø as much as 20 cm.

The quartz-feldspar schist, which occurs as pebbles in all the observed conglomerates, is entirely granoblastic and dense in texture. Its grain size is of the Ø 0.05 mm order. In chemical and mineralogical composition, it is arkose (anal. 25, 27; Fig. 17). The proportional amounts of quartz and feldspar in the pebbles vary locally. The rock corresponds approximately to the acid parts of the Alavieska quartz-feldspar schist. In this schist, as in places in the pebbles of the conglomerate, the dense varieties are common. Especially

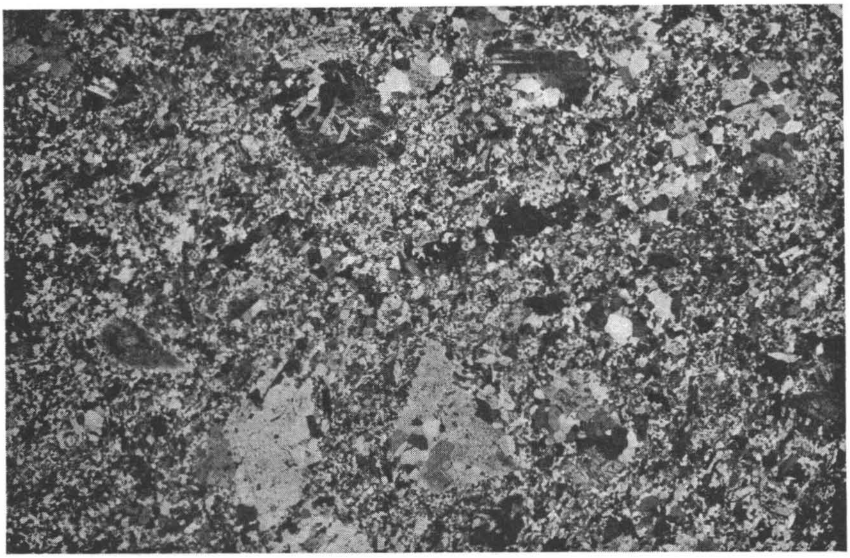

Fig. 18. Graywacke-like pebble of conglomerate. Nic. +, 1: 10. Ylivieska.

in the conglomerate located east of the Ylivieska syncline, pebbles resembling graywacke are often met with (anal. 24, Fig. 18).

Quartz pebbles forming the main part of some conglomerate occurrences are of quartz which has become granulated into a fine-grained form.

Mica-schist pebbles are rather scarce.

Plagioclase and uralite porphyrite pebbles are fairly common. Especially in the zones of Ylivieska, they occur as many varities. They could be compared with the porphyrites of numerous varying types located NE of the church of Ylivieska. One of the best-known types is a coarse ophitic plagioclase porphyrite, a few pebbles of which occur in the conglomerate belts of Ylivieska and Alavieska (Fig. 19). Similar coarse ophitic porphyrite is to be seen here and there throughout the whole area, sometimes cutting dyke-like uralite porphyrite or gabbro, sometimes gradually merging with them. The amphibolite pebbles mainly contain hornblende and plagioclase. They are mass-like or schistose, but it cannot be said that they represent as such any of the rock types proper occurring in the area. The metamorphic recrystallization has apparently caused them to change.

The pebbles rich in epidote found in the conglomerates do not represent any rock type in the area. The pebbles rich in epidote may have evolved from the lime-rich intercalating layers by means of boudinage (Fig. 20). At least the conglomerate E of the Alavieska schist zone contains an abundance of lime-rich material as intercalating beds.

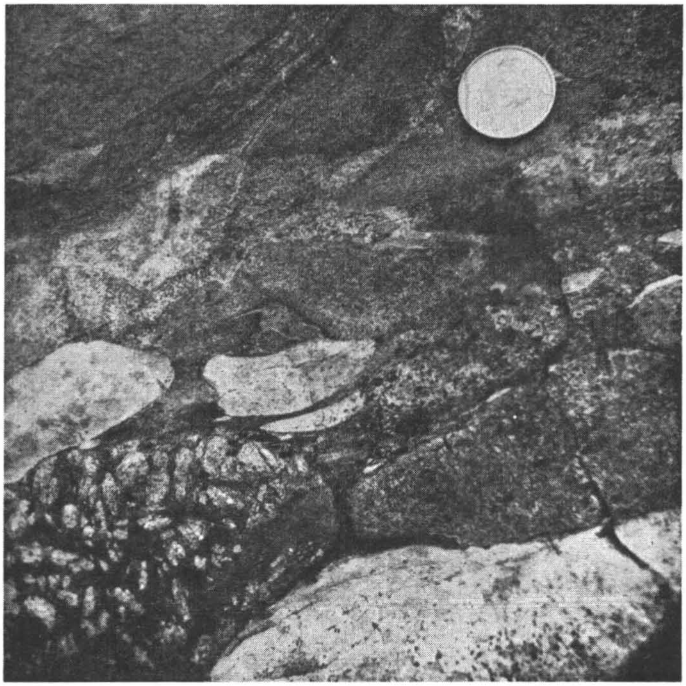

Fig. 19. Pebble of coarse ophitic plagioclase porphyrite in conglomerate. Ylivieska.

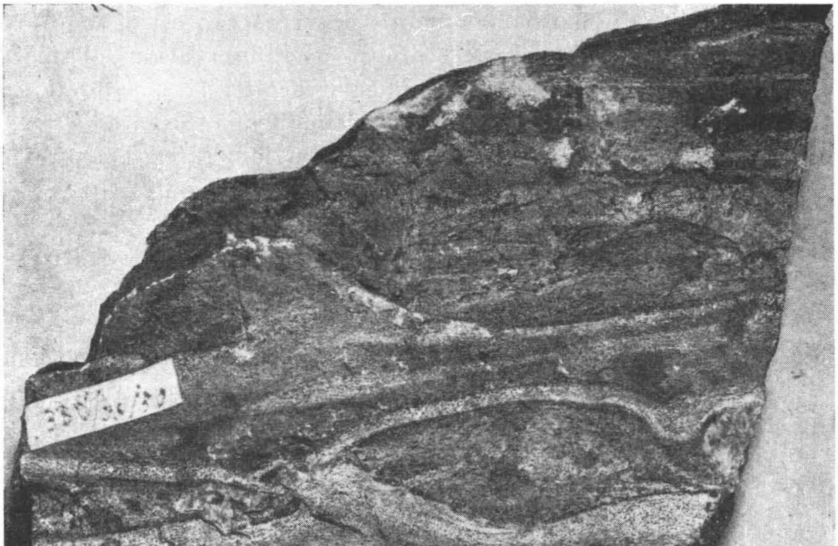

Fig. 20. Boudinaged intercalations in conglomerate. Epidote indicates richness in lime. Alavieska.

These conglomerates generally show a distinct stratification. The phenomenon is caused by the varying size of the pebbles in different parts of the beds, or by the difference in grain size between the pebbles and the graywacke schist in the bed. This enables determination of the direction of the base of the beds. When other schists, like quartz-feldspar schist or mica schist, occur as intercalations between the conglomerate beds, differences in coarseness can be observed in the conglomerate beds. Most often the conglomerate bed starts with large pebbles (Ø 20 cm) and ends with a graywacke portion. Cross-bedding is often characteristic of the graywacke schist (Fig. 16).

The bedding is often steep. A gentler than 60° bedding dip has not been found in the conglomerate occurrences. Transverse schistosity is met with particularly in the conglomerates of Niemelä.

The conglomerate occurrences of Ylivieska form two separate zones, between which lie various other schists. In view of the observed direction of its base, this formation may be considered to have a synclinal structure. It leans its eastern flank towards an extensive field containing volcanogeneous schists, while its western flank is in contact with granodiorite. The conglomerate beds dip steeply and the whole syncline leans to some extent westwards (see p. 24).

The conglomerates of Niemelä lie in the neighbourhood of the north end of the large Ylivieska gabbro massif. Particularly in these conglomerates, the transverse schistosity is evident, being approximately perpendicular to the bedding in the middle occurrence.

The two more significant conglomerate occurrences west of the Alavieska quartz-feldspar schist zone are, according to the observations of their base, located above the Alavieska quartz-feldspar schist. It is true that their beds tilt westward, but then the whole anticline leans the same way.

The pebbles have been elongated in all the conglomerates. The proportions of elongation of the pebbles vary. Whereas the elongation in the NE occurrence of Ylivieska is 2x, it is 3—4x in the middle occurrence of the village of Niemelä. In general, the average elongation can be stated as 2—2.5x. The elongation can be attributed to flattening and rolling (Figs. 21 and 22).

The thicknesses of the Alavieska conglomerate occurrences vary considerably. Whereas the Himanka conglomerate bed containing quartz-feldspar schist pebbles is only a few meters thick, the Ylivieska conglomerate extends some hundreds of meters in thickness. It is conceivable that miniature folding had caused the Ylivieska conglomerate bed to swell. Because reversed directions of base were not observed the present thickness of the bed must be considered to be of the original order.

As these conglomerates never contain any pebbles of plutonic or migmatic rocks and never seem to have been deposited upon a known basement, but

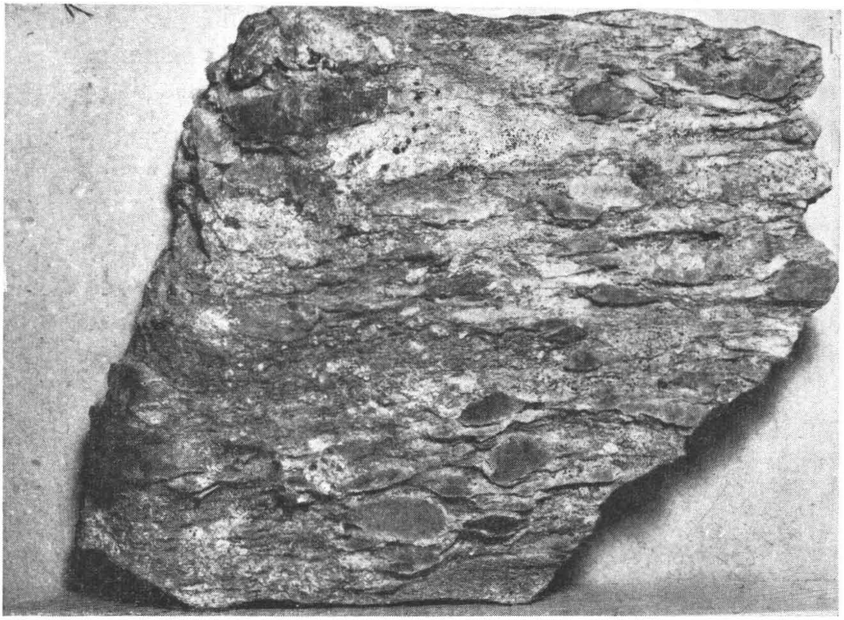

Fig. 21. Conglomerate pebbles elongated by flattening and gliding. Niemelä, Ylivieska.

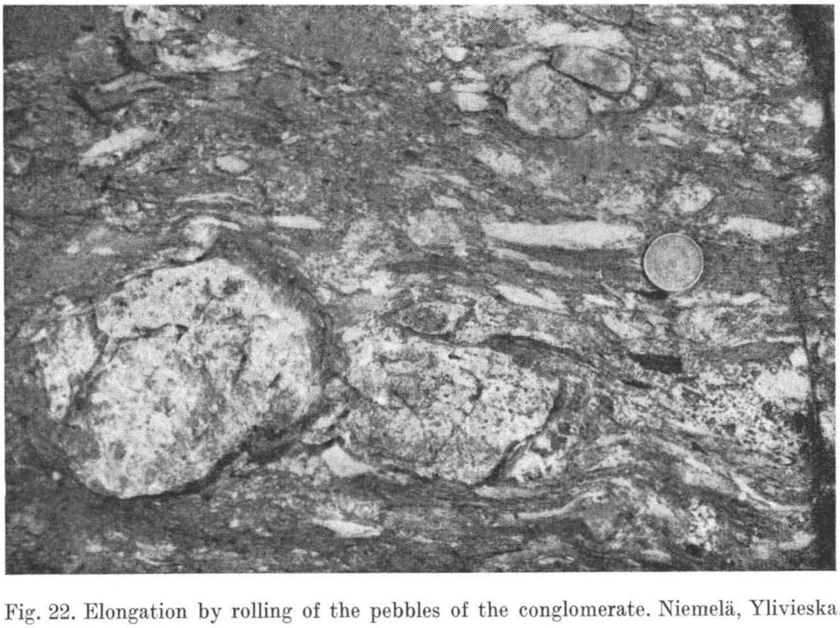

Fig. 22. Elongation by rolling of the pebbles of the conglomerate. Niemelä, Ylivieska.

lie in all cases conformably upon the schists belonging to the same group, they cannot be considered as basal conglomerates of the formation. They are local in character and lie immediately adjacent to the other schist series of the area.

CONDITIONS OF SEDIMENTATION

The tables (1—3, pp. 62—64) and diagrams (Figs. 23 and 24) were consulted while studying the chemical and petrographic composition of the sedimentogeneous rocks of the area in the light of chemical and planimetric analyses. The chemical analysis reveals that the composition of the small-grained rocks identified as quartz-feldspar schists corresponds completely to the average composition of arkoses as reported by Pettijohn (1949, p. 259). The microtexture of these rocks is granoblastic or blastoclastic and the grains measure less than 0.5 mm in diameter. The triangular diagram (Krumbein and Sloss 1951, p. 130) in which the mineral composition of several typical quartz-rich rocks of fine grain or medium coarseness are plotted, shows that the composition points fall in a clearly limited area of the field, which occurs along the border of the graywacke-arkose fields. Only two of them fall in the arkose field while the others clearly lie in the graywacke field. By selecting the more acid-looking among the fine-grained quartz-feldspar schists, the chemical composition generally turns out to be arkose. If such rocks are taken that apparently contain some micas and perhaps chlorite or hornblende, the analysis results in a graywacke composition. The last-mentioned group clearly predominates in area. The smaller-grained rocks with a graywacke composition scarcely contain rock fragments, but sharply angular and fragmentary feldspars and quartz do appear and the texture approaches the clastic. On the other hand, the coarser rocks with a graywacke composition contain rock fragments in varying amounts.

The merging of graywackes, arkosites and mica schists in the same sedimentary sequence represents a gradual transition. As a connecting link between the arkosite and graywacke schists, there exists an even-grained schist without any rock fragments. It contains micas about a third of its total composition, and about equal amounts of quartz and feldspars. The composition point of this schist falls in the graywacke field and the chemical analysis also indicates graywacke. The graywackes and mica schists either merge into each other gradually or they are interbedded. The porphyroblastic mica schist represents material rich in argillaceous material. The abundance of Al-rich minerals crystallized as porphyroblasts (andalusite, cordierite, staurolite, almandine) here demonstrates excess of Al in the sediment (anal. 22). The presence of argillaceous material in certain horizons proves undisturbed conditions in the sedimentation basin and the existence of a deep sea. Espe-

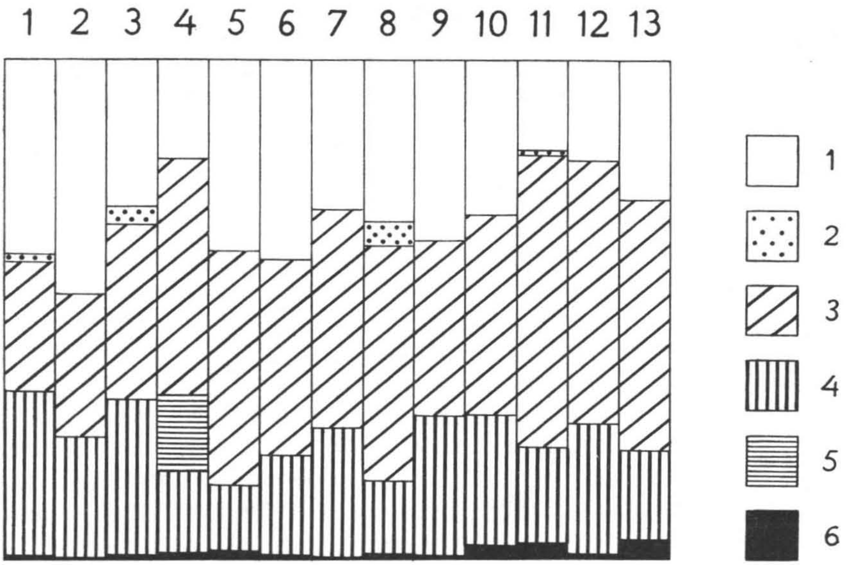

Fig. 23. Compositions (planimetric analyses) of some acid schists of the Ylivieska—Himanka area.1. Quartz. 2. Potassium feldspar. 3. Plagioclase. 4. Biotite. 5. Hornblende. 6. Accessories.

cially in the Himanka schist belt numerous such stages of interbedding are to be found. Since the graywacke must be considered as a shallow sea sediment, the Himanka zone evidences rhythmical alternations of the transgression and regression of the sea. The lowermost fine-grained quartz-feldspar schist, which contains a great amount of quartz, may also be assumed to be a shallow water sediment.

The amount of volcanic matter in the sedimentary rocks of the area is difficult to estimate reliably. Yet its existence cannot be denied. The same is proved by the great number of volcanogeneous pebbles in the conglomerates. It must be assumed that also the finer-grained material, like the matrix of the conglomerates and the graywackes, contains volcanic material. There is more volcanic material in the uppermost bed of the Ylivieska belt than of the Himanka belt, where a mica schist—graywacke complex dominates.

Estimation of the sedimentary beds, especially in the Himanka belt, produces rather high figures:

fine-grained quartz-feldspar schist	200— 500 m
graywacke-mica schist	3 000—3 500 m
metavolcanics	200— 500 m
	3 400—4 500 m

These thicknesses may be considered correct only in terms of their order of magnitude, for later changes cannot be taken into account here.

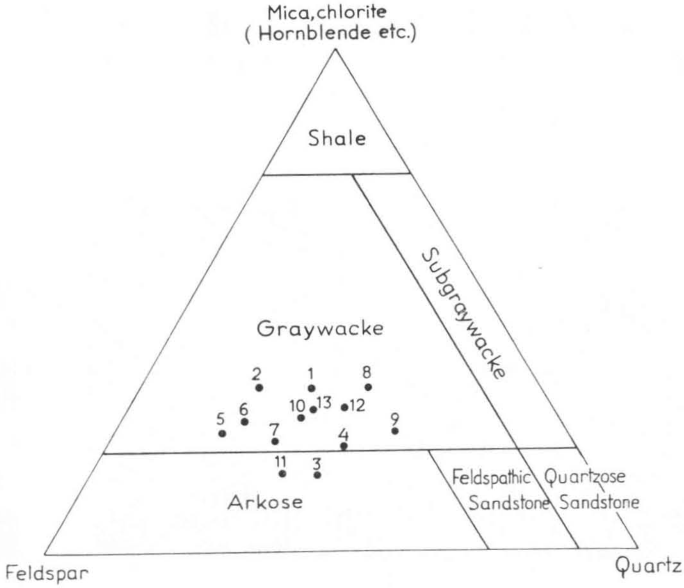

Fig. 24. The planimetric analyses plotted in the triangular diagram by Krumbein and Sloss (1951, p. 130).

When the character of the sedimentary rocks of the area is scrutinized in the light of earlier investigations, the following special features are observed:

1.— the remarkable thickness of the sedimentary beds, especially in the Himanka belt;
2.— the lack of sorting in the sedimentary material in general and the abundance of graywacke schists;
3.— the lack of pure quartzites in the sedimentation zone, the sandstone complex consisting mainly of graywacke or arkose;
4.— the lack of limestones;
5.— the great amount of volcanic material, particularly in the uppermost beds, and its direct association with the normal sedimentary material;
6.— the local, interformational character of the conglomerates and the great thicknesses (Ylivieska).

Many researchers, including Pettijohn (1943, 1949), Tyrrell (1933), Bailey (1930, 1936), Krynine (1941) and Schwetzoff (1934), regard particularly the great thickness of the beds and the abundance of graywacke as evidence of a geosynclinal formation. As they see it the thick local conglomerate beds inside the formation belong typically to the geosynclinal facies.

Also other peculiar features mentioned earlier may be considered as pertaining typically to geosyncline sedimentation (Pettijohn 1949, Krumbein and Sloss 1951). Pettijohn (1943, p. 956) says: »Graywacke, like arkose, requires an environment in which erosion, transportation and deposition are so rapid that complete chemical weathering of the material does not take place.» Also the comparatively cold climate may have retarded the weathering process (Eskola 1932). The estimated thicknesses of the Himanka schists, 3 400—4 500 m, are sooner modest than great when compared with the thicknesses of younger sedimentary beds (e.g., Pettijohn 1949). The same can be said when these are compared with, for instance, the thicknesses of the schist formations of the Tampere area (Simonen 1953). The schist formations of Tampere may in other respects be taken as comparable with the formation of Ylivieska—Himanka. Simonen *(op. cit.)* has noted that the schist belt of Tampere belongs to the geosyncline formation. In his early day, Sederholm (1897) interpreted the Tampere schist as a sort of delta formation. Pettijohn (1949, p. 444) remarks: »The geosynclinal facies, no doubt, commonly has been called a deltaic deposit. The filling of a geosyncline may be deltaic sedimentation in part, but if so numerous coalescing deltas were involved geosynclinal deposits have too great a longitudinal extension to be interpreted as the delta of a single stream». The Ylivieska—Himanka schists could be assumed to belong to a greater geosyncline, which might include, for example, the schists of the Skellefteå district on the western side of the Gulf of Bothnia. Gavelin and Grip (1946) and Gavelin and Kulling (1955) have investigated them. According to the latest research (Kautsky 1957), the schists of the Maurliden series occurring there correspond well wiht respect to their rock types and character to the Ylivieska—Himanka schists whereast the discordat schists, above the Maurliden series are lacking in the Ylivieska—Himanka area. Further, having studied the Ylivieska—Himanka schists in the field, in 1959, Grip considers them to be of the same type as the Skellefteå schists. Both contain an abundance of graywacke as an essential part.

Stille (1941) divides geosynclines into eugeosynclines and miogeosynclines. Consequently, abundant volcanic eruptions were associated with the eugeosynclines, especially during their late stage, but were totally lacking in the miogeosynclines. Thus, the Ylivieska—Himanka formation belongs to a eugeosyncline. Its uppermost horizon contains an abundance of various volcanogeneous rocks (pillow lava, agglomerates, porphyrites, tuffites).

The schist complex in question differs, of course, in many respects from the features which the afore-metioned geologists regard as typical of a eugeosyncline. Among others, Bailey (1936) observed that cross-bedding and graded bedding do not belong to the same sedimentation facies. In the Ylivieska—Himanka area they are seen side by side. According to Pettijohn

Fig. 25. Graywacke-like beds folded through gliding before diagenesis. 1: 3. Merijärvi.

(1949, p. 445) graded bedding is typical, cross-bedding less frequent, and glidings common in the unhardened beds. Also the last-mentioned phenomenon is met with in the Ylivieska—Himanka area (Fig. 25). Kay (1944, 1947) indicates that all geosynclines do not resemble each other in every respect, and some features may be lacking in one and yet occur quite commonly in another. On the other hand, this may be interpreted as evidence of transgression and regression of the sea in the sedimentation basin; thus, shallow and deep sea facies may exist side by side.

THE RELATIONS BETWEEN THE LINEATION (ELONGATION) AND THE FOLDING AXIS

Although the measurements of the direction of the folding axis are rather rare in the Ylivieska—Himanka region, they were nevertheless performed especially in the anticline area of Alavieska. The axial direction of the main folding is supposed to run parallel to the length of the isocline and determinations of axial directions, which are parallel to it and gently sloping, were succesfully made. At the southern end of the anticline, north of the gabbro body of Ylivieska, the b-axis of the main folding reaches its local culmination. Here as well as at the eastern and western sides of the anticline, transversal positions of the axial direction are observed. Nor are these directions markedly steep. Owing to this cross-folding, a distinct transversal schistosity is to be seen in the field, its plane nearly at right angles to that of the bedding. The contacts of the schists of the anticline against igneous rocks consequently appear densely winding on the geological map. There is another folding axis, which cuts the b-axis of the main folding axis approximately at right angles, and in which secondary folding has taken place, and at this place it is so clear as to be easily noticed (Map 3).

Many researchers have investigated the relation between the main folding and the cross-folding. The first experimental research was carried out by Hungerer (1922). Yet the term »cross folding» had already been used by Van Hise (1894). Argand (1912) suggested that the main and cross foldings in the Alps (Nappes) were of simultaneous origin. Engel (1949), King and Rast (1956 a and b), Gross (1955), Rast and Platt (1957) and many others have assumed that the main and cross folds of many metamorphic rocks are synchronous. The latest experimental study yielding the same result, was done by Bhattacharji (1958).

The measurements of the lineation in the whole Ylivieska—Himanka area were carried out as densely as possible. To obtain any conception of the relation of this direction to the folding axis, at least two main lineations must be distinguished. One of them agrees well with the b-axis of the main folding, and the other differs from the former by having a remarkably large angle (90°). No result could reasonably be expected by the statistical method, owing to the small number of exposures in the Alavieska anticlinal area. A very coarse network of observations does not offer enough material. The lineation was mainly measured in the schistosity plane as the longitudinal directions of the individual biotite and hornblende crystals. Also the elongation of the pebbles of conglomerate schists was measured. Their elongations seem to follow the local lineation (*cf.* Williamson 1955). These pebbles are not so much elongated as they are flattened conformably with the schistosity. Thus the lineation mainly originated through the growth of the minerals and the movements on the S-planes (Cloos 1946). Concerning the relation of lineation to the direction of the folding axis, Newhouse (1955) remarked: »Compositional lineation and the axes of small drag folds appear to be perpendicular to the local line of slip. Therefore, these features are 'approximately parallel' to the principal axial direction of folding where, . . ., the effect of cross-folding is small».

Among the results obtained from lineation investigations in southern and southwestern Finland, mention should be made of the work of Neuvonen and Matisto (1948), and Simonen (1949, 1952, 1953). In every case the lineation is noted to be mainly perpendicular to the principal folding axis. Härme and Seitsaari (1950), again, have verified that on the eastern side of Lake Näsijärvi the magma-tectonic changes have caused a strong lineation in the direction of movement of the granite massif. Härme (1955) has observed the lineation to have a different trend, but its horizontal projection in no case runs perpendicular to the b-axis of the principal folding. In the area of the map sheet of Suomusjärvi, Salli (1955 d) has observed the lineation in most cases to follow the b-axis of the principal folding.

INFRACRUSTAL ROCKS

As is shown in the map, infracrustal rocks cover about half of the area investigated. The most common of these rocks is granodiorite. It borders the schist zones, in some cases with slightly curved brecciating contacts, cutting across the zone, in other cases penetrating them concordantly and forming migmatites with them in the manner of veined gneiss. Basic plutonics appear in the area as smallish bodies of varying size and mostly as stocks entirely surrounded by granodiorite. Ultrabasic portions are often associated with the basic plutonics, gabbros to diorites. The basic rocks sometimes follow the rim of a plutonic massif, thus becoming situated between the schist zone and the granodiorite. Granitic rocks are scarce in the area investigated. Concordantly running potash pegmatites occur between the schists in the Himanka schist zone. A couple of smallish granite occurrences are close to the NE corner of the area. Some dyke-like pegmatite-granite stripes have also been met with there. Particularly south of Kalajoki, near the coast, potash-rich granite and pegmatite dykes occur both in the schists and the infracrustal rocks. To present a coherent view of the infracrustal rocks of the area, they are here classified into massifs using local names, the various massifs being designated according to their principal rock and the associated rocks described in the same connection.

GRANODIORITE OF KALAJOKI

The plutonic massif called Kalajoki granodiorite extends from the northern border of the area investigated in Kalajoki to the village of Mutkalampi, Kannus, in the south; on the east it is bordered by the Rautio and Alavieska schists, while its western border reaches to the sea.

This plutonic massif is fairly diverse as to its rocks. The most extensive area is covered with quartz diorite and granodiorite. They occur especially in the central parts of the massif and along the coast. Although their composition has a wide range of variation, they can be considered a coherent rock type. Predominating on the coast, in Kalajoki, is an oligoclase-granitic rock which contains abundant quartz. It usually displays distinct mineral parallellism. The main minerals are fairly acid oligoclase ($An_{\sim 20}$), quartz and biotite. Also hornblende may occur in varying amounts. Potash feldspar is met with in nearly every sample but always less than oligoclase. Often it can just barely be detected. Oligoclase generally forms largish crystals, round at the edges, showing primary zoning. Sericite occupies their centers as an alteration product. The quartz grains, granulated or with an undulatory extinction are smaller than the oligoclase crystals. The dark minerals, biotite and hornblende, usually collect in clusters. Toward the center of the massif, the rock becomes granodiorite-like, and the amount of hornblende increases while that of quartz decreases. The most typical variety contains plagioclase, approximating the composition of andesine (An_{25-28}). It greatly exceeds in amount the other pale constituents of the rock. The quartz content is scarcely $1/4$ that of oligoclase. Potash feldspar is extremely scarce being totally lacking in some samples. The oligoclase is sometimes clear and seldom zoned. In some instances it shows strong primary zoning, and sericite and epidote appear in the centers as alteration products. The amount of hornblende exceeds that of biotite. Dark minerals are present in dot-like clusters.

The last-mentioned biotite-hornblende-quartz diorite is usually called tonalite. It is slightly bluish grey in colour. Sometimes biotite is totally lacking in the quartz diorite. The plagioclase of such a hornblende-quartz diorite is andesine (An_{30-40}). The amount of quartz is also less than in biotite-bearing quartz diorites. This transitional form between quartz diorite and diorite is found here and there in the center of the massif, where also diorites and gabbros form smaller bodies. Several such gabbro-diorite occurrences appear along the Kalajoki river between Kalajoki and Alavieska. Their rock is medium-grained and mostly homogeneous. With respect to their composition, they sometimes represent basic hornblende gabbros, and sometimes pass into dioritic varieties. The mineral assemblage of a gabbro-like rock comprises green hornblende, plagioclase (mostly andesine, $An_{\sim 50}$), biotite, some apatite, titanite, and magnetite. Pyroxene, usually diopside, is met with in some specimens. In certain cases the hornblende and pyroxenes have altered into serpentine and chlorite. Biotite is extremely scarce. Plagioclase is in such cases strongly saussuritized.

Particularly in the part of the massif which extends over the northern boundary of the area investigated, granodiorite containing porphyritic grains of potash feldspar occupies large areas. The granodioritic ground mass, which is usually grey in colour, contains potash feldspar grains 1—2 cm in diameter and scattered more or less densely. Microscopically these porphyritic grains are observed to contain fragmentary oligoclase inclusions. The ground mass contains very little potash feldspar and the total composition of the rock is nearer to granodiorite than granite. It usually contains oligoclase

($An_{\sim 20}$), quartz, biotite and hornblende. Such a porphyritic granodiorite gradually passes into both massive, even-grained quartz diorite or granodiorite and more basic infracrustal rocks. Particularly to the south, there occur even-grained, reddish or grey rock types, representing the microcline-quartz diorite described by Mäkinen (1916). The amount of microcline is smaller in these than in the porphyritic granodiorite varieties described in the foregoing. They are usually small- or medium-grained, while the porphyritic granodiorites are mostly coarse-grained. Mineral parallellism is usually a striking feature.

Southeast of the village of Kurikkala toward the border of the Himanka schist zone, pegmatite dykes containing potash feldspar in abundance have penetrated the granodioritic rock. The rock has become migmatic and in places brecciated. Also the homogeneous rock displays a reddish hue more often and the potash feldspar content approaches that of granite. In some instances, the plagioclase has turned more acid and turbid ($An_{\sim 15}$). Considerable amounts of epidote appear as an accessory in the rock.

Close to the coast, acid porphyries occur associated with the granodiorites near the boundary of the Himanka schist zone. They are reddish in colour. The ground mass is granoblastic and small-grained (Ø∼0.1 mm). In addition to oligoclase and quartz, it contains some biotite. The phenocrysts lie densely scattered. The majority of them are primarily of zoned oligoclase, but also quartz grains are present. Their diameter is ∼ 0.5 mm. The central parts of the oligoclase grains are saussuritized.

GRANODIORITE OF SUSINEVA

South of the Rautio church a thick quartz-granodiorite body extends over the southern border of the map area. Together with the granodiorite of Kalajoki, described in the preceding chapter, this massif comprises rather varying infracrustal rocks, which are described here in the same chapter for the sake of unity. The even-grained quartz diorite and granodiorite met with in the center of the massif represent a typical pale-grey, hornblende-bearing, even-grained rock. Its compositional changes from quartz diorite to granodiorite take place too gradually to reveal any demarcation lines.

The granodiorite in the center of the massif on the road from Rautio to the west contains dark inclusions peculiar to granodiorite, consisting of small fine-grained, gabbro-like amphibolite. The rock exhibits mineral parallellism to some extent, and its inclusions are elongated conformably. The rock proper mainly contains plagioclase (An_{20-35}), quartz, hornblende and biotite. The plagioclase is primarily zoned and slightly sericitized at the center of the grains. Generally, the crystals are sharp-edged and larger than the quartz crystals. The hornblende has biotitized rims and the dark constituents appear in clusters. Accessories are apatite, titanite and ore grains. Perthitic potash feldspar is observed in some thin sections. In some cases, plagioclase occurs as platy grains in the rock. Toward the northern border of the massif, the rock gradually becomes more basic, and the dioritic variety becomes predominant. Gabbro-diorite surrounds the northern border of the massif like a collar in places forming a rim about 1 km thick.

This rim represents typical even-grained, sometimes small-grained hornblende-rich gabbro. Pyroxenes are seldom present. The rock is partly ophitic, resembling diabase. At its northeastern border it passes imperceptibly into coarse plagioclase porphyrite.

Toward the southern border of the massif, the rock passes into a coarser-grained type resembling porphyritic granite. The hornblende content decreases. The feldspar crystals, which consist mainly of potash feldspar and include flaky plagioclase remnants and are round in form, and larger than the medium grain size of the rock, become more and more predominant. The rock here would be more in the nature of porphyritic granite than granodiorite. To some extent, in appearance it resembles the porphyritic granodiorite met with in the northern parts of Kalajoki. Yet its mineral parallellism is weaker and dark gabbro-like inclusions are rarer than in Kalajoki. Just at the southern border of the map sheet area, in the southern part of Susineva, there are densely situated potash granite and pegmatite dykes which sharply cut the granodiorite.

The relation of the Susineva granodiorite massif to the surrounding schists cannot be observed in outcrops, as their contacts are hidden. It is partly discordant at the northern boundary, but it is concordant to the schists of Rautio in the east, the same being the case also at the west side, adjacent to the schist zone of Himanka.

GRANODIORITE OF TALUSKYLÄ

East of Taluskylä, Alavieska, there is a body of infracrustal rocks some 100 km^2 wide whose northern boundary against the schists is curved. The southern boundary is forked in many places, penetrating the schists.

This body is granodiorite. It includes as essentially associated parts both gabbro-dioritic and ultrabasic rocks. The granodiorite is in places reddish and contains more than usual amounts of potash feldspar. In some places it displays mineral parallellism. This is particularly observable close to the northern boundary of the occurence. Strikes are seen here to follow the curved northern border of the body. This granodiorite is most homogeneous at its center and near its northeastern border and close to the basic body. Toward the northwest, again, the granodiorite contains abundant fragments

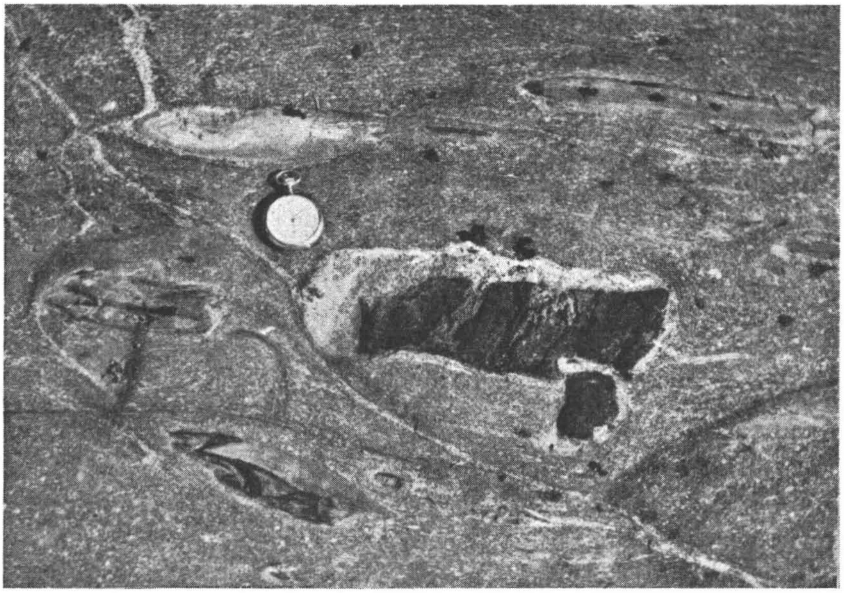

Fig. 26. Intrusive breccia in the contact zone of the granodiorite against the schist. Taluskylä, Alavieska.

of other rocks, sometimes derived even from basic plutonics (Fig. 26). Usually the granodiorite contains considerably hornblende in such cases representing ordinary hornblende-biotite granodiorite. Toward its western boundary the rock of the body passes into a more acid variety, which has a higher content of potash feldspar. At the same time, also the hornblende disappears nearly entirely and the composition of the rocks equals that of oligoclase granite. In places, the amount of potash feldspar is large enough to make the rock a granite.

The zone of basic infracrustal rocks lies in the western border of the stock, toward the schist zone. It comprises an ultrabasic rock, the so-called Kunnari rock, which gradually passes into gabbro-diorite. This peridotite is a coarse-grained (Ø 1—3 cm) brown-green rock. Its surface is weathered to a great extent. The mineral assemblage includes olivine as roundish grains, which have largely altered to serpentines. Serpentinization occurred not only along the borders but also inside the olivine crystals, where fine serpentine and ore veins criss-cross the grain. Another important mineral is hypersthene, which appears here and there in the rock. It forms irregularly shaped crystals criss-crossed to a considerable extent by serpentine veins. Also biotite is found in the rock. It is strongly pleochroic ($\gamma = \beta =$ dark brown, $\alpha =$ yellow brown). Its borders and cleavage planes are often chloritized.

Some 5 km west of this locality at the granodiorite massif of Taluskylä, there are three smallish ultrabasic occurrences. The northernmost of them has hornblende and hypersthene, the latter being dominant. Serpentinization has scarcely touched it. It is an even-grained rock, which, in addition to pyroxene and hornblende, contains some biotite along the borders of the hornblende grains. The rock in the southernmost occurrence is an even-grained hornblendite in which the hornblende is quite pale and hardly pleochroic. The amount of other minerals in the rock is minimal. Fissures parallel to the c-axis of the hornblende are filled with ore stripes, making the mineral look dirty. Diopside forms smallish clusters between the hornblende grains.

The small occurrence to the northwest is also predominantly hornblende. The texture of the rocks is ophitic because the hornblende occurs as thin splinters about 1—2 cm long, which markedly exceed the main grain size of the rock. Besides hornblende the matrix proper contains some basic plagioclase (An_{60-70}). The mode of occurrence of this rock is dyke-like.

The peridotite of Kunnari passes gradually into gabbro and diorite, which in turn pass little by little into the acid infracrustal rocks described above. The gabbro-diorite is a hornblende-dominated, pyroxene-bearing rock. It is even-grained, of medium coarseness and mostly quite homogeneous. The hornblende is of the pale type. The diopside is the most common pyroxene, but also hypersthene has been noticed in some samples. Serpentine appears as an alteration product, as does chlorite, around the biotite grains. Plagioclase (An_{45-60}) is always included.

GRANODIORITE OF OULAINEN

West and southwest of the church of Oulainen there is a sizable infracrustal rock body. Its main rock is quartz diorite, partly consisting of granodiorite. In the center of the body, the rock is mainly quartz diorite, which contains as pale constituents plagioclase (An_{30-35}) and quartz in varying amounts. The mafic minerals are principally hornblende and biotite in lesser amounts. The rock is even-grained and of medium coarseness. Only slight mineral parallellism is observable. The texture of the rock is to some extent hypidiomorphic. The plagioclase displays primary zoning, although the centers of the crystals are often saussuritized. Also quite transparent plagioclase lacking any zoning is to be observed. The plagioclase usually forms platy crystals, but cross sections of these plates are longish and splinter-like, which gives the rock partly an ophitic appearance. Some potash feldspar always accompanies the other minerals. It fills, together with grained quartz and plagioclase mass, the interstices between larger quartz and oligoclase grains. Hornblende and biotite, which are both strongly pleochroic, form dot-like clusters. The biotite is slightly chloritized at its borders. Accessories are apatite, titanite and ore grains.

A schist extension projects into this granodiorite massif from the west. Its rather broad (ca. 1 km) border zone against the granodiorite is strongly brecciated. The brecciating agent is the granodioritic matter which has torn and captured schist fragments. Several varieties of local schists occur. This part of the granodiorite is also more acid, corresponding to the composition of oligoclase granite. South of the extension of the schist zone the rock slowly begins to become more basic. In one exposure it appears as a diorite-like, even-grained rock. Rock resembling intrusive breccia has also been met with at the center of the stock, the place being marked on the map. Granodioritic matter has there brecciated some intermediate supracrustal rock containing pebbles and ejecta. It is difficult indeed to decide whether that supracrustal rock had been a true conglomerate or some volcanic conglomerate or agglomerate.

Potash feldspar-dominated pegmatite granite occurs about 10 km south-southeast of Oulainen at the eastern border toward the schists. It is reddish in colour and very coarse-grained. The chief minerals are potash feldspar, which forms more than half the total composition of the rock, and quartz, which is also abundant. The dark mineral is biotite, and, in addition, chlorite is present as an alteration product. Alteration of biotite into chlorite is not discernible in the coarsest varieties. Potash feldspar occurs as large crystals containing some antiperthite. Their interstices are filled with granulated quartz, which has an undulatory extinction, or with a potash feldspar mass, having a grain size smaller than the individual large potash feldspars. The biotite forms thick piles. These are black spots at their alteration points resulting from ore pigmentation. This pegmatite granite occurrence is dyke-like in character, forming a lenticular body. Cataclastic features appearing there also indicate a dyke formation.

SMALL INFRACRUSTAL BODIES

Several smallish plutons northeast of Rautio deviate from the afore-described roundish massifs by forming narrow bands intruded between the schist zones. Between Rautio and the village of Kähtävä, Alavieska, there is a granodiorite belt over ten kilometers in length and only some 3 km in width at its broadest. Its central and northern parts are of the same granodiorite as is the Susineva granodiorite, possessing in places the composition of quartz diorite. At its southern end, it passes into a granitic rock penetrated by pegmatite veins rich in potash feldspar. A strip of associated

Fig. 27. Curly granodiorite. Niemelä, Ylivieska.

basic infracrustal rock is also here marked at the eastern border of the southern end. No outcrop observations have been made to support it, but on the basis of aeromagnetic indications the strip was included in the map.

The most interesting of these bodies is, however, the one east of Niemelä village in Ylivieska. It is marked on the map as an arch circling the northern end of the Ylivieska schist isocline and the associated volcanic zone in the east. The shape of the body is presumably true, owing to the relatively abundant outcrops. The dip of the schists is rather gentle at the northern end; hence, the granodiorite inclines northward. Moving from the village of Niemelä over the amphibolite zone to the granodiorite, one's first impression is that in large exposures the granodiorite is curly and tectonized (Fig. 27). As may be seen, the figure there consists of criss-crossed quartz-rich veinlets across the curls. This rock is biotite granodiorite in composition. Its structure, as is to be expected, is markedly cataclastic and the biotite is partly chloritized. The potash feldspar does not exceed the amount usually found in normal granodiorite. A few hundred meters farther to the east, there occurs a rock having the appearance of normal granodiorite with all the common features. The rock is hornblende-biotite granodiorite. It further contains basic small-grained inclusions peculiar to granodiorite. In places the rock resembles quartz diorite. The mineral parallellism is weak. Associated with the body on this side are also basic varieties including ultrabasic hornblendite. The hornblende met with on the northern shore of Kekajärvi and in the island contains almost solely pale hornblende ($2V\alpha = 83°$, $c \wedge \gamma = 19°$). The hornblende appears as large crystals lying side by side. It is barely pleochroic.

This granodiorite continues from its western extension further southward along the schist isocline of Ylivieska. The density of the outcrops is also here so great that the map should give a true picture. It must, however, be borne in mind that the Kalajoki river here looks like a tremendous rupture zone in the direction of which faults are not excluded. They may have changed the relations of the rocks to a such an extent that it is not certain where the break between the conglomerate of the village of Niemelä and the conglomerate of Ylivieska should be located or whether they are still connected with one another. In any case, the granodiorite pushes another extension to the eastern side of the Ylivieska schist isocline. The position of this extension has not been ascertained. This extension is much more acid than the other. Varieties approaching potash granite are associated with it, particularly at its northern end. In the region of Raudaskylä, there is a coarse-grained biotite granodiorite intruding between the schist zones. Its potash feldspar content approaches the limits of granodiorite and granite, but the rock resembles granodiorite in appearance. Fairly marked mineral parallelism or parallel structure and some basic inclusions are characteristic of it. Especially in the extension directed eastward, the granodiorite displays its concordant character. Muscovite-bearing, potash-rich pegmatite has intruded between the northern border of the body and the schist zone. It contains micropegmatic potash feldspar as large grains, measuring as much as Ø ~ 10 cm, as well as granulated quartz and muscovite piles, occurring here and there.

Some kilometers NW of Alavieska, there is a granodiorite stock roughly 5 km^2 wide. It comprises ordinary even-grained granodiorite, which represents a hornblende-biotite granodiorite of medium coarseness. The mineral parallelism is weak, in places scarcely noticeable. The stock is on all sides surrounded by schist zones. On all sides, but particularly in the west, it is surrounded by a contact zone nearly 1 km broad which has throughout the character of intrusive breccia. Its main constituents are different schists brecciated by the granodioritic mass. Garnets are often found in this mass. They have been roentgenographically determined: almandine 78 %, grossular 12 %, pyrope 10 % (K. J. Neuvonen). The refractive index is 1.807. In places the character of the breccia is such that granodioritic mass is nearly lacking. Only rounded fragments of different rocks are present, between which the granodioritic mass winds as if it were a matrix in a conglomerate. The granodiorite stock appears to be in a comparatively steep position, so the surrounding breccia belt presumably continues comparatively deep.

In the eastern part of the map sheet area a portion of a wide pluton is to be seen. It is occupied mainly by granodioritic and quartz dioritic rocks. This border is only a small part of an extensive area of infracrustal rocks, and therefore the description of these rocks is omitted in this connection. A few words should be mentioned about the gabbro-diorite body which exists

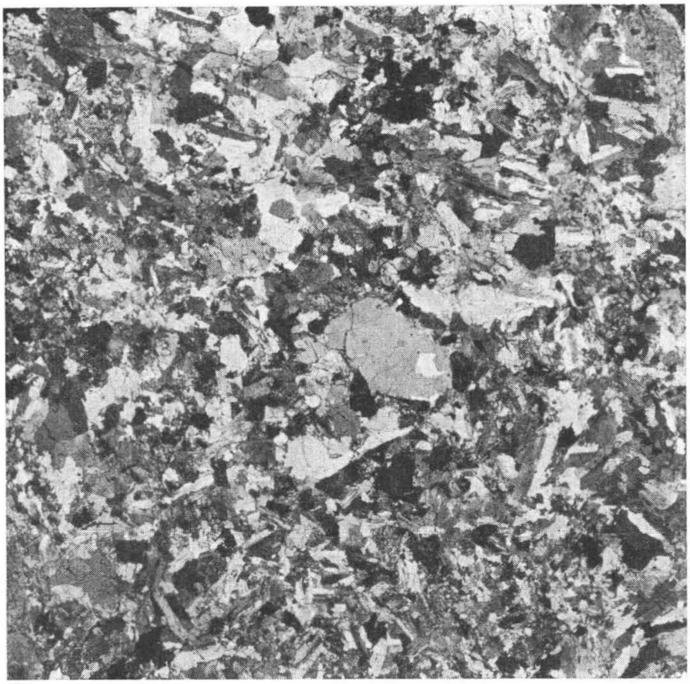

Fig. 28. Partly ophitic diorite. Nic. +; 1: 8. Oulainen.

alongside the area of infracrustal rock some kilometers southeast of Oulainen. The rock is mainly hornblende gabbro with dioritic varieties, some of them ophitic in texture (Fig. 28). Every exposure is densely penetrated by feldspar-rich dykes. Potash feldspar occurs in places as crack veins or forms porphyroblasts. In the gabbro mass it seldom occurs. This mineral strange to gabbro, is found in some samples, having corroded plagioclase inside it. It is not, however, a migmatite proper because the passing of the gabbro into migmatite is not dominant and the character of the gabbro as such has not suffered to any noteworthy degree.

GABBRO MASSIF OF YLIVIESKA

West of the Ylivieska church there is a smoothly rounded gabbro massif some 9 km long and 5 km broad. It is called the Ylivieska gabbro. On the north, and west and south it is limited by schist zones, while the eastern side is bordered by granodiorite, which occurs as a narrow belt separating the gabbro from the Ylivieska syncline. To determine the shape of the Ylivieska gabbro massif, aeromagnetic indications and the distinctly marked contact line displayed in aerial photographs, particularly at the southern end, were used in addition to the rather densely scattered net of exposures. Petrographically the Ylivieska gabbro is partly an olivine-bearing pyroxene gabbro, partly a hypersthene gabbro. The olivine content is revealed even to the naked eye at the eastern border of the gabbro massif between Perkkiö and Ylivieska, near the railway line. At its northern end, the gabbro contains an abundance of magnetite. The texture of the rock is generally hypidiomorphic, although in places a tendency toward an ophitic texture is apparent. The grain size varies considerably throughout the massif. The very same outcrop may display a wide range of grain sizes. The most common grain size in the coarser variety is 3—5 mm in diameter the smallest grains measuring only 0.5—1 mm in diameter. Small-grained varieties usually are ophitic. The gabbro is dark green, in places black-brownish-greenish in colour. Thin sections show the main mineral to be a clear, densely lamellar plagioclase (An_{75-80}) and not zoned, and there is also some pleochroic hyperstehene (α = nearly colourless, β = slightly reddish, γ = greenish) and round grains of olivine with characteristic fracture lines. Both the olivine and the hypersthene have, to some extent, altered to serpentine and chlorite along their cleavage and fracture lines. Associated with these alteration products are ore grains. Alteration products form small-grained mass-like clusters. Predominating in the massif is, however, hypersthene gabbro. Its minerals, already described, are slightly pleochroic hypersthene, plagioclase ($An_{\sim 60}$), biotite and some pale hornblende. Accessories are chlorite, epidote, and apatite. Very close to the northwest corner of the massif there is abundant ilmenite-magnetite and titanite. The grain size varies there markedly. Even nearly pegmatitic varieties occur, in which case the coarse part has a dyke-like appearance. Yet such dykes pass gradually into a smaller-grained rock. Their contact against the primary rock is too vague to show any line between the dyke and the host rock.

Although the Ylivieska gabbro massif is bordered by schists along two-thirds of its extent, no contacts between the schists and the gabbro are visible. Schist-like rock is met with as fragments in the gabbro at the north-western corner of the massif.

GRANITES AND PEGMATITES

Granites are scarce in the area. In connection with the description of other infracrustal rocks, their associated potash-rich granites have already been discussed. A few kilometers north of Kangas an even-grained, dyke-like granite exists as a separate longish body. The rock is small- or medium-grained (Ø ~ 1—4 mm) and quite homogeneous in appearance and slightly reddish in colour. The main minerals are potash feldspar and quartz as the pale and biotite as the dark constituents. Plagioclase is scarce, and it is primarily zoned and at the centers of the grains consists of sericitized acid oligoclase. The mode of occurrence of the granite is dyke-like, as shown in the map, although it attains a breadth of about half a kilometer. Another granite occurrence roughly 1 km long and $\frac{1}{2}$ km broad, located nearly 10 km northeast of the former, may be regarded as of the same type. It is somewhat coarser than the former rock. It is also redder in colour. As to its tectonic location, it seems to be comparable to the former.

Within the area of the Himanka schist zone, there are several potash-rich pegmatite granites intruded between the schists. The amount of quartz usually equals that of the potash feldspar and graphic intergrowths are common. Muscovite is more common than biotite among the micas. Muscovite sometimes occurs as radiated aggregates, which presumably are pseudomorphs after some earlier Al-mineral. Tourmaline-bearing pegmatite has been met with in the islands off Himanka. Some pegmatites also occur in the eastern part of the area investigated. In Raudaskylä there is quite a coarse, potash-rich pegmatite, which occurs as a narrow band wedged between the schist zone and the granodiorite. The same tectonic position appears to be represented by two pegmatite bodies some kilometers southeast of Oulainen. In the village of Niemelä in Ylivieska, potash-rich pegmatite also occurs as a penetration between the granodiorite and the schist zone. As it has been pointed out, all these pegmatites are alike in their location, in that they appear between the schist zone and the granodiorite. In a broader sense they may be considered dyke formations which have penetrated into the weaker zone at the contact between infracrustal rock and schist.

ON THE TECTONIC CLASSIFICATION OF THE INFRACRUSTAL ROCKS

As far as schist zones are concerned, the stratigraphy has been dealt with in the appropriate chapters. As shown in table 4 on page 64, all the infracrustal rocks are younger than the schists. On the other hand, the basic infracrustal rocks and basic volcanogeneous porphyrites are seen to pass directly and gradually into each other in the area.

To this area Saksela (1932, 1935, 1936, 1953, 1961) has applied a tectonic classification of infracrustal rocks according to which he divides infracrustal rocks into two series, synkinematic and late-kinematic. Belonging to the same orogeny, both exist as complete differentiation series, from ultrabasic peridotite to acid potash-rich granite. According to Saksela infracrustal rocks that occur concordantly as narrow bodies between schist zones must be regarded as synkinematic. At an early phase of mountain folding, while the schists still remained plastic, these infracrustal rocks intruded between them and participated in the movements during the early stage of folding. The trend of these infracrustal rocks runs concordantly with that of the schists. Rather narrow, longish bodies of infracrustal rock are found in the investigation area. Associated with them, besides granodiorites and granites, are also more basic varieties, particularly around Rautio, Alavieska and Ylivieska. Narrow pegmatite granite bands without any more basic infracrustal rocks occur in the Himanka schist zone.

According to Saksela (*op. cit.*) synkinematic granites form veined gneisses with the schists of their surroundings. As the contacts are mostly covered by an overburden, it is not possible to observe them directly. But within the Himanka schist zone, there is a veined gneiss formation close to the contact between granite and schist, although rather broad pegmatite dykes also occur. Infracrustal rocks from ultrabasic to granitic are found in the Rautio—Ylivieska area, and they can be considered to form a differentiation series. Although transition zones are seldom seen, the different members of the series join at least areally.

According to Saksela (*op. cit.*), late-kinematic infracrustal rocks in the area crystallized at a late stage of orogeny. The wall rock was so far solidified that magma could not intrude concordantly; but instead in the wall rock, when movements continued, ruptures and fractures appeared which no longer concordantly followed the strikes of the supracrustal rocks but cut them. Infracrustal rock masses which intruded at that time cut the supracrustal rocks, and they usually occur as round stocks whose internal orientation also is of a discordant character. Their contacts with the schists are brecciated. Moreover at the borders of such intrusive bodies, more basic infracrustal rocks are to be seen. In the area investigated intrusives forming roundish plutons occur. Examples are the Taluskylä and Oulainen granodiorites. In their contact zones against the schists, as mentioned earlier (pp. 52—53, 55), there are intrusive breccias.

In my opinion, it is entirely possible that at an early phase of orogeny in the Ylivieska—Himanka area infracrustal rocks from ultrabasic until the granitic ones formed, according to the differentiation principle. They may likewise have originated at the so-called late-kinematic stage. At least locally, differentiation may attain the granitic phase earlier in one than another part of the same orogenic cycle.

Infracrustal rocks in the area investigated are of two types with respect to their mode of occurrence. Some have intruded concordantly between the schist zones as longish bands. Others are discordant toward the schist zones with rounded contacts. The lack of exposed contacts has, however, prevented the author from solving their age relations. Radiological age determinations could perhaps cast more light on the matter. At the moment, the possibilities of carrying out such determinations are limited. It is, in any case, evident that the different mode of occurrence of these two infracrustal rock types can be attributed to their tectonic relation to the surrounding rocks.

Table 1. Mineral compositions of some acid schists of the Ylivieska—Himanka area. (Point couting method)

	1	2	3	4	5	6	7	8	9	10	11	12	13
Quartz	38.9	47.3	29.5	19.9	38.3	40.0	29.8	32.5	36.4	31.2	18.3	20.6	28.0
Potash feldspar	1.6	0.2	3.1					4.8			1.1		
Oligoclase	26.7	28.5	35.2	47.0	46.5	39.0	43.7	47.4	35.0	40.1	56.7	50.3	50.0
Micas	31.8	23.7	31.2	16.5	13.1	20.0	26.0	14.0	27.6	25.6	20.4	27.5	18.0
Hornblende				15.4									
Accessories	1.0	0.3	1.0	1.2	2.1	1.0	0.5	1.3	1.0	3.1	3.5	1.6	4.0

1. Graywacke-like schist, Ylivieska
2. Graywacke-like schist, Mutkalampi
3. Quartz-feldspar schist, Alavieska
4. Graywacke-like schist, Alavieska
5. Graywacke-like schist, Rautio
6. Graywacke-like schist, Himanka
7. Graywacke-like schist, Mutkalampi
8. Graywacke-like schist, Himanka
9. Graywacke-like schist, Himanka
10. Graywacke-like schist, Ylivieska
11. Quartz-feldspar schist, Alavieska
12. Graywacke-like schist, Alavieska
13. Graywacke-like schist. Alavieska

Table 2. Compositions of the volcanogeneous rocks of the Ylivieska—Himanka area.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	47.66	51.87	52.06	60.84	71.66	72.92	58.81	62.08	64.45	65.06	65.05	65.42	66.43	66.97	68.43
TiO_2	0.97	0.89	1.22	0.67	0.17	0.23	0.61	0.48	0.74	0.64	0.76	0.70	0.67	0.74	0.84
Al_2O_3	15.01	15.90	18.55	15.60	14.80	14.00	18.9	18.72	16.0	15.97	16.58	15.2	16.04	15.97	14.4
Fe_2O_3	2.41	2.07	2.79	0.09	0.60	0.49	2.28	2.94	1.02	1.24	0.67	1.46	1.27	0.72	1.39
FeO	9.66	8.72	7.72	5.27	1.74	1.81	3.62	2.78	3.78	3.90	5.10	3.29	3.27	4.06	3.30
MnO	0.23	0.18	0.17		0.05	0.02	0.07	0.08	0.05	0.07	0.07	0.06	0.07	0.08	0.05
MgO	6.46	5.35	3.28	4.42	0.65	0.96	3.77	2.01	3.24	2.64	3.37	2.92	2.60	1.74	2.57
CaO	9.09	8.43	8.00	6.98	1.28	1.39	3.66	3.22	3.56	3.52	1.78	3.52	2.13	2.73	2.09
Na_2O	2.77	2.94	3.40	4.01	3.20	3.32	4.11	3.73	3.91	3.05	3.12	3.70	3.47	3.01	3.05
K_2O	1.30	1.41	1.38	1.87	5.02	4.02	2.51	2.59	2.08	2.33	3.28	2.13	2.90	3.00	2.96
P_2O_5	0.39	0.32	0.38		0.03	0.03	0.16	0.22	1.18	0.18	0.19	0.19	0.22	0.19	0.23
CO_2	2.01	0.00	0.00		0.32	0.00	—	—	—	—	—	—	—	—	—
H_2O+	1.68	1.52	1.28		0.45	0.69	1.66	1.55	0.71	1.56	1.00	0.08	1.43	1.13	1.07
H_2O-	0.12	0.14	0.11	0.61	0.04	0.04	0.08	0.12	0.04	0.07	0.11	0.03	0.26	0.10	0.14
	99.76	99.74	100.34	100.30	100.01	99.92	100.24	100.52	99.76	100.23	101.08	99.42	100.76	100.44	100.52

1. Uralite porphyrite, Oulainen. Anal. P. Ojanperä
2. Plagioclase porphyrite, Ylivieska. Anal. P. Ojanperä
3. Plagioclase porphyrite, Ylivieska. Anal. P. Ojanperä
4. Plagioclase porphyrite, Ylivieska. Anal. P. Ojanperä
5. Acid tuffite, Oulainen. Anal. A. Heikkinen
6. Acid tuffite, Oulainen. Anal. A. Heikkinen
7. Graywacke schist, Kähtävä, Alavieska. Anal. A. Heikkinen
8. Graywacke schist, Taluskylä, Alavieska. Anal. P. Ojanperä
9. Graywacke schist, Rautio.Anal. P. Ojanperä
10. Graywacke schist, Himanka. Anal. P. Ojanperä
11. Graywacke schist, Mutkalampi, Kannus. Anal. P. Ojanperä
12. Quartz-feldspar schist, Kähtävä, Alavieska. Anal. A. Heikkinen
13. Quartz-feldspar schist, Ylivieska. Anal. P. Ojanperä
14. Quartz-feldspar schist, Mutkalampi, Kannus. Anal. P. Ojanperä
15. Quartz-feldspar schist, Kähtävä, Alavieska. Anal. A. Heikkinen

Table 3. Compositions of the sedimentogeneous rocks of the Ylivieska—Himanka area.

	16	17	18	19	20	21	22	23	24	25	26	27
SiO_2	71.41	63.48	64.32	64.2	68.1	75.5	60.84	68.59	68.82	78.36	60.00	75.40
TiO_2	0.45	0.65	0.67	0.05	0.7	—	0.83	0.56	0.53	0.11	1.04	0.16
Al_2O_3	15.10	16.89	16.44	14.1	15.4	11.4	17.91	13.44	13.48	11.27	14.34	12.45
Fe_2O_3	0.43	1.60	1.38	1.0	3.4	2.4	1.48	1.55	0.60	1.13	3.02	1.32
FeO	2.35	3.74	4.36	4.2	3.4	—	5.47	5.26	3.64	0.82	5.30	1.03
MnO	0.05	0.07	0.06	0.1	0.2	0.2	0.06	0.07	0.04	0.01	0.12	0.02
MgO	1.07	2.99	2.00	2.9	1.8	0.1	3.23	2.33	2.33	0.33	4.31	0.31
CaO	2.79	3.21	2.07	3.5	2.3	1.6	1.04	1.30	3.15	1.06	4.53	1.72
Na_2O	3.25	3.60	2.85	3.4	2.6	2.0	2.26	1.86	2.35	3.08	3.30	2.71
K_2O	1.90	2.48	3.86	2.0	2.2	5.6	4.71	3.04	4.40	3.46	2.53	4.30
P_2O_5	0.15	0.18	0.23	0.1	0.2	traces	0.19	0.17	0.15	0.03	0.19	0.05
CO_2	—	—	—	1.6	—	0.4	—	—	—	—	—	—
H_2O+ ...	1.09	1.21	1.79	2.2	2.1	0.6	1.78	1.77	0.71	0.28	1.06	0.23
H_2O- ...	1.18	0.07					0.14		0.00	0.03	0.10	0.05
	100.22			99.35			99.94		100.20	99.97	99.84	99.75

16. Quartz-feldspar schist, Mutkalampi. Anal. P. Ojanperä
17. Graywacke schist, average of 6 analyses, Alavieska—Rautio. Anal. A. Heikkinen
18. Graywacke schist, average of 12 analyses, Tampere schists. Simonen 1953, p. 44.
19. Graywacke, average analysis. Pettijohn 1949, p. 250.
20. Graywacke, average analysis. Tyrrell 1933, p. 26.
21. Arkose, average analysis. Pettijohn 1949, p. 259.
22. Andalusite mica schist, Ylivieska. Anal. P. Ojanperä.
23. Mica schist, average analysis, South Finland, average of 9 analyses, Simonen 1953, p. 44
24. Graywacke-like pebble of conglomerate, Ylivieska. Anal. A. Heikkinen
25. Quartz-feldspar schist pebble of conglomerate, Alavieska. Anal. A. Heikkinen
26. Amphibole schist, matrix of conglomerate, Alavieska. Anal. A. Heikkinen
27. Quartz-feldspar schist pebble of conglomerate, Alavieska. Anal. A. Heikkinen.

Table 4. Sedimentation, movements, volcanic eruptions and intrusions.

Deposits and intrusions	Movements	Sedimentary facies
Different plutonites		
Clayey sediments	stable	axial
Graywackes and arkoses		
Graywackes and conglomerates	non-stable	proximal
Small-grained arkoses (volcanic ash in the material?)	stable	distal
Basal formation unknown		

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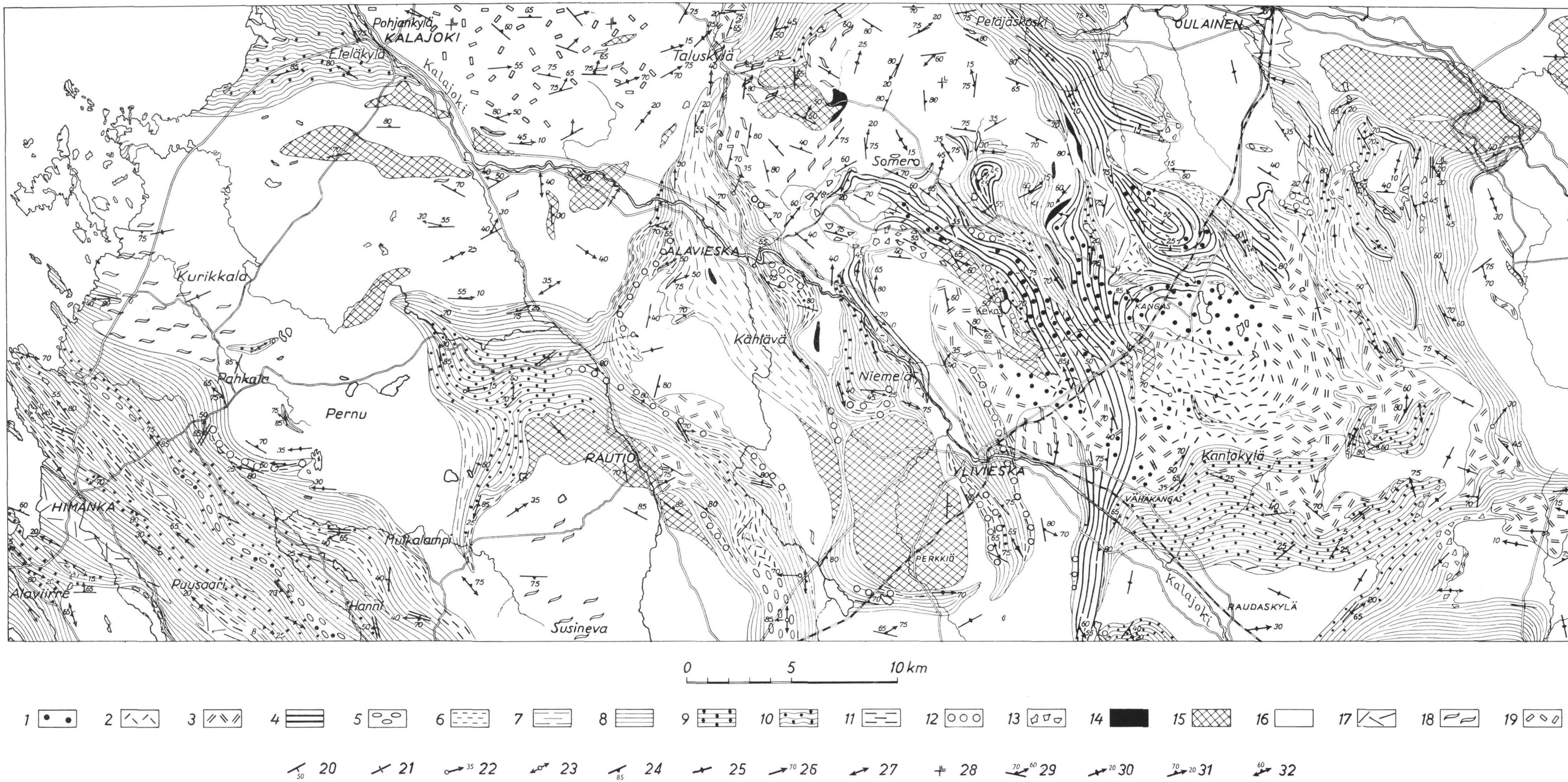
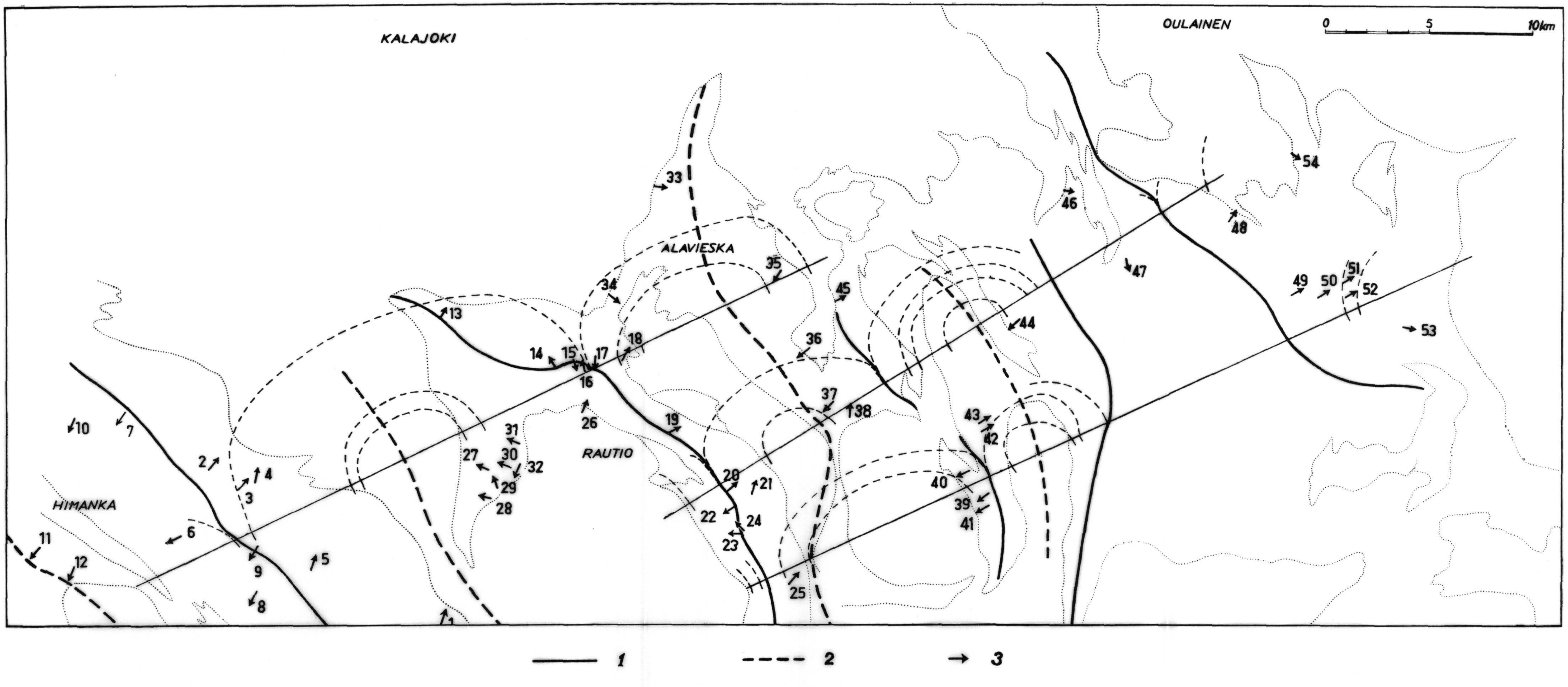
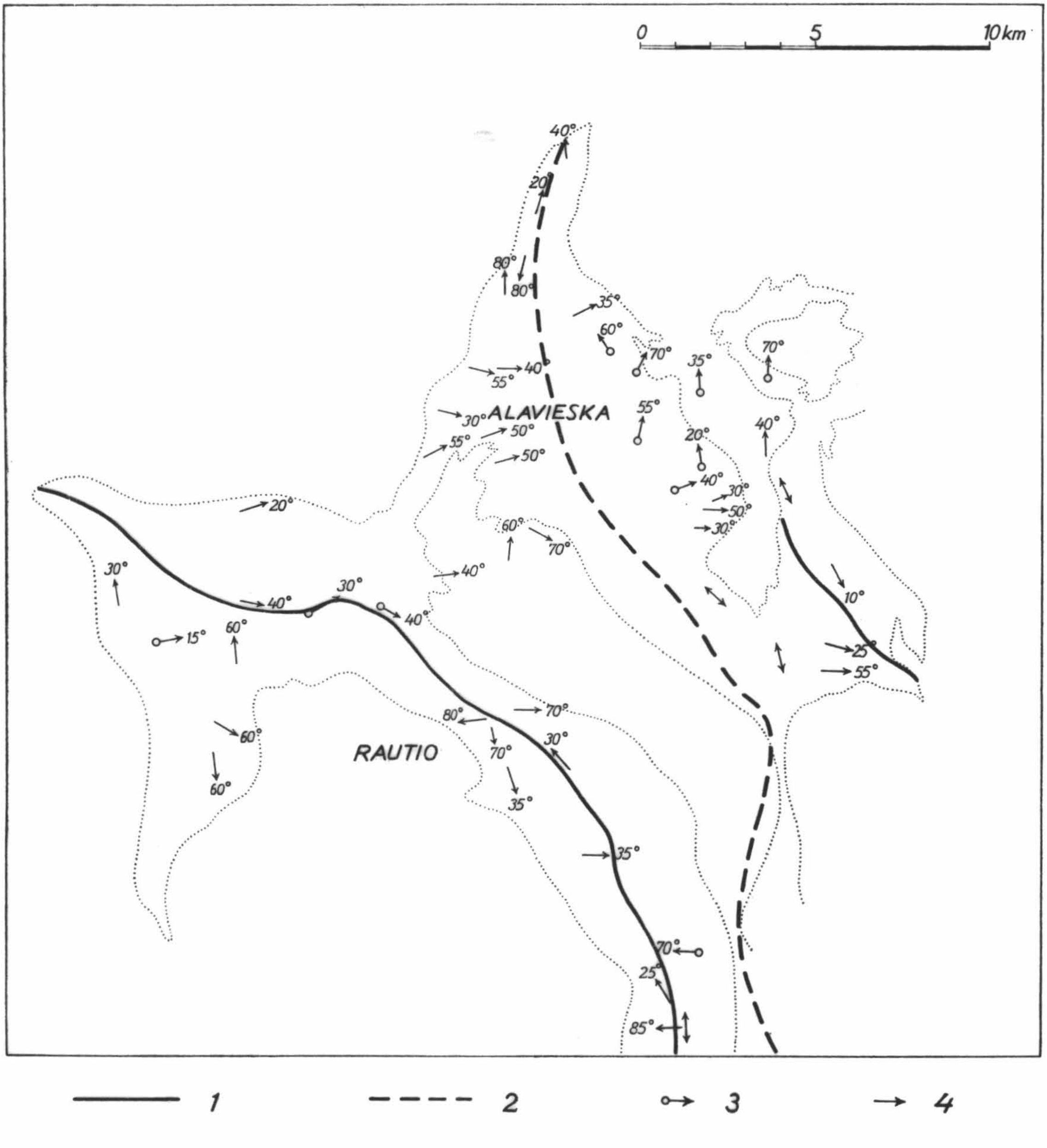


LEGEND

1. Uralite porphyrite
2. Plagioclase porphyrite
3. Ophitic plagioclase porphyrite
4. Amphibolite
5. Agglomerate schist
6. Acid volcanics
7. Quartz-feldspar schist (leptite)
8. Graywacke-like schist (fine-grained)
9. Mica schist (porphyroblastic)
10. Mica gneiss (porphyroblastic)
11. Graywacke-like schist (coarse)
12. Conglomerate schist
13. Intrusive breccia
14. Ultrabasic rock
15. Gabbro and diorite
16. Quartz diorite and granodiorite
17. Granite and pegmatite
18. Migmatite and veins rich in potash feldspar
19. Potash feldspar as phenocrysts
20. Strike and dip of stratification
21. Vertical stratification
22. Fold axis
23. Horizontal fold axis
24. Strike and dip of foliation
25. Vertical foliation
26. Lineation (elongation)
27. Horizontal lineation
28. Vertical lineation
29. Foliation and lineation
30. Lineation and vertical foliation
31. Foliation and lineation
32. Foliation and lineation



1. Axis of syncline 2. Axis of anticline 3. Basal direction



1. Axis of syncline 2. Axis of anticline 3. Fold axis 4. Lineation