GEOLOGIAN TUTKIMUSKESKUS
GEOLOGICAL SURVEY OF FINLAND

Opas – Guide 21

INTERNATIONAL
GEOLOGICAL
CORRELATION
PROGRAMME

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PROJECT No. 235 "METAMORPHISM AND GEODYNAMICS" EXCURSION IN FINLAND 15.6.–19.6.1988

Edited by Matti Pajunen

Geological Survey of Finland
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INTRODUCTION

This excursion is an integral part of the activities of IGCP project No. 235, "Metamorphism and geodynamics" in Finland. With its focus on crustal evolution and tectono-metamorphic studies, the project has involved researchers from a number of disciplines. The crust of southern Finland is composed of an Archaean craton in the east and Proterozoic formations in the west. The participants on the excursion will be given an introduction to the evolution of the craton margin in the Proterozoic Rantasalmi-Sulkava (I) and Pielavesi-Kiuruvesi (II) areas, and in the Archaean Varpaisjärvi-Iisalmi (III) area (Fig. 1). As well as field excursions there will be a poster session that will deal with the volcanism, isotope geology, fluid studies and geophysics of the craton margin. The articles in the excursion guide are largely based on papers by Korsman (1977), Korsman et al. (1984), Paavola (1984 and 1988), Korsman ed. (1986) and Korsman ed. (1988), which will not be referred to in the following.

OUTLINES OF THE FINNISH PRECAMBRIAN

The Archaean basement complex in eastern Finland, which developed into a craton over 2500 Ma ago, is mainly composed of 3100-2600 Ma old granitoids with narrow isoclinally folded greenstone belts of supracrustal rocks squeezed between them (Simonen 1980).

The Archaean granitoids vary from quartz diorite to granite in composition (Simonen 1980), although enderbitic plutonic rocks are encountered in some granulite grade blocks. The bulk of the craton underwent amphibolite or epidote-amphibolite grade metamorphism. The granitoids are often

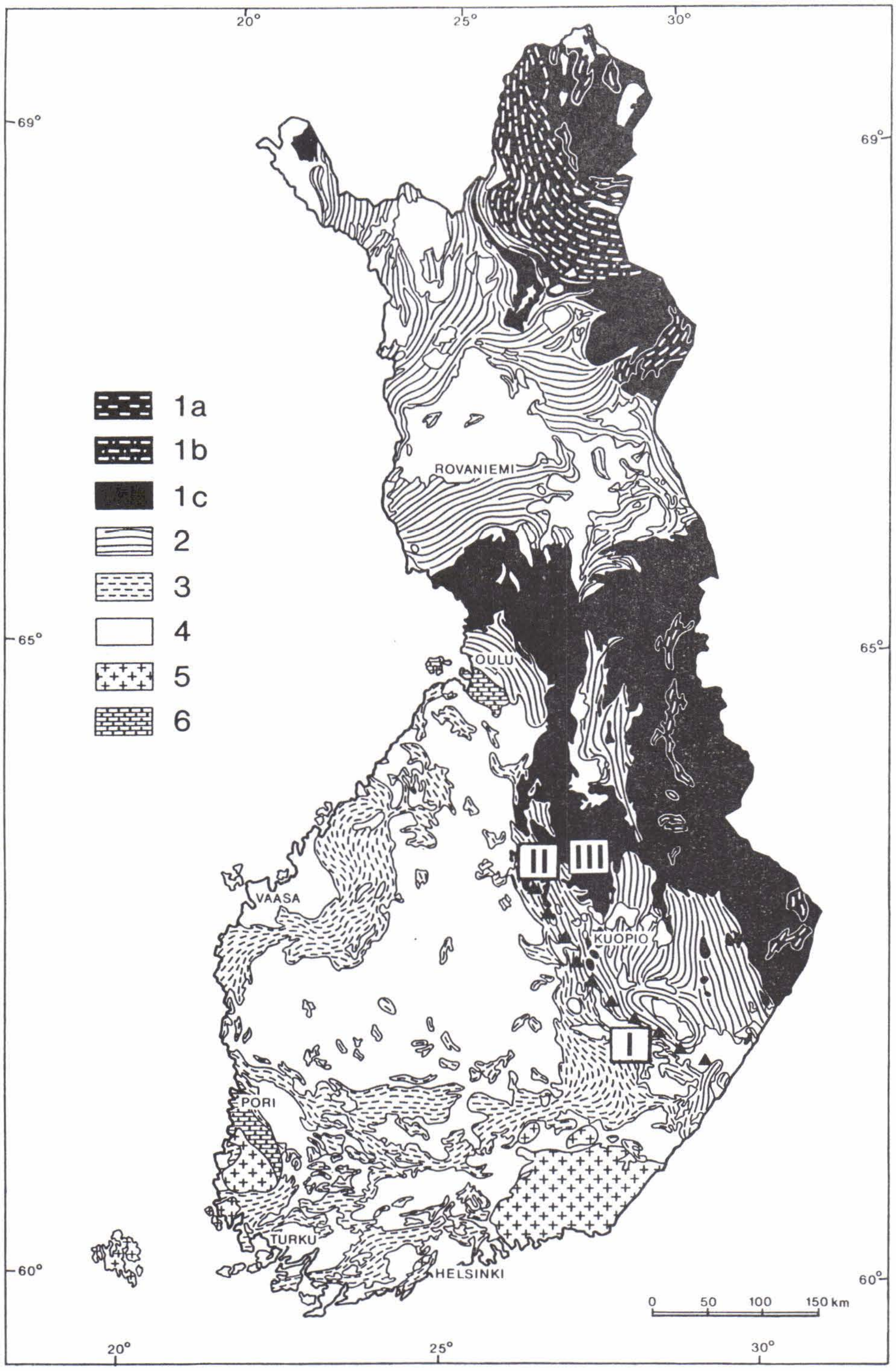

Fig. 1. The locations of the excursion areas on the map of the main structural units of Precambrian in Finland: I = Rantasalmi-Sulkava, II = Pielavesi-Kiuruvesi and III = Varpaisjärvi-Iisalmi. Presvecokarelidic: 1a = schist and paragneiss, 1b = granulite, 1c = orthogneiss. Svecokarelidic: 2 = Karelidic schist belt, 3 = Svecofennidic schist belt, 4 = orogenic plutonic rocks. Postsvecokarelidic: 5 = rapakivi granites, 6 = Jotnian sediments. After Simonen (1980). Black triangles = suture zone between Arhaean and Proterozoic.

gneissose, cataclastic and migmatic in structure. Intermingled with them are banded gneisses that are either orthogneisses or paragneisses (Simonen 1980).

The greenstone belts are mainly composed of mafic metavolcanics with associated minor ultramafic and acid metavolcanics; the volcanic rocks are lavas and pyroclasts in origin. The metasediments are meta-arcoses, phyllites, mica schists, black schists and quartz-banded iron ores (Simonen 1980).

The impact of the Proterozoic orogeny on the Archaean crust is a subject of keen debate. According to Luukkonen (1985 and 1988), seven deformation stages can be recognized in the Archaean crust, but only the youngest, which did little more than reactivate the weakness zones already existing in the crust, is due to Proterozoic deformation. The Proterozoic overprint is, however, clearly evident in the rejuvenated K-Ar ages (Simonen 1980).

In the west the Archaean craton is bounded by a suture zone (Fig. 1) along which a Proterozoic island arc system collided with the Archaean continent (Neuvonen et al. 1981 and Koistinen 1981). However, the Archaean complex is extensively covered with Proterozoic formations, the Archaean rocks occurring only in mantled domes in the Proterozoic bedrock (Simonen 1980). The effect of the Archaean crust on the Proterozoic formations east of the suture manifests itself in the Sm-Nd isotope compositions; some granitoids and metasediments east of the suture show a distinct Archaean component, which is very small in the western formations (Huhma 1986 and 1987).

A sequence of epicontinental rocks Jatulian clastic sediments, conglomerates, quartzites, dolomites and calcareous sediments deposited on the Archaean craton. Volcanic activities took place simultaneously with Jatulian sedimentation 2200-2000 Ma ago (Simonen 1980). The diabase dykes encountered in the weakness zones of the Archaean crust are also products of Jatulian volcanism (Luukkonen 1985). Thick Kalevian (c. 2000-1900 Ma) geosynclinal sediments deposited on the transgressive

Jatulian rocks (Simonen 1980). According to Koistinen (1981), extensive areas on the eastern side of the suture zone belong to an alloctonic formation which has overthrusted from west to its present position. According to Kontinen (1987), the Proterozoic ophiolite complex at Jormua (1.97 Ma) was emplaced in a rift that developed in the Archaean crust during the extensional stage of the Svecokarelidic orogeny, and moved to its present position during the compressional stage of the Svecokarelidic orogeny.

The crust west of the suture is mainly composed of marine sediments, island arc volcanics and granitoids, including the extensive Central Finland granitoid complex. The primary depositional basement of the sediments is unknown (Simonen 1980). The northern part of the craton margin developed earlier than the southern part, and so the differences between these areas in the evolution of the crustal structures are key topics of the excursion. The east-west trending schist belt in southern Finland, traditionally called the Svecofennian schist belt (Simonen 1980), is characterized by mica schists and mica gneisses, metabasalts and amphibolites, quartz-feldspar schists and minor quartzites and limestones. The most recent studies have shown that the evolution of the Svecofennian schist belt and the island arc system was highly complex and can be divided into several separate stages. It is also apparent that there is a collision zone between the Svecofennian schist belt and the northern part of the island arc system. Outlining the tectono-metamorphic evolution of the Proterozoic island arc system has been the main objective of IGCP project No. 235.

The emplacement of the 1670-1540 Ma old rapakivi granites (Vaasjoki 1977) and deposition of the unmetamorphosed Jotnian sediments represent later stages in the evolution of the Proterozoic crust. The rapakivis and Jotnian sediments are intruded by Postjotnian diabase dykes, 1275-1250 Ma in age (Simonen 1980).

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FIRST DAY, 16th JUNE

The topics of the first excursion day are the tectono-metamorphic evolution of the island arc system at the margin of the Archaean craton and the differences in evolution between the northern (Pielavesi-Kiuruvesi) and southern (Rantasalmi-Sulkava) parts.

THE RANTASALMI-SULKAVA AREA

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The Rantasalmi-Sulkava area is composed of Proterozoic metapelites, tholeiitic volcanics with ultramafic lavas, tonalites, migmatizing potassium granites, and tourmaline and beryl-bearing pegmatite dykes. The youngest plutonic rocks are equigranular granites and granodiorites. Limestones and quartzites are encountered occasionally. The Au mineralizations are the most important in terms of ore geology.

Metamorphic zones and crystallization conditions

The metamorphic grade in the Rantasalmi-Sulkava area rises towards the Sulkava thermal dome, and the following metamorphic zones have been established (Fig. 2): andalusite-muscovite (stop 1-3), potassium feldspar-sillimanite, cordierite-potassium feldspar, garnet-cordierite-biotite (stop 1-2) and garnet-cordierite-sillimanite, that is, the Sulkava thermal dome (stop 1-1). The metamorphic zoning is due to the following simplified reactions:

andalusite = sillimanite (stop 1-3),
muscovite+quartz = sillimanite+potassium feldspar,
biotite+sillimanite+quartz =
    potassium feldspar+cordierite+melt and
biotite+sillimanite+quartz =
    potassium feldspar+cordierite+garnet+melt.

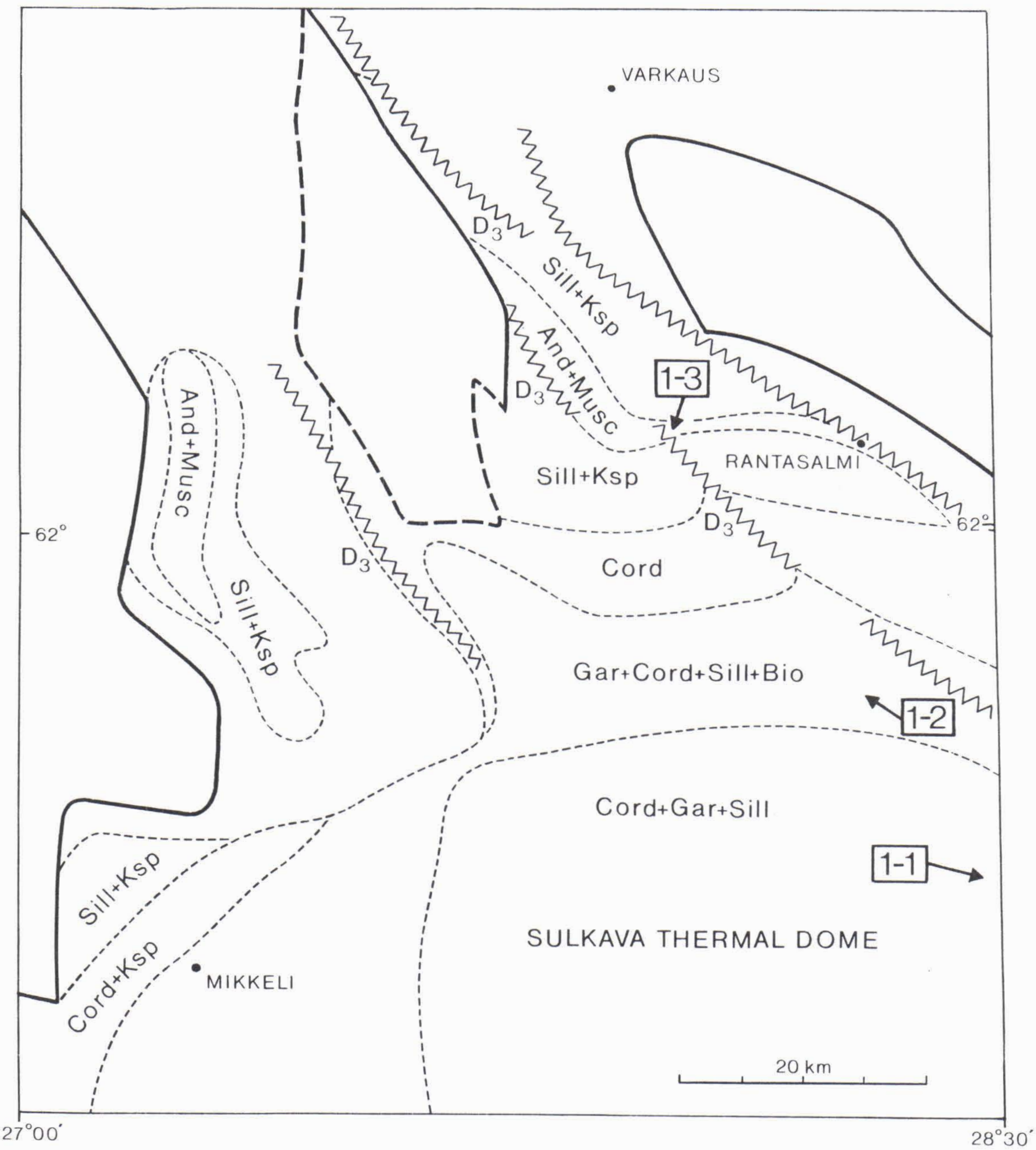

Fig. 2. Excursion stops on the metamorphic map of the Rantasalmi-Sulkava area.

Andalusite altered into sillimanite almost simultaneously with the decomposition of muscovite. The sillimanite that crystallized in the decomposition reaction of muscovite is fibrous whereas the sillimanite replacing andalusite is prismatic. Melting began in the cordierite-potassium feldspar zone, but some of the potassium feldspar porphyroblasts, which crystallized in the decomposition reaction of micas, are preserved as far as the southern part of the garnet-cordierite-biotite zone (stop 1-2). Not until the Sulkava thermal dome is the melting of granitic components complete (stop 1-1). The garnet-cordierite gneisses are migmatized or intruded by a coarse-grained potassium granite. The migmatization degree increases parallel to the rise in metamorphic grade.

Metamorphic reactions buffered the rise in temperature in the garnet-cordierite-biotite zone, where the crystallization temperature increases at a very slow rate towards the Sulkava thermal dome. Therefore, the products of prograde crystallization are very well preserved, even in the southern part of the garnet-cordierite-biotite zone (stop 1-2). By the Sulkava thermal dome, however, these relics have been almost completely obliterated. On the basis of the metamorphic reactions and the garnet-cordierite and biotite-garnet pairs, crystallization on the potassium feldspar-sillimanite isograd during progressive metamorphism took place at 650°C and 4 kb, on the garnet-cordierite isograd at 670°C and 4 kb, in the southern part of the garnet-cordierite zone at 680°C and 4.8 kb, and in the Sulkava thermal dome at 750°C and 4.5 kb. As the prograd features are preserved in the metapelites, the temperatures can be considered as maximum ones, excluding those recorded from the Sulkava thermal dome.

Temporal evolution of the metamorphism and its relation to deformation

The fold structures of the first deformation stage are encountered only in the andalusite-muscovite zone (stop 1-3). Andalusite crystallized and muscovite and biotite were decomposed during the D_2 deformation but garnet and cordierite were not equilibrated until afterwards. As shown by the relics of products of the decomposition reactions of muscovite and biotite, metamorphism gets younger towards the Sulkava thermal dome. Garnet and cordierite were equilibrated earlier in the Sulkava thermal dome than in its environment. D_2 also gets younger towards the Sulkava thermal dome, and the lag between D_2 and D_3 decreases towards the thermal dome.

Tonalites, which were deformed during the D_2 phase and metamorphosed in progressive metamorphism, are the oldest plutonic rocks in the Rantasalmi-Sulkava area. The U-Pb age on zircons from the tonalites, 1888±15 Ma, represents the maximum age of progressive metamorphism and the D_2 deformation. The structures of progressive metamorphism are cut by 1800 Ma old granitoids. The zircon age of the garnet-cordierite-sillimanite gneiss in the Sulkava thermal dome is 1810±10 Ma. Zircon was completely recrystallized during progressive metamorphism. The above ages suggest that both progressive metamorphism and the associated D_2 deformation evolved 1890-1810 Ma ago.

The monazite age of a garnet-cordierite gneiss is 1840 Ma. However, the corresponding age from the garnet-cordierite-biotite zone is 1796±15 Ma. These data corroborate the concept that the strongest thermal pulse gets younger outwards from the Sulkava thermal dome.

Mineral growth is seldom associated with the D_3 deformation, which is fragmentizing in character. This deformation had a strong impact on the structural elements visible on the present erosional surface and particularly on the bending of the isograd surfaces in the northern Rantasalmi-Sulkava area. The migmatizing potassium granite was folded by D_3. The U-Pb age on zircon from potassium granite is 1833±16 Ma. However, as shown by the compositions of the garnet inclusions and fluid inclusions in garnet, the crystallization history of the potassium granite is long and complex. The D_3 structures are crosscut by the 1800 Ma old granites, and they, in turn, are folded by the D_4 deformation.

Beryl and tourmaline-bearing pegmatite dykes rich in sodium mainly occur in the sillimanite-potassium feldspar and andalusite-sillimanite terranes. The dykes have not been radiometrically dated; however, they are postmetamorphic and in places crosscut the D_3 deformation but in other places are syntectonic with it.

Progressive metamorphism in the Rantasalmi-Sulkava area took place in two stages. The decomposion reactions of muscovite and biotite get younger towards the Sulkava thermal dome, whereas garnet and cordierite were equilibrated earlier in the thermal dome than outside it. Like the decomposition reactions of the micas, D_2 is associated with overthrust tectonics in the northern part of the area. Therefore, the early stages of progressive metamorphism can be attributed, at least partly, to metamorphism of the tectonically thickened crust. The strong thermal flow in the Sulkava thermal dome, however, cannot easily be ascribed solely to metamorphism of the tectonically thickened crust. On the basis of the temporal evolution, the heat pulse of the thermal dome could be due to rifting of the crust during the tensional stage, as suggested by some 1800 Ma old granitoids.

Excursion stops

Stop 1-1. The Sulkava thermal dome, Säviönsaari; X = 6849.70, Y = 577.90.

At this site participants will see a metapelite with the assemblage garnet-cordierite-sillimanite-potassium feldspar-quartz. This metapelite has undergone the strongest metamorphism in the Rantasalmi-Sulkava area. The gneiss also contains biotite, but it is a retrograde rather than a stable phase in the sillimanite-bearing rocks within the Sulkava thermal dome. The granitic components of the metapelites were almost completely melted and the gneisses were cut and heavily migmatized by a coarse-grained potassium granite. The garnet-cordierite-sillimanite gneiss crystallized at 750°C and 4.4 kb (X_{Mg} = 0.20 for garnet and X_{Mg} = 0.58 for cordierite). The U-Pb age on zircon from the garnet-cordierite gneiss is 1810±16 Ma and from the potassium granite 1833±16 Ma. The K-Ar age on biotite is 1651±20 Ma.

Stop 1-2. The southern part of the garnet-cordierite-biotite zone, Metsälä; X = 6864.58, Y = 567.57.

The metamorphic grade of this outcrop is distinctly lower than that at the first stop; migmatitization is less intense than in the Sulkava thermal dome, the biotite abundance is fairly high and biotite is a stable phase in sillimanite-bearing rocks. The gneiss crystallized at 685°C and 4.8 kb (X_{Mg} = 0.20 for garnet and X_{Mg} = 0.63 for cordierite). The crystallization temperature deduced from the garnet-biotite pair is 680°C. The crystallization stages of prograde metamorphism are clearly visible in the outcrop. The first cordierite phase crystallized on the sillimanite porphyroblasts produced by decomposition reactions of muscovite. The potassium feldspar porphyroblasts produced by these decomposition reactions crystallized over the S_1 schistosity, which is therefore preserved as relics only in the early potassium feldspar porphyroblasts. Some cordierites that crystallized due to the first decomposition reaction of biotite are syntectonic with D_2, but some have overgrown the S_2 schistosity. Garnet and cordierite were clearly equilibrated after D_2.

Stop 1-3. The andalusite-muscovite zone and the andalusite-sillimanite isograd, Vuotsinsuo; X = 6806.45, Y = 552.08.

The most important deformation phases in the Rantasalmi-Sulkava area are visible at this site. D_1 manifests itself in isoclinal or subisoclinal folds with a wavelength of hundreds of metres. Andalusite has overgrown the early stage of D_2 syntectonically with S_2. In the outcrop, andalusite occurs for the first time together with sillimanite. Sillimanite, too, is syntectonic with D_2, although it grew later than andalusite. The beryl pegmatites are partly syntectonic with D_3 but in places crosscut the D_3 structures. The D_4 deformation folds the beryl pegmatites.

THE PIELAVESI-KIURUVESI AREA

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Geological Survey of Finland

The tectono-metamorphic and temporal evolution of the Proterozoic crust in the Pielavesi-Kiuruvesi area in the northern part of the Archaean craton (Fig. 1) differs from that in the Rantasalmi-Sulkava area in the southern part. In the Pielavesi-Kiuruvesi area the crustal structure is characterized by metamorphic blocks that, apart from granulite grade block III (stop 1-4) and transitional amphibolite-granulite facies block IV (stop 1-5), were metamorphosed under conditions of amphibolite facies (Fig. 3). The prograde stage of metamorphism took place earlier in the north (1920-1890 Ma) than in the south (1880-1810 Ma) and its peak coincided with magmatic activity. The crust also stabilized earlier, for intense orogenic evolution was still going on in the south while the post-tectonic granitoids were being emplaced in the Pielavesi-Kiuruvesi area (stop 2-1).

Adjacent to the craton margin there are clastic sediments (block I) that grade into pelitic sediments (blocks I and II) farther west. Pelitic rocks are less abundant in the other blocks of the Pielavesi-Kiuruvesi area as the volcanic matter increases. The volcanism was of the bimodal island arc type (see Kousa and Lahtinen, abstr., this volume). The area is also characterized by garnet-cordierite-orthoamphibole/orthopyroxene rocks (stops 1-4 and 1-5). As well as post-tectonic pyroxene granitoids there are syntectonic gabbros and granitoids (two-pyroxene granitoids in the granulite block) and gneissose tonalite (1930-1920 Ma), whose relation to the surrounding schists has not been established. The marginal area of the craton, known as the Raahe-Ladoga belt, contains a considerable proportion of Finland's sulphide ore resources, primarily the massive Cu-Zn-(Pb) ores and the Ni-Cu ores in mafic intrusions.

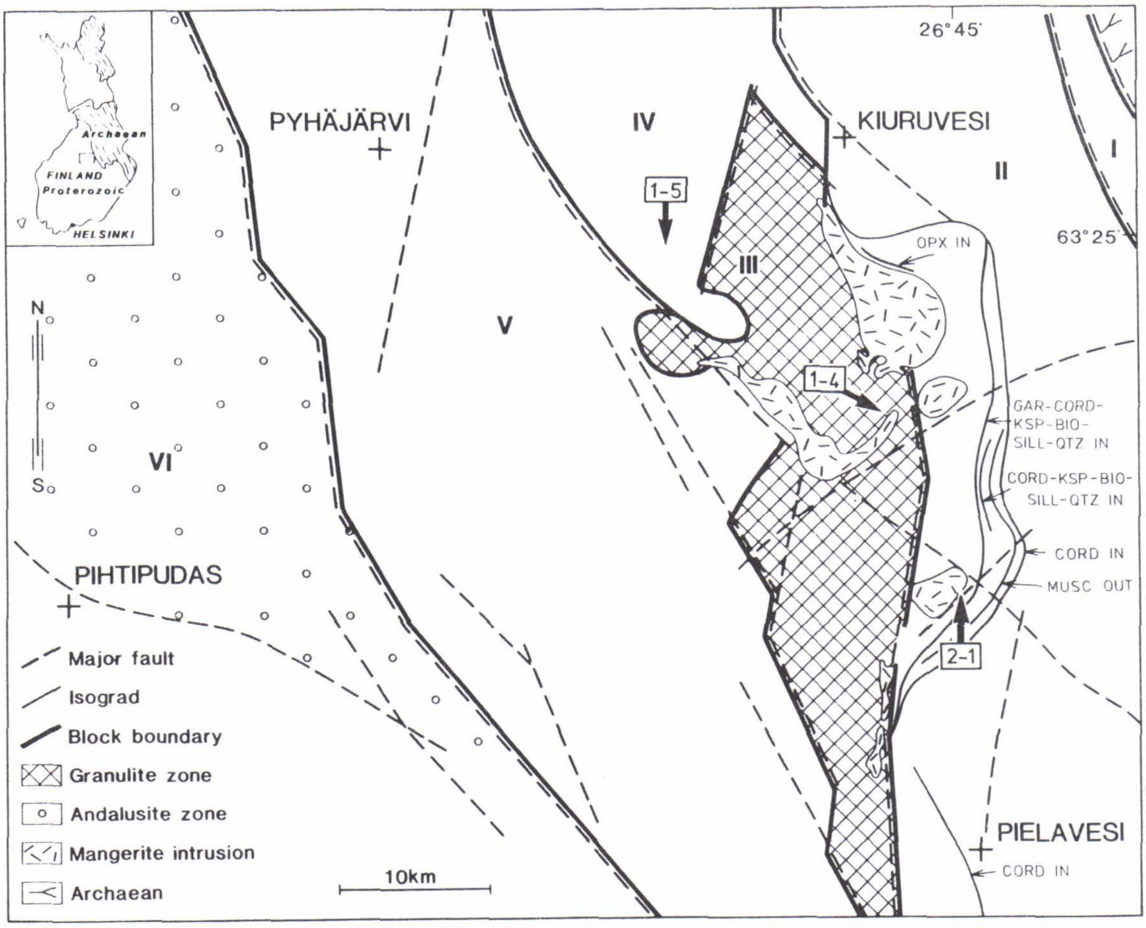

Fig. 3. Excursion stops on the metamorphic map of the Pielavesi-Kiuruvesi area. I = medium amphibolite facies (staurolite-sillimanite grade), II = medium amphibolite facies (sillimanite grade, staurolite as relics), III = granulite facies (orthopyroxene grade), IV = amphibolite-granulite transitional zone (garnet-cordierite-sillimanite-quartz equilibrium, orthopyroxene sporadic), V = medium to upper amphibolite facies (garnet-cordierite-sillimanite-quartz equilibrium rare) and VI = low amphibolite facies (andalusite grade).

Deformation and metamorphic crystallization conditions

The first two deformation stages were associated with prograde metamorphism. Unlike in the Rantasalmi-Sulkava area, the first deformation stage in the Pielavesi-Kiuruvesi area was intense and generated strong mineral schistosity mostly subparallel to the layering. Isoclinal F_1 microfolding is only visible in places (Koistinen, oral comm., 1988).

D_2 is tight half-open folding. The axial plane schistosity, S_2, is usually less intensely developed than S_1 and manifests itself as biotite schistosity, recrystallization of minerals and crenulation structure. Metamorphism did not culminate until a static state had been reached and D_2 had ceased. At the same time, mobilization took place in the crust.

A zircon age, 1889±3 Ma, from a garnet-cordierite-hypersthene rock in the granulite block (stop 1-4) shows that the lag between granulite grade metamorphism and the emplacement of the post-tectonic granitoids (stop 2-1) was short.

The Sm-Nd isochron of garnet and plagioclase gives an age of 1891±5 Ma. The age of monazite, 1873±5 Ma, is almost the same as that of the monazite from the hypersthene granitoid, and obviously refers to the age of regional cooling to below 500-600°C.

The isograds encircling the hypersthene granitoids (Figs. 3 and 4), and thermobarometer determinations on the inclusions in the garnet from the granulite area show that the crust was reheated as a result of post-tectonic pyroxene granitoid magmatism after the peak of regional metamorphism.

D_3, which fragmented the crust, is an important regional deformation stage. The whole margin of the craton is characterized by intense NW-SE trending faults. In the Rantasalmi-Sulkava area the isograds are bent by D_3, whereas in the Pielavesi-Kiuruvesi area the changes in metamorphic grade often take place at the D_3 faults. The deformation was accompanied by fluid activity resulting in granitization. D_3 is also an important deformation stage in terms of mineralization. The emplacement of the Ruostesuo (stop 1-5) and Hallaperä sulphide ores was controlled by a D_3 fault. The Hallaperä sulphide ore deposit exhibits metamorphic zoning, retrograde metamorphism with hydration and sulphurization reactions during mineralization. The Ruostesuo deposit is located in an environment of altered rocks. The sulphides follow the shape of an F_2 fold as a stratigraphic horizon but they were upgraded during D_3, or even later (Koistinen, oral comm., 1988). The signs of later sulphurization are not as clear in the contact of the Ruostesuo sulphide orebody as in the contact of the Hallaperä orebody.

Excursion stops

Stop 1-4. Kiuruvesi, Sahinperä; X = 7042.94, Y = 482.02.

The outcrop is garnet-cordierite-hypersthene rock with garnet-biotite-plagioclase-quartz, garnet-cordierite-orthopyroxene-plagioclase-quartz-iron oxide±hercynite and cordierite-quartz-iron oxide±sillimanite assemblages. This rock, like the other garnet-cordierite-orthpyroxene rocks in the granulite block, shows several corona and replacement structures such as the alteration of orthopyroxene, cordierite and iron oxide into garnet. On the other hand, garnets are often rimmed with orthopyroxene or orthopyroxene-plagioclase coronas or cordierite-orthopyroxene symplectite, demonstrating that the reactions garnet+quartz = orthopyroxene+plagioclase or garnet+quartz = orthopyroxene+cordierite proceeded in both directions. On the basis of thermobarometric data, the reactions that generated the garnet coronas are attributed to an almost isobar cooling, and the orthopyroxene coronas to uplift of the granulite block. The pyrope content of the garnet cores is about 0.30-0.35. The X_{Mg} of orthopyroxene is 0.50-0.60, that of cordierite about 0.75 and that of biotite 0.5-0.6. The garnet-orthopyroxene-plagioclase-quartz barometer indicates an average pressure of 5.5 kb and the garnet-orthopyroxene thermobarometer a temperature of 800-880°C, measured from the cores of the minerals.

Stop 1-5. Kiuruvesi, Ruostesuo.

Two localities are visited at this site:

a) X = 7054.93, Y = 468.50.

The outcrop is composed of garnet-cordierite-orthoamphibole gneiss that resembles the garnet-cordierite-hypersthene rock in the granulite grade block at stop 1-4 but represents a lower grade. The gneiss shows S_1 and S_2 structures developed during the prograde stage of metamorphism. S_1 is a mineral schistosity almost parallel to the layering. The outcrop is located in the crest of a big F_2 fold in which S_2 crenulates S_1 at a high angle (Koistinen, oral comm., 1988). Biotite$_1$, cordierite$_1$ and orthoamphibole$_1$, which crystallized along S_1, were stabilized in the gneiss during D_1. Biotite was replaced by orthoamphibole in a reaction that did not produce other potassium-bearing phases. Therefore, D_1 also reduced the potassium content. During D_2 orthoamphibole$_2$ recrystallized into grain clusters, and the fine-grained biotite$_2$ crystallized on the S_2 plane. The poikiloblastic cordierite$_2$ probably also crystallized during the D_2 stage in the decomposition reaction of biotite. Some garnet-cordierite pairs stabilized during D_2, but the bulk of the garnet did not crystallize until after the dynamic stage of D_2, thus representing the thermal peak of metamorphism.

b) X = 7054.65, Y = 468.22.

The bedrock of the locality is composed of iron-rich garnet-cordierite-orthoamphibole gneisses, coarse-grained cordierite-orthoamphibole rocks, garnet-cordierite-sillimanite gneisses and acid cordierite-sillimanite gneisses. The structures of the rocks are characterized by layering and S_1 schistosity. In places F_2 folds with weakly developed S_2 axial plane schistosity are visible. In the garnet-cordierite-anthophyllite rocks the crystallization of garnet, which occasionally has S_1-S_2 as S_i structure, continued after the dynamic D_2 stage, overprinting the earlier deformation structures. In the garnet-cordierite-sillimanite gneisses, the big garnet grains on the flank of the F_2 fold are syntectonic, indicating that garnet started to crystallize early, simultaneously with the development of S_2. The garnet-cordierite thermobarometer indicates a crystallization temperature of about 700°C and a pressure of 4-5 kb. The exotic rocks in the area show evidence of reactions reflecting the evolution of the PT conditions. For example, the rare sapphirine-bearing rocks exhibit reactions, which, unlike in the Archaean granulite terrane (stop 3-2), resulted in the decomposition of sapphirine into spinel, thus indicating falling temperature and pressure in the PT field (Hudson, oral comm., 1988).

SECOND DAY, 17th JUNE

In the morning the participants will have a chance to study the geotectonic position, contact effects and geochemical character of the Vaaraslahti pyroxene granitoid intrusion. In the afternoon there will be a poster session on the studies undertaken in the area.

THE VAARASLAHTI PYROXENE GRANITOID INTRUSION

Pentti Hölttä, Seppo Lahti and Matti Pajunen
Geological Survey of Finland

The lag in evolution between the northern (Pielavesi-Kiuruvesi) and southern (Rantasalmi-Sulkava) parts of the craton margin is evident in the age relations of post-tectonic magmatism. While the post-tectonic pyroxene granitoids were intruding about 1880 Ma ago in the north intense orogenic activity was going on in the south, where the 1880 Ma old granitoids are syntectonic. Shown at the stop is the contact of the Vaaraslahti pyroxene granitoid as a representative of post-tectonic magmatism in the northern part of the craton margin, and its thermal and tectonic effect on the surrounding semipelitic mica gneisses and Ca-rich gneisses.

The Vaaraslahti granitoid (Fig. 4) was emplaced in two stages. The earliest pulse, quartz syenitic in composition, is brecciated by a granitic phase. The major minerals are potassium feldspar (intermediate microcline or orthoclase), plagioclase (An_{28-38}), biotite, orthopyroxene (Fs_{77-83}) and ferrohastingsite. Granite is poorer in mafic minerals and richer in quartz; orthopyroxene is poorer in iron (Fs_{70-77}), and potassium feldspar is microcline. The accessories are ilmenite-magnetite, monazite, zircon, apatite and garnet.

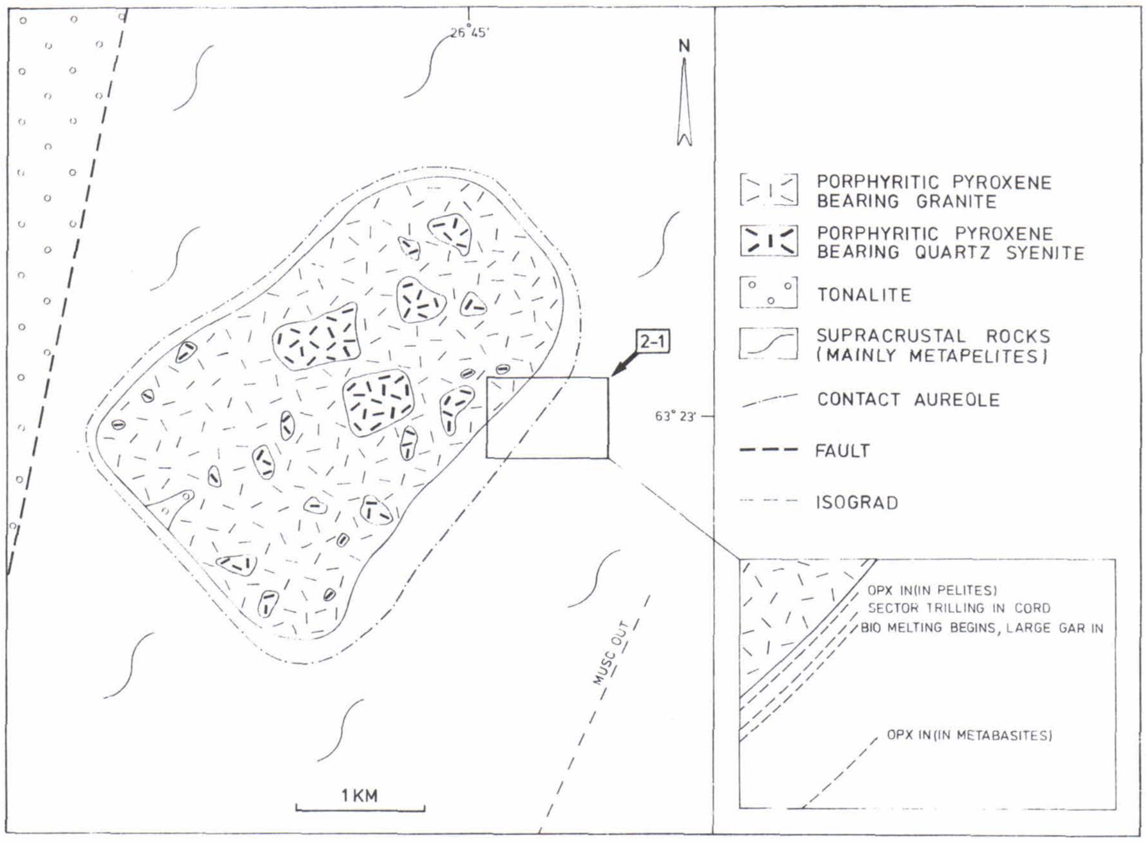

Fig. 4. Excursion stop on the geological/metamorphic map of the Vaaraslahti intrusion.

The granitoid is I-type in geochemical character, but its Nd isotope composition (ϵ_{Nd} = -0.6) and slightly peraluminous nature (A/CNK = 1.0-1.13) show that crustal assimilation has also taken place. The chemical difference between the two magma pulses can be attributed to fractional crystallization and assimilation. The Fe and Ba values in the granitoids are exceptionally high: syenite contains 4-7% Fe_2O_3 and 2000-3800 ppm Ba, granite somewhat below that. Rare earths fractionated into the last granite differentiates, and the fractionation of the rare earths in granite is more advanced (Ce_n/Yb_n = 23) than in quartz syenite (Ce_n/Yb_n = 15).

The isograds of the prograde reactions (Fig. 3) follow the shape of the granitoid and demonstrate that the thermal effect of the Vaaraslahti intrusion is evident up to one kilometre from the intrusion. The contact metamorphism caused by the intrusion cuts the older amphibolite grade regional metamorphism. Close to the granitoid body, at about 100 m from the contact, granulite grade conditions were attained: the garnet-cordierite temperature is about 750°C and the pressure about 4.5 kb, which is lower than the crystallization pressure of the rocks in the environment by about one kilobar.

In the contact rocks of the Vaaraslahti granitoid, S_1 is penetrative biotite schistosity that developed approximately parallel to the S_0 layering and along which felsic minerals segregated to some extent. The granitoid crosscuts the S_0-S_1 structure at a high angle. In the north of the Savo schist belt the thermal peak of metamorphism was reached during, or even after, the D_2 deformation. In the northern part of the craton margin, D_2 is a moderately intense folding stage, although the associated axial plane schistosity, S_2, is often only weakly developed. The Vaaraslahti granitoid was emplaced during the tensional stage that followed D_2.

The rise in temperature towards the intrusion resulted in a succession of tectonic structures around the granitoid. Their development was facilitated by the partial melt enriched in potassium and generated by the decomposition reactions of biotite; neosome often rims garnet grains and occurs as veins associated with the plastic crenulation parallel to the contact. The migmatitic contact gneiss is intruded by an anatectic garnet-cordierite rock with a plutonic texture and a composition similar to that of banded garnet-cordierite gneiss. Weak biotite schistosity parallel to the contact of the granitoid developed in both the anatectic rock and the migmatitic gneiss.

The thermal influence of the granitoid is also seen in the radiometric ages of the contact gneiss. Right in the contact of the granitoid, where the temperature reached about 800°C, the detrital zircon (1892±5 Ma) is fully recrystallized, being of the same age as the zircon from the granitoid (1884±5 Ma), within the limits of error. Farther away from the contact (about 80 m), in the potassium feldspar-garnet-cordierite stability area, the zircon age is rejuvenated but not totally reset. The monazite age of the contact rock (1879±3 Ma), which is about the same as that of the granitoid (1874 Ma), is interpreted as denoting the date when the temperature dropped below the blocking temperature of monazite. Farther from the contact, monazite shows an older age (1887±4 Ma).

The contact zone of the granitoid has cataclastic zones that are younger than the contact metamorphism and show retrograde muscovitization caused by an increase in potassium activity.

Excursion stop

Stop 2-1. Pielavesi, Yijäkönmäki; X = 7031.30, Y = 488.10.

POSTER SESSION

The geochemistry of basic metavolcanic rock in Pyhäjärvi, Rautalampi and Rantasalmi - Jukka Kousa and Raimo Lahtinen, Geological Survey of Finland

The supracrustal rocks of the Raahe-Ladoga belt that occur in Pyhäjärvi, Rautalampi and Rantasalmi are Lower Proterozoic Svecofennidic schists. The volcanics in the Pyhäjärvi area are predominantly medium-grade metamorphic mafic and acid lavas and pyroclastics. The preserved pillow lava structures show that at least some of the volcanics erupted in a subaquatic environment. The mafic metavolcanics of the bimodal volcanism correspond to basalts and basaltic andesites, and the acid varieties to quartz keratophyric Na-predominant rhyolites. The intermediate metavolcanics, which are less common in the area, are andesitic-dacitic. The mafic metavolcanics are transitional in geochemistry between the products of calc-alkalic and tholeiitic magmatism and resemble recent island arc volcanics.

The Rautalampi area underwent granulite grade metamorphism and corresponds to the Pielavesi-Kiuruvesi area in tectono-metamorphic evolution. The volcanic, slightly tholeiitic low-K amphibolites in the area and the Na-rich acid gneisses constitute a bimodal unit. The amphibolites resemble basalts and basaltic andesites of recent marine-transitional island arcs in geochemistry.

The mafic-ultramafic volcanic unit in Rantasalmi was metamorphosed in the potassium feldspar-sillimanite zone. The metavolcanics of the unit are picritic-tholeiitic basalts in composition, the most primitive being komatiitic in character. The pillow lavas and the surrounding greywackes indicate a marine extrusion environment, as do the geochemical features similar to those of the recent MOR basalts.

The metavolcanics in Pyhäjärvi and Rautalampi are similar in geochemistry. The bimodality of the volcanism is suggestive of a tensional stage and incipient island arc rifting. A clear greywacke environment lacking acid volcanics characterizes the Rantasalmi area. The primitive nature of the metavolcanics in the area (MORB) also points to tensional conditions and possibly to the development of the upper slope basin of the island arc system. The relationship between the tensional stage in Rantasalmi and that in Pyhäjärvi and Rautalampi has not been established.

The U-Pb mineral chronology of the Raahe-Ladoga zone - Matti Vaasjoki and Matti Sakko, Geological Survey of Finland

U-Pb dating of zircons, monazites and titanites along the Raahe-Ladoga zone indicates several phases of magmatic and metamorphic activity, which can be summarized as follows:
(1) volumetrically minor but spatially widely distributed

granitoid rocks in the central part of the zone registering ages between 1930 and 1910 Ma;

(2) extrusion of intermediate-silicic volcanic rocks about 1910-1900 Ma ago;

(3) intrusion of Ni-bearing early orogenic gabbros 1900-1880 Ma ago;

(4) intrusion of syntectonic granitoids, hypersthene granites and plagioclase porphyrites/ophitic gabbros throughout the length of the belt accompanied by the peak of regional metamorphism in the central and northwestern parts 1890 to 1875 Ma ago;

(5) emplacement of post-tectonic rocks in the central and northwestern parts 1880-1850 Ma ago;

(6) peak of regional metamorphism with simultaneous migmatization in the southeastern part of the belt 1830-1810 Ma ago;

(7) intrusion of post-tectonic granitoids in the southeast about 1800 Ma ago.

It appears that the new Svecofennian crust was rapidly generated between 1930 and 1850 Ma ago by the collision of a Proterozoic oceanic plate with an Archaean continent. Subsequent underplating from W to E south of 62°N resulted in migmatization at about 1820 Ma and the intrusion of the ca. 1800 Ma post-tectonic granites in southern Finland.

Result from metapelites indicate that whereas zircon increasingly tends to lose its radiogenic lead as the temperature of regional metamorphism rises, total resetting is not achieved, not even at the garnet-cordierite-biotite grade. Only intense migmatization and/or immediate contact effects of hypersthene granites, approaching temperatures of 800°C, are sufficient to totally reset the U-Pb record of zircons.

Metamorphism and uplift history of the Svecokarelides in the Pihtipudas-Iisalmi and Joroinen-Sulkava areas - Ueli Haudenschild, University of Bern, Switzerland

K-Ar age determinations on biotite, white mica and hornblende, and Rb-Sr age determinations on mica and whole rock samples have allowed us to develop a detailed picture of metamorphism and subsequent cooling history of the Pihtipudas-Iisalmi and Joroinen-Sulkava areas, eastern Finland.

Previous studies indicate intrusive ages of synorogenic granitoids at around 1920 Ma and 1880 Ma. Rb-Sr whole-rock ages on metapelitic rocks suggest an age of metamorphism between 1810 Ma and 1830 Ma. One single isochron indicates the existence of an older metamorphic event, correlated with granulite-facies metamorphism in the Pielavesi block at 1920 Ma to 1880 Ma. The same metamorphic phase is postulated to have overprinted the Vaaraslahti block, as the contact metamorphism of an 1880 Ma synorogenic hypersthene-granite overprints older metamorphic structures. Early differences in the uplift rates of different parts of the areus predating the 1810 Ma metamorphism led to a weak overprint of the Pielavesi and Vaaraslahti blocks during 1810 Ma event, while the neighbouring blocks and the Joroinen-Sulkava area metamorphosed under amphibolite facies conditions.

The subsequent cooling history was similar in both areas. Cooling rates between the metamorphic overprint and the subsequent cooling to 500°C were low. There are also differences in the uplift rates between different blocks caused by the fault zone of Kinturi. The period between 500°C and 350°C shows a very high cooling rate due to strong uplift of the areas followed by a slower cooling to 300°C between 1750 Ma and 1600 Ma.

The distribution of biotite K-Ar ages shows a gradual decrease in age between Pihtipudas and Pielavesi, Pielavesi and Lampaanjärvi, and Rantasalmi and Sulkava, corresponding to an increase in the grade of metamorphism in the Pihtipudas and

Rantasalmi-Sulkava areas, e.g. a dip in the surface at temperatures below 300°C. Between Korppinen and Pielavesi, Joroinen and Rantasalmi and probably between Vaaraslahti and Lampaanjärvi, a jump in the biotite ages indicates the existence of fault line, which was active before the dipping of the blocks.

Apparent K-Ar ages of coexisting biotite and hornblende in Archaean gneisses - Juha Karhu, Geological Survey of Finland

Most of the published K-Ar data on biotite from the Archaean basement show younger Proterozoic ages at around 1.8 Ga, suggesting episodic Ar loss during the Svecokarelian orogeny. In order to study the extent and nature of this reheating event we have compared the K-Ar isotope systematics of coexisting biotite and hornblende in 30 samples from the Archaean basement area in eastern Finland.

The apparent K-Ar ages of biotite and hornblende define an array ranging from about 2.7 Ga to 1.8 Ga for both minerals. Contrary to earlier knowledge, some biotites clearly have a significant Archaean Ar component. As can be expected, the apparent ages calculated from hornblende are almost invariably higher than those from coexisting biotite, with a difference ranging up to 0.8 Ga.

The extent of the Ar loss can be related to the mineralogical and textural features of the rock samples. The samples retaining a significant Archaean Ar component in both biotite and hornblende represent granulite facies terrains and typically contain orthopyroxene. Biotite and hornblende are primary in these samples, and the Ar loss can mainly be ascribed to volume diffusion. The samples in which hornblende has retained an Archaean Ar component but biotite has been almost completely rejuvenated show distinctive features of intense retrograde recrystallization. Plagioclase has been saussuritized and hornblende has been partially replaced by biotite and epidote aggregate. This suggests that Ar loss occurred through combined effects of mineral reactions and volume diffusion under low-grade conditions.

The rock samples in which both biotite and hornblende have been completely rejuvenated are mostly granoblastic biotite-hornblende-plagioclase gneisses with unaltered plagioclase, although some epidote-bearing samples are also included. Low K-Ar ages of about 1.8 Ga, together with the common lack of retrograde low-grade minerals, suggests recrystallization, possibly coupled with diffusional Ar loss from primary minerals, under amphibolite facies conditions.

In conclusion, the Archaean basement in eastern Finland was affected by a strong thermal pulse during the Svecokarelian orogeny. Only samples from the high grade terrains avoided intense recrystallization and significant Ar loss, possibly due to the low initial water content.

Evolution of the metamorphic fluid phase during progressive metamorphism in the Rantasalmi-Sulkava area, southeastern Finland, as indicated by fluid inclusions - Matti Poutiainen, University of Helsinki

The study of fluid inclusions in metamorphic rocks may throw light on the metamorphic history of the rocks in which they occur. The inclusions provide a direct way of determining the composition of the fluids present during metamorphism. Recent studies have shown that fluid inclusions may be used to constrain the pressure and temperature conditions of metamorphism. In addition, successive generations of inclusions may be used to outline the PT path the metamorphic terranes followed during the uplift and erosion.

About 60 samples covering the whole area affected by progressive metamorphism and anatexis were investigated by microthermic methods. The samples were collected from quartz veins of different relative ages, metapelites, premetamorphic tonalites, pegmatites and migmatizing microcline granite. Quartz veins occurring in the metapelites (denoted in the study pre-D_2 or syn-D_2 and D_3 veins) were folded by D_2 and D_3. Thus, they are readily recognizable in the metapelite outcrops in the less intensely metamorphosed zones. In higher-grade zones the quartz veins are more obscure and where the abundance of migmatitic granitic material is relatively high, the samples were only collected from metapelites. As has been pointed out, the relationship between progressive metamorphism and deformation phases indicates a decreasing age of metamorphism towards the Sulkava thermal dome. Thus, it has been possible to outline the evolution of the fluid phase during the different stages of progressive metamorphism.

Fluid inclusions are much more abundant in the quartz veins and migmatizing granites than in the host rock (metapelites), where they are largely restricted to the matrix quartz. They fall into four main categories: (1) CO_2-rich inclusions, (2) H_2O-rich inclusions, (3) mixed H_2O and CO_2 and (4) CH_4-N_2 inclusions. The CO_2-rich inclusions are the most abundant, varying in size from <10 to 60 μm. They are monophase or biphase at room temperature, and are irregular to negative crystal in shape. These carbonic inclusions have been subdivided into three successive generations with decreasing age and fluid density. This division is supported by the morphology of the inclusions and their manner of occurrence. The threefold division of CO_2 inclusions is clear in the frequency histograms of homogenization temperatures. Isolated or small clusters of CO_2-rich inclusions (type I) are considered to be older than CO_2 inclusions occurring in an intragranular trail (within a single quartz crystal, type II). The youngest carbonic inclusions (type III) occur along healed fractures which generally crosscut the grain boundaries (intergranular trails). The lower homogenization temperatures for CO_2 inclusions (homogenization in a liquid state) correspond to early inclusions (type I and II), whereas the higher homogenization temperatures correspond to late inclusions (type III, homogenization in a gaseous state). Only a few CO_2 inclusions contain a daughter mineral (nacholite, $NaHCO_3$?).

Aqueous inclusions vary in size from <10 to 200 μm. They have planar arrangement, often with crosscutting arrays of CO_2-rich inclusions. H_2O-rich inclusions vary in form from highly irregular (very young inclusions, monophase at room temperature) to regular (early type inclusions, biphase at room temperature). Daughter minerals in aqueous inclusions are rare. The manner of occurrence and relationship indicate late entrapment.

Mixed H_2O-CO_2 inclusions are rare. They are a dominant fluid type only in the quartz core of beryl-bearing pegmatite. These composite inclusions occur mostly at intersections of H_2O and CO_2 inclusion trails. Thus, the proportion of H_2O to CO_2 inclusions and their morphology are highly variable.

CH_4-N_2 inclusions have been encountered only in the northern part of the study area. They are very dark and monophase (gaseous) at room temperature and range in shape from more or less irregular to tubular. The CH_4-N_2 inclusions are generally larger (20-60 μm) than the aqueous and carbonic inclusions. Their very low dənsity and manner of occurrence suggest entrapment at very low pressures and late in the metamorphic evolution of the rocks.

The regional distribution of the different fluid inclusion types and their relative abundance indicate that the progressive metamorphism is marked by a progressive change in fluid composition from H_2O-dominant inclusions in the north to CO_2-dominant in the south. This is a general rule for amphibolite-granulite-facies transitions. The increase in CO_2 content with increasing metamorphic grade is also shown by the premetamorphic tonalites.

The composition and density of fluid inclusions were dominated using a FLUID INC. adapted U.S.G.S. gas-flow heating/freezing system. The accuracy and precision of the results are estimated to be ±0.5°C or better, partly depending on the size and morphology of the inclusions studied. The melting temperatures of CO_2-rich inclusions range from -53.6°C to -64.8°C. Depression of melting points below the triple point of pure CO_2 (-56.6°C) indicates the presence of additional components such as CH_4 and N_2. Homogenization temperatures of these inclusions vary from -28°C to +30°C corresponding to CO_2 densities in the range 1.05-0.65 g/cm^3 for early inclusions (type I-II) and 0.10-0.25 g/cm^3 for late inclusions (type III). The density of early carbonic inclusions decrease with increasing metamorphic grade. These density data, in combination with estimates of metamorphic temperatures in the different metamorphic zones, indicate a pressure range of 3.5-5.0 kb. This is consistent with the data derived from mineral geobarometry and metamorphic assemblages. Thus, the high-density data on early type-I CO_2 inclusions, when plotted with the pressure-temperature data obtained from mineral chemistry, indicate their entrapment near peak metamorphic conditions. There are no significant pressure differences over the whole area. Later successive generations of carbonic inclusions with decreasing fluid density indicate the possible uplift path of the whole terrain. Since this path is slightly convex towards the temperature axis, the temperature decrease lagged somewhat behind the pressure decrease. The intrusion of migmatizing microcline granite from a somewhat lower crustal level (5-6 kb) to higher level at which the metapelites metamorphosed (about 4 kb) in the area of Sulkava thermal dome is indicated by the early type-I CO_2 inclusions.

The salinity of the aqueous inclusions has a tendency to decrease with increasing metamorphic grade from 6.5 wt-% eq. NaCl in the andalusite-muscovite zone to 1.9 wt-% eq. NaCl in the garnet-cordierite-sillimanite zone. The homogenization temperatures of H_2O-rich inclusions vary from <120°C to 430°C and the density ranges from 0.52 to 1.00 g/cm^3. It is evident from the homogenization data that there are several generations (with possible multiple sources at different times) of aqueous inclusions and that most of them were trapped late in the metamorphic evolution of the rocks at near-surface conditions (i.e., below 2 kb).

Gravity anomaly maps of central Finland - Seppo Elo, Geological Survey of Finland

Gravity anomaly maps based on two different sets of data will be presented. The first data set, with an average station spacing of 5 km, is the national network of the Finnish Geodetic Institute. The second data set, with an average station spacing of about 0.5-1.0 km, is the network of the Geological Survey of Finland, which so far only covers some selected areas of interest. Maps of Bouger anomalies and their second vertical derivates and horizontal gradients, petrophysical data, and model interpretations will be shown.

An aeromagnetic crustal model for Finland: activities on map sheets 32 and 33 - Juha Korhonen, Geological Survey of Finland

As a part of the Finnish contibution to ILP, a model of the upper and lower crust in Finland is under construction. The work is based on aeromagnetic low and high altitude maps and petrophysical parameters of rocks. By the end of 1988 it will have about 70% coverage of petrophysical parameters and aeromagnetic low altitude surveys in the area of map sheets 32 and 33.

The aeromagnetic maps are used to delineate the main stratigraphic and tectonic units and the petrophysical parameters to classify the formations on the basis of their physical properties. Most stratigraphic supergroups have a distinctive tectonic style as interpreted from aeromagnetic maps, which also emphasize major faults and suture zones. The petrophysical properties of the same supergroups have different characteristics. The density and intensity of remanence in particular can be used to distinguish between supergroups geophysically.

The degree of metamorphism correlates with the ferromagnetic susceptibility. The correlation is positive or negative depending on the area. The vertical dimensions of formations are calculated on the basis of Bouguer anomalies and aeromagnetic

DGRF-65 anomalies using measured density and magnetic properties as physical constants, in which way shallow and deep seated sources of long wavelength anomalies can be separated.

Magnetic (high altitude, 150 m) hill-shading map of central Finland - Tapio Ruotoistenmäki, Geological Survey of Finland

THIRD DAY, 18th June

Participants will study the Archaean crust close to the craton margin in the Varpaisjärvi-Iisalmi area.

THE VARPAISJÄRVI-IISALMI AREA

Pentti Hölttä and Jorma Paavola
Geological Survey of Finland

The bedrock in the Varpaisjärvi-Iisalmi area (Fig. 5.) is part of the marginal zone of the Archaean craton, i.e. of the Iisalmi plate, which is characterized by very intense blocking. The blocking is partly due to the Iisalmi plate pushing against the eastern Archaean basement from the west and, at least in the south, clearly overriding it.

The crust thickened by the overthrust was eroded rapidly and equilibrated both isostatically and thermally. Therefore, the blocks in the area expose lithologies with mineral assemblages that crystallized during metamorphism of the Archaean granulite grade. Thus these high-grade rocks represent a fairly deep crustal section.

The blocks are bounded by fault zones with blastomylonitic quartz-epidote rocks and amphibolites.

The bedrock in the area is composed of amphibolite-banded tonalitic-trondhjemitic migmatites or granitoids, most of which have undergone polyphase deformation (stop 3-1). Homogenized or banded enderbitic rocks predominate (stops 3-3 and 3-4) in the terranes of high-grade metamorphism (deeper erosion niveau). The proportion of amphibolitic horizons is also high. They are mainly pyroxene amphibolites (two-pyroxene rocks) and often garnetiferous (stop 3-3).

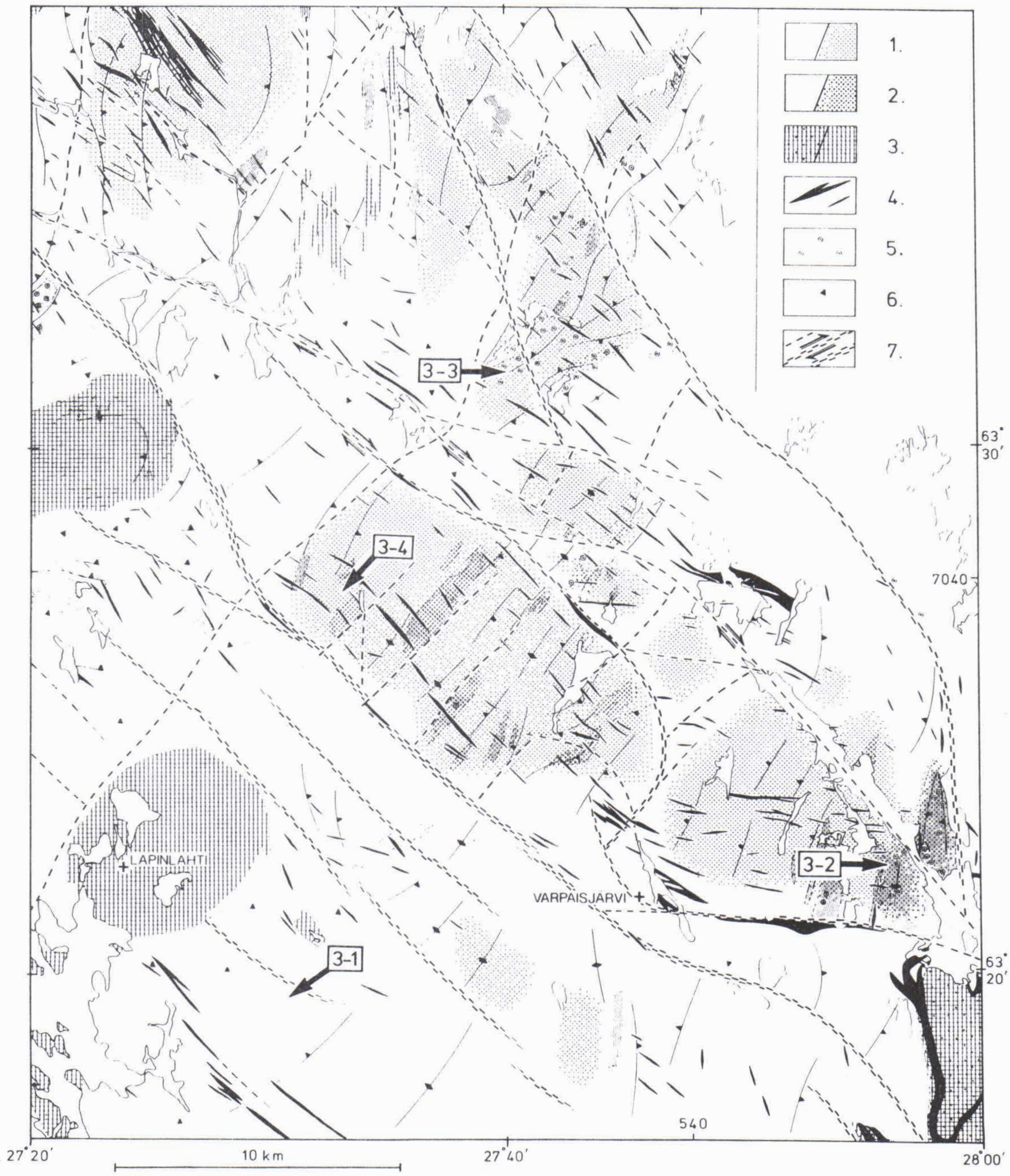

Fig. 5. Excursion stops on the geological map of the Varpaisjärvi-Iisalmi area. 1 = Archaean amphibolite banded tonalitic-trondhjemitic migmatite / hypersthene-bearing Archaean tonalitic-trondhjemitic migmatite (enderbite), 2 = Archaean amphibolite / pyroxene amphibolite (two-pyroxene rock), 3 = Proterozoic metasediment / intrusive, 4 = Proterozoic diabase, 5 = garnet, 6 = predominant direction of banding and 7 = fracture or fault.

The garnets of the granitoids are rich in calcium, X_{Ca} = 0.17-0.20 and X_{Mg} = c. 0.25. Garnet is almost invariably decomposed into orthopyroxene, clinopyroxene, plagioclase and hornblende. Orthopyroxene-plagioclase, clinopyroxene-plagioclase and hornblende-plagioclase symplectites often rim garnet grains.

The amphibolites in the eastern part of the area have narrow horizons of garnet-cordierite-sillimanite rocks, quartzitic cordierite rocks and ultramafic corundum, kornerupine and sapphirine-bearing rocks (stop 3-2). The ferromagnesium minerals in these horizons are very rich in magnesium: the X_{Mg} of garnet is 0.50-0.60, of cordierite about 0.90, of kornerupine about 0.75, of sapphirine and orthopyroxene about 0.80 and of gedrite 0.70-0.75. The crystallization pressures indicated by the garnet-cordierite and garnet-orthopyroxene-plagioclase-quartz barometers are 8-10 kb (grain cores); the temperatures indicated by the garnet-orthopyroxene thermometer are about 750-800°C. The temperatures determined from the symplectites and garnet margins are about 50°C lower and the pressures one kilobar lower.

The Proterozoic pyroxene diabase dykes are most abundant in the terrane of high-grade rocks. These blocks and their enderbitic rocks in particular show up as strong positive anomalies on magnetic maps.

Calc-alkalic in chemistry, the Archaean granitoids and migmatites are characterized by the high Al_2O_3 content and high Na/K ratio typical of Archaean rocks.

Two U-Pb zircon ages, 3095 and 3136 Ma, have been recorded from the quartz dioritic palaeosome of the banded basement migmatite. The ages refer either to primary crystallization of the palaeosome or to early high-grade metamorphism. The enderbitic rocks in the high-grade block show concordant zircon U-Pb ages of 2682 and 2693 Ma, which have been attributed to the lattice blocking that followed high-grade regional metamorphism. This stage was characterized by intense formation of neosome.

The K-Ar ages of hornblende are about 2.7 Ga both in the high-grade block and outside it. They, too, probably represent the fairly primary lattice blocking that followed metamorphism, and did not suffer much from Ar diffusion, not during the Proterozoic either, even though the diffusion is common in the Finnish Archaean crust.

Two biotite K-Ar ages (2088 and 2386 Ma) are also clearly older than the typical biotite ages (c. 1800 Ma) of the Archaean rocks, which were totally reset during the Proterozoic orogeny.

The strong retrograde metamorphism in the Archaean crust was accompanied by intense epidotization, which is a characteristic feature of gneissose granitoids. In places it seems to have been coupled with the migration of a CO_2-rich fluid through the crust during a late stage. Many of the microcracks in the rocks are filled with calcite, and hornblende is altered into cummingtonite and amphibole depleted in calcium. Two carbon isotope determinations were made on the calcite produced by these reactions, one from outside the granulite block (Kiikkukallio, stop 3-1; $\delta^{13}C$ = -3.3, PDB) and the other from the granulite block (Rokuankangas; $\delta^{13}C$ = -4.36). According to the data, the carbon dioxide may have been juvenile (Karhu, oral comm., 1988).

Excursion stops

Stop 3-1. Lapinlahti, Kiikkukallio

Two outcrops will be visited:

a) X = 7024.60, Y = 525.76.

Exposed in the outcrop is a polyphase-deformed amphibolite-banded tonalitic-trondhjemitic migmatite. Its palaeosome consists of the assemblage hornblende-epidote-cummingtonite-chlorite-plagioclase-quartz±biotite. Hornblende is altered into chlorite, and cummingtonite and epidote have crystallized along the crystal boundaries of hornblende and plagioclase. Hornblende is altered into bright green amphibole along its margins. Neosome has the mineral assemblages: biotite-cummingtonite-iron oxide-quartz and biotite-chlorite-cummingtonite-epidote-calcite-plagioclase-quartz±hornblende. Hornblende, which occurs only as small relics, is altered into chlorite and cummingtonite. Abundant chlorite, epidote and calcite have crystallized along the fissures and margins of plagioclase. Iron oxide is occasionally rimmed with garnet.

b) X = 7024.75, Y = 525.57

The locality shows fairly homogeneous dioritic to quartz dioritic palaeosome of the Archaean basement. The U-Pb age on zircon is 3136±20 Ma. The K-Ar age on hornblende is 2666±80 Ma and that on biotite 2088±63 Ma.

Stop 3-2. Varpaisjärvi, Jouhimäki; X = 7029.55, Y = 546.92.

The garnet-cordierite-sillimanite rock in the outcrop has a narrow dismembered horizon of ultramafic orthoamphibole-kornerupine-sapphirine-bearing rock. The mineral assemblage of the garnet-cordierite-sillimanite gneiss is garnet-biotite-sillimanite-quartz-iron oxide±plagioclase±cordierite. Several assemblages occur in the kornerupine rock horizon. They contain corundum, sapphirine, spinel, rutile, högbomite, iron oxide, ilmenite, orthopyroxene, gedrite, kornerupine, phlogopite, cordierite and sillimanite in the quartz-deficient middle parts of the horizon, and orthopyroxene-orthoamphibole/phlogopite-quartz and garnet-cordierite-sillimanite-orthopyroxene-rutile-quartz at the margins of the horizon. Sapphirine, kornerupine and hypersthene form coronas around spinel (stop 1-5) and corundum. Sapphirine also occurs as exsolution lamina in orthopyroxene and gedrite. Spinel, which is encountered only as inclusions in sapphirine, is often altered into corundum and iron oxide. Corundum also occurs as inclusions in sillimanite and kornerupine. At the margin of the horizon, orthopyroxene is decomposed into biotite-quartz symplectite. Garnet coronas have developed on orthopyroxene as a result of the reaction: enstatite+sillimanite+quartz = pyrope+cordierite.

Stop 3-3. Sonkajärvi, Kumisevanmäki; X = 7047.0, Y = 533.4.

Banded tonalitic-trondhjemitic basement migmatite with hypersthene-bearing (enderbitic) and pyroxene-amphibolitic garnetiferous horizons is seen in the locality. The enderbite has the assemblage clinopyroxene-orthopyroxene-hornblende-plagioclase-quartz-biotite. Biotite is retrograde and clinopyroxene symplectite has crystallized on hornblende. Orthopyroxene is altered into cummingtonite along the margins. The garnetiferous bands exhibit the garnet-clinopyroxene-orthopyroxene-hornblende-plagioclase-quartz assemblage. Garnet is altered into clinopyroxene, hornblende and plagioclase, and is often rimmed with hornblende-plagioclase symplectites. In the epidote-bearing portions the brown hornblende is altered into light green amphibole, and epidote has crystallized on the amphibole and plagioclase grains. Garnet is also epidotized, biotitized and amphibolitized. The iron oxides are rimmed with titanite. The epidotization is often associated with fissures in the bedrock.

Stop 3-4. Lapinlahti, Lampiensalmi; X = 7039.46, Y = 527.86.

The outcrop is of fairly homogeneous Archaean enderbite. The rock is plagioclace-rich with hornblende, hypersthene, biotite and quartz. Apatite and magnetite are typical accessory minerals. The U-Pb age on zircon is 2693 Ma. K-Ar age of hornblende is 2692±80 Ma and that of biotite 2386±72 Ma.

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