Radiometric age determinations from Finnish Lapland and their bearing on the timing of Precambrian volcano-sedimentary sequences
Edited by Matti Vaasjoki
Geological Survey of Finland, Special Paper 33, 85–93, 2001.

U-Pb ISOTOPIC AGE DETERMINATIONS FROM THE KOLARI-MUONIO AREA, WESTERN FINNISH LAPLAND

by
Jukka Väänänen and Matti I. Lehtonen

Väänänen, J. & Lehtonen, M.I. 2001. U-Pb isotopic age determinations from the Kolari-Muonio area, western Finnish Lapland. *Geological Survey of Finland, Special Paper 33,* 85–93. 5 figures, 2 tables and one appendix.

Four zircon age groups of igneous rocks have been defined in the Kolari-Muonio area: 1) Archean (c. 2.6 Ga) for the granodioritic gneisses and granodiorites of the basement, 2) 2027±33 Ma for diabases intruding the volcanic rocks of the Kolari Formation, 3) 1860-1890 Ma for synorogenic granitoids of the Haaparanta Suite, and 4) c. 1.8 Ga for postorogenic microcline granites.

Several Archean and Paleoproterozoic zircon populations from the basement granodiorites in the Muonio area indicate apparently a Paleoproterozoic reactivation of the Archean basement. The titanite age, 1845 Ma, of the granodioritic gneisses and the titanite age distribution of 1885-1800 Ma of Paleoproterozoic rocks reflect metamorphic resetting of the Archean basement and the Paleoproterozoic rocks. Neither magmatic nor tectonometamorphic event are known to explain the exceptionally young zircon age of 1747 Ma and titanite age of 1748 Ma obtained for a mafic pegmatoid and a skarn rock, respectively, in the Rautuvaara mine.

Key words (GeoRef Thesaurus, AGI): absolute age, U/Pb, zircon, titanite, granites, diorites, gabbros, diabase, Paleoproterozoic, Archean, Kolari, Muonio, Lappi Province, Finland

Jukka Väänänen, Geological Survey of Finland, P.O. Box 77, FIN-96101 Rovaniemi, Finland. E-mail: Jukka.Väänänen@gsf.fi
Matti I. Lehtonen, Geological Survey of Finland, P.O. Box 96, FIN-02151 Espoo, Finland. E-mail: MI.Lehtonen@gsf.fi

INTRODUCTION

The pioneering geological work in the Kolari-Muonio area was done during the first decades of the 20th century (Hackman 1927, Mikkola 1936, 1941). The geological picture of the area was updated in the 1970s and 1980s (Hiltunen & Tontti 1976, Rastas 1980, Lehtonen 1984, 1988, Hiltunen 1982, Lindroos & Henkel 1981, Lehtonen et al.1985, Väänänen 1989, Geological Map, Northern Fennoscandia, 1:1 mill. 1987). In conjunction with the 1:100,000 scale geological mapping of the Muonio, Kihlanki, Kittilä, Kolari and Kurtakko map sheets a number of radiometric age determinations were carried out (Lehtonen 1980, 1981, Rastas 1984, Väänänen 1984, 1992, 1998). The results from the Muonio area have been published and discussed already in detail by Lehtonen (1984). Hiltunen (1982) published and discussed data from various rock types collected in connection with the mineral exploration by the Rautaruukki Oy in western Lapland. In this paper these previous results are briefly summarized and some new datings are reported. The datings were performed by O. Kouvo and discussed in his unpublished reports (archives of the GTK).

GENERAL GEOLOGY

The bedrock of the Kolari-Muonio area forms the western extension of the Paleoproterozoic Central Lapland Greenstone Belt (Fig. 1). The Kolari-Muonio area is predominantly occupied by supracrustal formations intruded by granitoid rocks and by minor dykes. In the Kolari area the supracrustal sequence lies on top of the Venejärvi Complex, which is mainly composed of migmatitic metasedimentary rocks and granites. From oldest to youngest, the Paleoproterozoic sequence comprises the following lithostratigraphic units: the Teuravuoma, Haisujupukka, Rautuvaara, Kolari and Tapojärvi Formations (Väänänen 1998). The Teuravuoma Formation consists of volcanic rocks corresponding with their stratigraphical position and geochemistry to the ultramafic and mafic volcanic rocks of the Onkamo Group (OnG c. 2.44 Ga) in the Central Lapland Greenstone Belt (see Räsänen et al. 1996, Lehtonen et al. 1998). The Haisujupukka Formation contains metasedimentary rocks, mainly quartzites, obviously correlative with the Virttiövaara Formation of the Sodankylä Group (SoG> 2.21 Ga). The amphibolites, graphite-sulphide schists, iron ores (Cu, Au) and skarn rocks of the Rautuvaara Formation and the volcanic rocks of the Kolari Formation can be assigned to the Savukoski Group (SaG> 2.05 Ga). The epiclastic metasedimentary rocks of the Tapojärvi Formation have been connected with the Lainio Group (LaG≤1.88 Ga). The stratigraphical sequence in the Muonio area matches well with that of the Kolari area (cf. Lehtonen 1984).

The most voluminous igneous rocks intruding the supracrustal sequence are synorogenic granitoids and gabbroic rocks as well as the postorogenic microcline granites. The synorogenic intrusions are variously deformed and have conformable contacts with their country rocks. These 1.89-1.86 Ga intrusions have been assigned to the Haaparanta Suite occurring widely in Western Lapland (called the Haparanda Series by Ödman et al. 1949 and Ödman 1957). These intrusions were called the Syenite Series by Mikkola (1941). Lehtonen (1988) divided the Haaparanta Suite into two lithological associations in the Muonio-Kihlanki area: the quartz monzodiorite association (QMD) and quartz diorite-tonalite-trondhjemite association (QTT). Microcline granites form plutons and migmatites cutting all the other rocks. They are comparable with the Lina granites in Northern Sweden (Ödman 1957).

PREVIOUS AGE DETERMINATIONS

Previously published age data (Hiltunen 1982, Lehtonen 1984) are summarized in Tables 1 and 2 and sample locations are shown in Figure 1. They have been recalculated using the IsoplotEx-program, and the results, including the MSWDs, are reported. If the data have been interpreted in a different manner than in the original papers, this is mentioned in the following paragraphs.

Monzonite samples A583 (1876±16 Ma) and A837 (1892±6 Ma) represent the quartz monzodiorite association (QMD), while the quartz diorite-tonalite-trondhjemite association (QTT) is represented by the granodiorite samples A967 (1850±41 Ma, combined fractions with A312), A523 (heterogenous zircon), A569 (heterogenous zircon), A838 (1832±7 Ma) and the sample A836 (heterogenous zircon, monazite age 1790 Ma). The granodiorite samples A835 (2591±16 Ma, titanite age 1845 Ma) and A378 (1977±46 Ma, 2444±96 Ma for two zircon fractions), and the pegmatitic microcline granite sample A966 (1778±2 Ma, MSWD=0.58) have been taken from the assumed Archean basement area in Muonio.

Samples A840 (1862±4 Ma) and A958 (1849±19 Ma) represent granitoids of the Haaparanta Suite in the vicinity of the Rautuvaara mine. A958 is an albititic contact variety taken from the foot wall of an ore body at Rautuvaara. The three zircon fractions analyzed are somewhat discordant and plot relatively close to each other. If the upper intercept for A958 is forced through the 1860 Ma point of the concordia curve, the MSWD increases from 0.57 to 2.1. Thus it may be argued that there is no significant difference between the results from the two samples. Samples A963 and A949 are skarn rocks associated with the Haaparanta Suite granitoids at the Hannukainen ore and Rautuvaara mine respectively. The three zircons from A963-

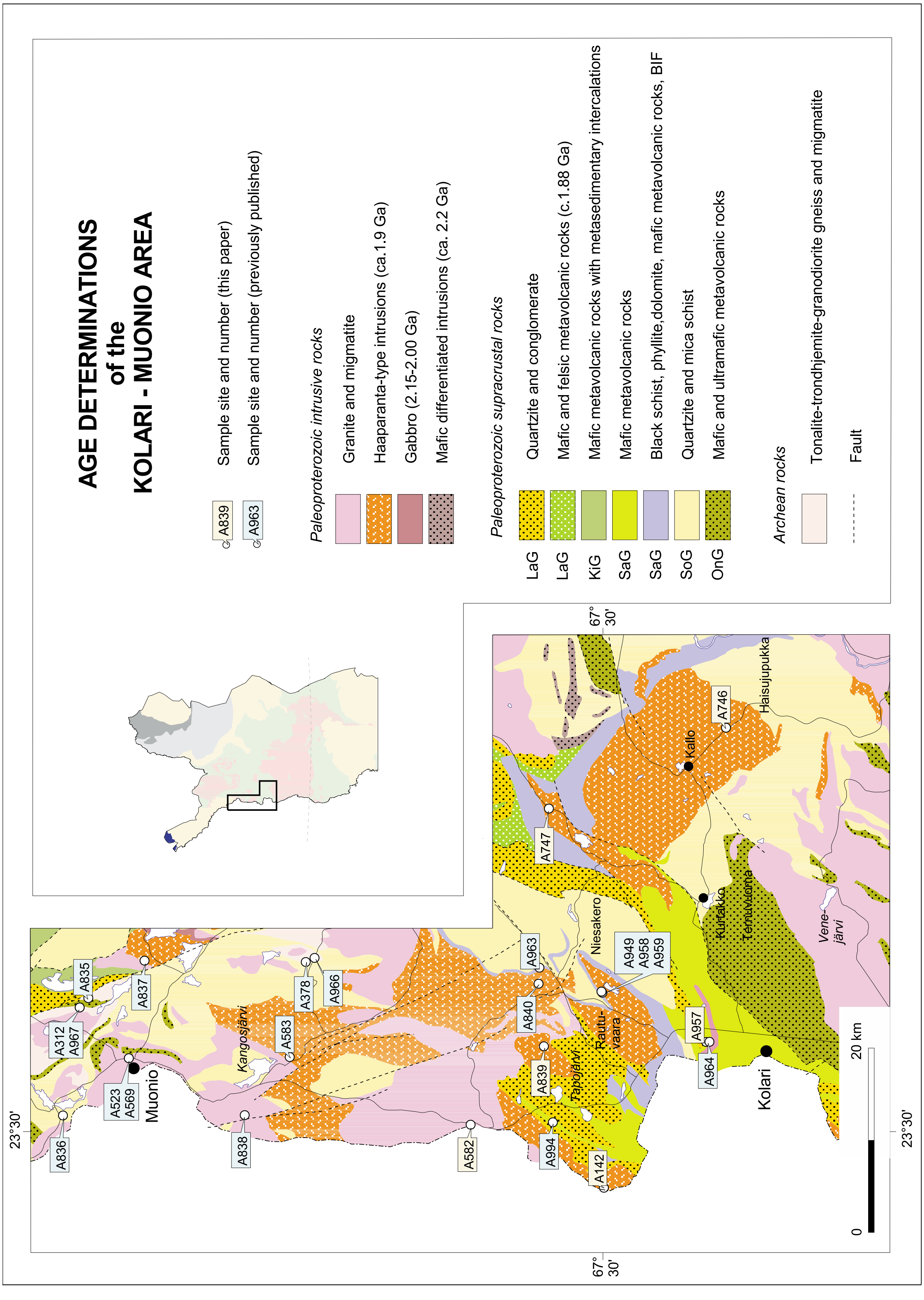

Fig. 1. Simplified surface geology and location of age determination samples from the Kolari-Muonio area, western Lapland. LaG = Lainio Group, KiG = Kittilä Group, SaG = Savukoski Group, SoG = Sodankylä Group, OnG = Onkamo Group.

Table 1. Previously published U-Pb age results from the Kolari-Kihlanki-Muonio area.

Sample	Map	Northing	Easting	Location	Lithology	Mineral	Age	Reference
A959	271312	7489.81	2496.95	Rautuvaara	Mafic pegmatoid	Zircon	1748±7	Hiltunen 1982
A963	271410	7496.79	2499.28	Kuervaara	Skarn	Zircon	1797±5	Hiltunen 1982
						Titanite	1800	Hiltunen 1982
A949	271312	7489.72	2496.82	Rautuvaara	Skarn	Titanite	1748	Hiltunen 1982
A840	271410	7496.80	2497.50	Kivivuopion-vaara	Monzonite	Zircon	1862±3	Hiltunen 1982
						Titanite	1783	Hiltunen 1982
A964	271311	7477.64	2491.93	Saarenpudas	Diabase	Zircon	2027±33	Hiltunen 1982
						Titanite	1820	Hiltunen 1982
A958	271312	7489.81	2496.95	Rautuvaara	Monzonite (albitite)	Zircon	1849±16	Hiltunen 1982
						Titanite	1783	Hiltunen 1982
A994	271407	7494.47	2482.14	Jaaravinsa	Keratophyre	Zircon	Archean	Hiltunen 1982
						Titanite	1793	Hiltunen 1982
A583	272307	7523.85	2488.00	Kangosjärvi	Monzonite	Zircon	1876±16	Lehtonen 1984
A838	272307	7528.50	2481.30	Kangosselkä	Paragneiss	Zircon	1832±7	Lehtonen 1984
A836	272309	7548.56	2480.27	Ylimuonio	Granodiorite (dyke)	Monazite	1790	Lehtonen 1984
						Zircon	heter.	Lehtonen 1984
A523	272309	7541.60	2487.00	Muonio	Granodiorite	Zircon	heter.	Lehtonen 1984
A569	272309	7541.60	2487.00	Muonio	Granodiorite	Zircon	heter.	Lehtonen 1984
A835	272312	7546.40	2493.48	Vuontisrova	Granodioritic gneiss	Zircon	2591±16	Lehtonen 1984
						Titanite	1845	Lehtonen 1984
A837	272312	7540.40	2497.95	Toras-Sieppi	Monzonite	Zircon	1892±6	Lehtonen 1984
						Titanite	1845	Lehtonen 1984
A967	272312	7547.30	2492.40	Kipparioja	Granodiorite	Zircon	1850±41	Lehtonen 1984
A312	272312	7547.30	2492.40	Kipparioja	Granodiorite	Zircon	heter.	Lehtonen 1984
A378	272310	7522.60	2498.87	Matala Nivunkijärvi	Granodiorite	Zircon	1977±46	Lehtonen 1984
						Zircon	2444±96	Lehtonen 1984
A966	272310	7521.00	2499.17	Matalan-Nivunginselkä	Pegmatite granite	Zircon	1778±3	Lehtonen 1984

Kuervaara and the two titanites from A949-Rautuvaara have upper intercept ages which overlap within experimental error at c. 1795 Ma. One titanite fraction from A963 is only slightly discordant and exhibits a similar age, while another titanite with very large errors in the Pb/U ratios (arising from a poor U concentration run) is concordant at 1710 Ma. The mafic pegmatoid sample A959 (1747±14 Ma, MSWD=12) is from a coarse-grained vein cutting skarn rock and iron ore in the Rautuvaara mine.

Sample A964 (2025±19 Ma, MSWD=6.7) has been collected from a differentiated diabase dyke at Saarenpudas intruding concordantly volcanic rocks of the Kolari Formation and sample A957 represents a mafic rock occuring close by. Only the results for sample A964 were published. The unpublished preliminary results for sample A957 will be briefly discussed in the subsequent text. Sample A994 with an Archean zircon age (2738 Ma, titanite age 1793 Ma) is from a keratophyre dyke of the Siekkijoki Formation (correlates to the Kolari Formation).

ISOTOPIC STUDIES FROM THE KOLARI-MUONIO AREA

A142-Jalokoski. This sample (Table 2) represents a gabbroic intrusion (c. 35 km^2) outcropping on the banks of the Muonio river at the Finnish-Swedish border. The Jalokoski gabbro was regarded by Mikkola (1941, p. 109) as belonging to the Syenite Series (Haaparanta Suite), and is now considered part of the quartz monzodiorite association (QMD) of the Muonio-Kihlanki area (Lehtonen 1988). The composition of the igneous body varies from ultrabasic to intermediate due to differentiation (Lindroos & Henkel 1981, Hiltunen 1982). The sample was taken from a rather coarse-grained (0.2-5 mm) rock type consisting mainly of plagioclase (c. An_{45}), orthopyroxene and biotite. Accessory minerals include magnetite, apatite, epidote and locally ilmenite. Plagioclase contains secondary scapolite. Orthopyroxene is typically altered to amphibole and green biotite.

The analytical data for the zircon fractions of the Jalokoski gabbro are shown on a concordia plot in Figure 2, and define an upper intercept age of 1866±6 Ma. Only three zircon fractions have been used, as the fractions are nearly concordant and their $^{207}Pb/^{206}Pb$ ages are so similar that additional analyses were deemed unnecessary.

A746-Haisuvuoma and A747-Härkimännikkö. These samples represent a large granitoid body called

Table 2. New U-Pb age data from the Kolari-Kihlanki-Muonio area.

Sample	Map	Northing	Easting	Location	Lithology	Mineral	Age	Comment
A957	271311	7478.00	2491.90	Saarenpudas	Diabase	Zircon	1969	^{207}Pb/^{206}Pb age
A582	271408	7503.54	2481.43	Kihlanki	Granite (Lina type)	Zircon	1805±10	
						Titanite	1792±5	^{207}Pb/^{206}Pb age
A839	271410	7495.88	2490.56	Kiuaskero	Quartz diorite	Zircon	1860	reference line
A746	273108	7477.50	2527.00	Haisuvuoma	Quartz monzodiorite	Zircon	1882±1	^{207}Pb/^{206}Pb age, average
						Titanite	1832±12	^{207}Pb/^{206}Pb age
A747	273204	7496.60	2517.04	Härkimännikkö	Quartz monzonite	Zircon	1885	reference line
A142	271306	7489.15	2474.40	Jalokoski	Gabbro	Zircon	1866±6	nearly concordant

the Kallo massif (Mikkola 1941) occurring mainly in the Kurtakko and partly in the Kittilä map sheet areas. The intrusion is c. 300 km^2 in size. The granitoid intrudes concordantly the metasedimentary and volcanic rocks of the Sodankylä and Savukoski Groups. Geographically, the Kallo massif occupies a topographic low and its flat surface is only rarely exposed. Mikkola (1941) assumed that the intrusion was a differentiate of the Syenite Series. Rantataro (1988) regarded the massif as a synorogenic zonal intrusion and classified it geochemically as a calc-alkaline, I-type granitoid.

Field observations show that the various granitoid types within the Kallo massif were generated by several magma pulses. The oldest phase comprises mafic autoliths and quartz diorite in the southeastern part of the intrusive. During the main phase of intrusion, the tonalitic outer margin, felsic autoliths and the prevailing Haisuvuoma quartz monzodiorite were generated. The tonalitic margin grades into quartz monzodiorite. This phase of intrusion was followed by more felsic quartz monzonites and granodioritic pegmatites. There are two separate bodies of felsic quartz monzonite within the Kallo massif: Härkimännikkö on the northwestern and Poro-Heikinpalo on the eastern side of the intrusion. Their oblong shape and location around the massif indicate that their emplacement was possibly controlled by thrust or fault zones (cf. Rastas 1984, Väänänen 1992). Sample A746 was taken from the dominant Haisuvuoma quartz monzodiorite and sample A747 from the Härkimännikkö felsic quartz monzonite. The tonalitic margin consists mainly of plagioclase, alkali feldspar, quartz, biotite and hornblende. In the prevailing quartz monzodiorite clinopyroxene occasionally occurs in addition to the above mentioned main minerals. Titanite is the principal accessory mineral in the Kallo massif while apatite, magnetite and zircon are other accessories. The felsic quartz monzonites are porphyritic to some extent. Petrographically and geochemically, the Kallo massif resembles the granitoids of the quartz monzodiorite association (QMD) of the Haaparanta Suite in the Muonio-Kihlanki area (Väänänen1998).

The relatively large zircon grains extracted from sample A746 are mostly broken, brown, transparent fragments of originally larger crystals. Distinct growth zones and clear crystal surfaces are typical features. Zircon grains in sample A747 are relatively small and turbid with L/B c. 1.5-2. Crystal edges are blunt, and the surfaces contain many inclusions. The concordia plot for analytical data from the Kallo massif is presented in Figure 3. The age is given by three nearly

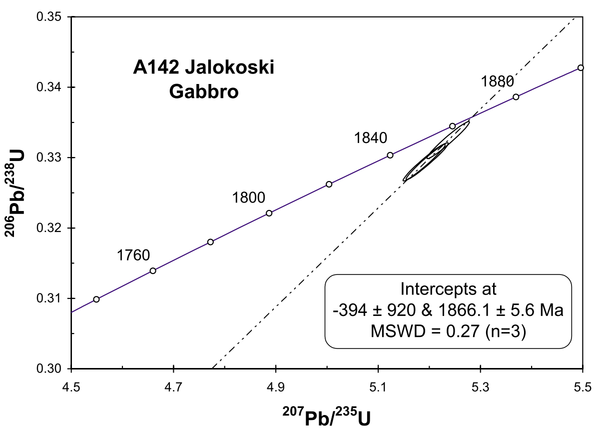

Fig. 2. Results for U-Pb determinations from zircon of the Jalokoski gabbro on a concordia diagram. The size of ellipses indicates the analytical error on a 2 -level.

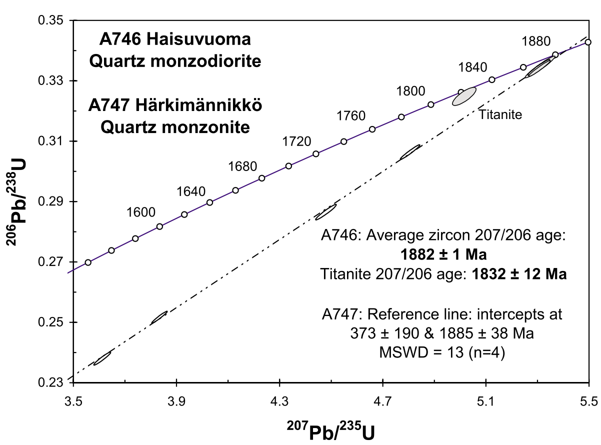

Fig. 3. Results for U-Pb mineral determinations from the Kallo massif on a concordia diagram. A746 closed symbols, A747 open symbols.

concordant zircon fractions from the Haisuvuoma quartz monzodiorite (A746) at 1882±1 Ma, while the titanite from the same rock yields an age of 1832±12 Ma. The turbid zircons from the Härkimännikkö quartz monzonite (A747) are rather discordant and exhibit a scatter in excess of analytical uncertainty (MSWD=13). Nevertheless, they define an upper intercept at 1885±38 Ma, which is in agreement with the result from A746 and supports a comagmatic origin for these rocks. The zircon and titanite ages of the Kallo massif are typical of the Haaparanta Suite in Western Lapland (cf. Tables 1 and 2).

A582-Kihlanki. The Kihlanki granite forms part of a large post-orogenic intrusion, which lies mainly on the Swedish side (so-called Lina-granite; Geijer 1931, Ödman 1957, Lindroos & Henkel 1981). In Finland, the dimensions of the Kihlanki granite are 10x15 km^2 (Lehtonen 1981). It belongs to the microcline granites of the Muonio-Kihlanki area (Lehtonen 1988), is medium-grained, massive and partly porphyritic (feldspar phenocrysts <1 cm). Country rock fragments and nebulitic mica-rich relics occur in the contact zones. The granite is clearly intrusive into its country rocks. Quartz, potassium feldspar and plagioclase are the main minerals. Biotite is the only dark mineral and forms 1-3 % of the total rock volume. Occasionally, the rock is sufficiently rich in magnetite (max. 2 %) to produce irregular anomaly patterns on the aeromagnetic map.

The zircon concentrates contained also rutile, which was removed by hand picking. The zircons from the Kihlanki granite often exhibit well developed 110-faces and are brownish in color. Large cores occur especially in big and broken crystals. The L/B ratio varies from two to more than ten. A few beautiful "micro-gem" specimens have also been seen. The data of six zircon and one titanite analyses are presented in Figure 4. The zircons define a linear trend

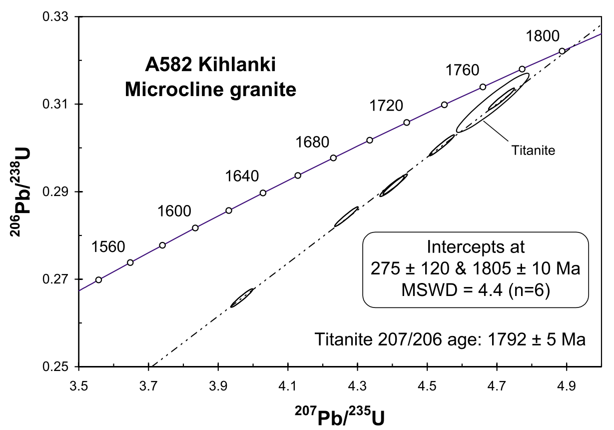

Fig. 4. Results for U-Pb mineral determinations from the Kihlanki granite on a concordia diagram.

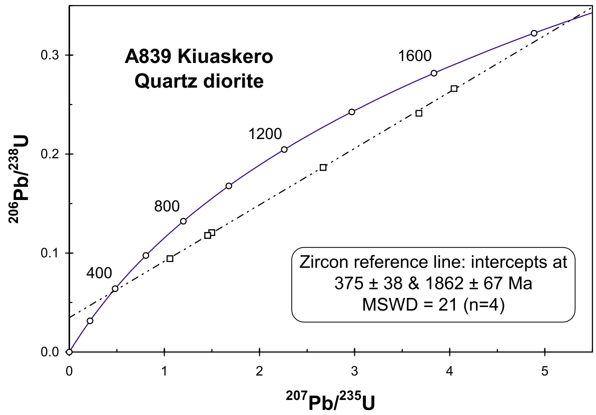

Fig. 5. Results for the Kiuaskero quartz diorite on a concordia diagram. Note that the scale is so large that displaying error ellipses is nonsensical.

with an upper intercept at 1805±10 Ma (MSWD=4.4). Although analytical errors overlap, the titanite is probably somewhat younger with a $^{207}Pb/^{206}Pb$ age of 1792±5 Ma.

A839-Kiuaskero. The dated quartz dioritic sample represents the Kiuaskero intrusion (c. 20 km^2) in the Kihlanki area c. 10 km northwest of Rautuvaara mine. The intrusion belongs to the quartz diorite-tonalite-trondhjemite association (QTT) of the Haaparanta Suite (Lehtonen 1988) and is intruded by the Kihlanki granite. The contact of the Kiuaskero intrusion with the Tapojärvi Formation in the south and west is deformed. Quartz monzodiorite inclusions occur in the intrusion, which is typically leucocratic and porphyritic; pink plagioclase phenocrysts (c. 1 mm) stand up in the finer-grained ground mass. The modal composition varies between quartz diorite and diorite.

All four zircon fractions from sample A839 have a high uranium concentration (1600-3900 ppm) and are consequently very discordant (Fig. 5). The radiation damage has probably also contributed to the apparent heterogeneity of the data (MSWD=21). The upper intercept of the line defined by the zircons is at 1862±67 Ma, which is consistent with the assumption that the Kiuaskero quartz diorite is part of the Haaparanta Suite. The two titanite analyses are rather imprecise, and the large common lead contents make them dependent on the value of the used for the common lead correction. If the two titanites are included in the linear regression, the result becomes 1865±31 Ma (MSWD=21).

A957-Saarenpudas. This sample has been collected from a road cut north of Kolari. The present authors are inclined to interpret it as a diabase similar to the rock represented by sample A964.

The sole zircon analysis from the rock is not particularly discordant and the result of c. 1970 Ma suggests that this dyke is somewhat younger than most of the Jatulian diabases.

DISCUSSION

The oldest zircon ages obtained in the northern Kolari-Muonio area, 2591±16 and 2444±96 Ma, are from a granodioritic gneiss (A835) and a hypidiomorphic granodiorite (A378), respectively, representing the assumed Archean basement. As evidence of metamorphism appears on the U-Pb concordia plot in the form of a very high lower intercept (Lehtonen 1984), these ages could be taken as minima. Two zircon populations and heterogenous zircons with darker outer rims extracted from sample A378 also indicate metamorphic reactivation of the basement gneisses.

The zircon age of the Saarenpudas diabase (A964) is 2027±33 Ma (Hiltunen 1982) suggesting that it corresponds to the younger age group (2.0-2.05 Ga) of diabases in the Kittilä greenstone area rather than the older group having an age of c. 2.2 Ga (cf. Lehtonen et al. 1998). On the other hand, sample A957, taken close by from a diabase gives a markedly younger age, c. 1970 Ma. The meaning of this age is unknown for the present.

The zircon age distribution of 1860-1890 Ma obtained for the Haaparanta Suite (A840, A958, A746, A747, A583, A837, A836, A312, A967 A839, A142) indicates many magmatic pulses of different ages within the suite (cf. Lehtonen 1988, Rantataro 1988). This age distribution is typical of synorogenic igneous rocks (cf. Skiöld & Öhlander 1989, Hanski et al. 2001, *this volume*).

The zircon ages obtained from the microcline granites vary from 1778±3 to 1805±10 Ma (A966, A582) indicating postorogenic crystallization. This event belongs to the same stage of felsic magmatism that produced the Central Lapland Granite Complex (Lauerma 1982) and the microcline and migmatite-granites (Lina granites) in northern Sweden (Skiöld 1981, 1982, 1988, Skiöld & Öhlander 1989, Bergman & Skiöld 1998). These zircon ages are consistent with the field observations showing that the granites belong to the youngest rocks in the study area.

The youngest zircon age of 1748±7 Ma in the Kolari-Muonio area is from a mafic pegmatoid (A959) cutting skarn rock and iron ore in the Rautuvaara mine. No regional magmatic event explaining the origin of the mafic pegmatoid is presently known (see Hiltunen 1982).

The zircon ages of the keratophyre layers or dykes (A994) are interesting but problematic. Hiltunen (1982, p. 53) writes: "One limitation on the interpretation of the zircon data is that only one fraction from two samples was available (2 mg and 6 mg). A tentative interpretation would be that the two-point chord joining them has an upper intersection equivalent to an age of 2738 Ma, or else that they may not be cogenetic and thus fall on diffusion lines corresponding to ages of 2410 Ma and 2505 Ma. No detailed conclusions can be drawn, but their distribution suggests an Archean age of crystallization close to a minimum age of 2400-2500 Ma, or a maximum estimate of 2738 Ma". Possibly these results can be taken as evidence for inherited Archean zircons (cf. Perttunen & Vaasjoki, 2001, *this volume*). 2366 and 1968 Ma old zircons from samples A569 and A523 indicate assimilation of older crustal material into the tonalitic melts of the QTT association of the Haaparanta Suite (Lehtonen 1988).

The titanite age, 1845 Ma, of the granodioritic gneisses (A835) and the titanite age distribution of 1885-1800 Ma of diabases (A964), skarn rocks (A949, A963), keratophyre (A994) and synorogenic rocks (A840, A958, A837, A746) reflect metamorphic resetting of the Archean basement and the Paleoproterozoic rocks in the Kolari-Muonio area. The exceptionally young titanite age, 1748 Ma, for a single crystal of titanite from skarn rock (A949) in the Rautuvaara mine, is of the same order as that mentioned before for mafic pegmatoid (A959). No tectonometamorphic or magmatic event explaining this young titanite is known.

Acknowledgements

This paper is based on the datings and reports of Olavi Kouvo. The authors wish to express their sincere thanks to him and also to an anonymous referee and Eero Hanski for their critical comments on the manuscript.

REFERENCES

Bergman, S. & Skiöld, T. 1998. Implications of 1.8 Ga metamorphic ages in the Pajala area, northernmost Sweden. In: Wilson, J. R. (ed.) Abstract volume 23. Nordiske geologiske vintermöde, Århus 1998, p. 32.

Geijer, P. 1931. Berggrunden inom malmtrakten Kiruna-Gällivare-Pajala. Summary: Pre-Cambrian geology of the iron-bearing region Kiruna-Gällivare-Pajala. Sveriges Geologiska Undersökning, Serie C. 366. 225 p.

Geological Map, Northern Fennoscandia, 1:1 mill. 1987. Geological Surveys of Finland, Norway and Sweden, Helsinki.

Hackman, V. 1927. Studien über den Gesteinaufbau der Kittilä-Lappmark. Bulletin de la Commission Géologique de Finlande 79. 105 p.

Hanski, E., Huhma, H. & Vaasjoki, M. 2001. Geochronology of northern Finland: a summary and discussion. In: Vaasjoki, M. (ed.) Radiometric Age Determinations from Finnish Lapland and Their Bearing on the Timing of Precambrian Volcano-Sedimentary Sequences. Geological Survey of Finland, Special Paper 33, 255-279.

Hiltunen, A. 1982. The Precambrian geology and skarn iron ores of the Rautuvaara area, northern Finland. Geological Survey of Finland, Bulletin 318. 133 p.

Hiltunen, A. & Tontti, M. 1976. The stratigraphy and tectonics of the Rautuvaara iron ore district, northern Finland. Bulletin of the Geological Society of Finland 48, 95-109.

Lauerma, R. 1982. On the ages of some granitoid and schists complexes in Northern Finland. Bulletin of the Geological Society of Finland 54, 85-100

Lehtonen, M. 1980. Muonio. Geological Map of Finland 1 : 100 000, Pre-Quaternary Rocks, Sheet 2723. Geological Survey of Finland.

Lehtonen, M. 1981. Kihlanki. Geological Map of Finland 1 :100 000, Pre-Quaternary Rocks, Sheet 2714. Geological Survey of Finland.

Lehtonen, M. 1984. Muonion kartta-alueen kallioperä. Summary: Pre-Quaternary rocks of the Muonio Map-sheet area. Geological Map of Finland 1 : 100 000, Explanation to the Maps of Pre-Quaternary Rocks, Sheet 2723. Geological Survey of Finland. 71 p.

Lehtonen, M. 1988. Muonion-Kihlangin alueen geologiasta ja granitoidien petrokemiasta. Unpublished licenciate thesis. University of Helsinki, Department of Geology and Paleontology. 102 p.

Lehtonen, M., Rastas, P. & Väänänen J. 1985. Geological map of West Northern Finland, 1 : 200 000. Espoo: Geological Survey of Finland.

Lehtonen, M., Airo, M-L., Eilu, P., Hanski, E., Kortelainen, V., Lanne, E., Manninen, T., Rastas, P., Räsänen, J. & Virransalo, P. 1998. Kittilän vihreäkivialueen geologia. Summary: The stratigraphy, petrology and geochemistry of the Kittilä greenstone area, northern Finland. Geological Survey of Finland, Report of Investigation 140. 144 p.

Lindroos, H. & Henkel, H. 1981. Beskrivning till berggrundskartorna och geofysiska kartorna. Huuki NV/NO, SV, SO, och Muonionalusta NV, SV/SO. Description to the maps of solid rocks and geofysical maps. Berggrundsgeologiska och Geofysiska kartblad. Skala 1 : 50 000, Sveriges Geologiska Undersökning Serie Af. Nr 35-39. 85 p.

Mänttäri, I. 1995. Lead isotope characteristics of epigenetic gold mineralization in the Palaeoproterozoic Lapland greenstone belt, northern Finland. Geological Survey of Finland, Bulletin 381. 70 p.

Mikkola, E. 1936. Muonio. The General Geological Map of Finland 1 : 400 000, Pre-Quaternary Rocks, Sheet B7. Geological Survey of Finland.

Mikkola, E. 1941. Tuntsa-Sodankylä-Savukoski. Summary in English. The General Geological Map of Finland 1 : 400 000. Explanation to the map of rocks, Sheets B7-C7-D7. Geological Survey of Finland. 286 p.

Ödman, O. 1957. Beskrivning till berggrundskarta över urberget i Norrbottens län. Sveriges Geologiska Undersökning, Serie Ca 41. 151 p.

Ödman, O, Härme, M., Mikkola, A. & Simonen, A. 1949. Den svensk-finska geologiska exkursionen i Tornedalen sommaren 1949. Geologiska Föreningen i Stockholm Förhandlingar 71, 113-126.

Perttunen, V. & Vaasjoki, M. 2001. U-Pb-geochronology of the Peräpohja Schist Belt, NW-Finland. In: Vaasjoki, M. (ed.) Radiometric Age Determinations from Finnish Lapland and Their Bearing on the Timing of Precambrian Volcano-Sedimentary Sequences. Geological Survey of Finland, Special Paper 33, 45-84.

Rantataro, J. 1988. Kallon batoliitin ja ympäröivien Lapponin liuskeiden geologiasta. Unpublished master´s thesis. University of Helsinki, Department of Geology. 133 p.

Rastas, P. 1980. Stratigraphy of the Kittilä area. In: Silvennoinen, A (ed.) Jatulian Geology in the Eastern Part of the Baltic Shield. Proceedings of a Finnish-Soviet Symposium held in Finland 21-26th August 1979. Rovaniemi: The Commitee for Scientific and Technical Co-operation between Finland and Soviet Union, 145-151.

Rastas, P. 1984. Kittilä. Geological Map of Finland 1 : 100 000, Pre-Quaternary Rocks, Sheet 2732. Geological Survey of Finland.

Räsänen, J., Hanski, E., Juopperi, H., Kortelainen, V., Lanne, E., Lehtonen, M.I., Manninen, T., Rastas, P., & Väänänen, J. 1996. New stratigraphical map of Central Finnish Lapland. In: Kohonen, T. & Lindberg, B. (eds.) The 22nd Nordic Geological Winter Meeting 8-11 January 1996 in Turku - Åbo, Finland: abstracts and oral poster presentations. Turku: University of Turku, p. 182.

Skiöld, T. 1981. U-Pb isotope analyses of zircons from a Precambrian gneiss area in northern Sweden and their chronostratigraphic implications. Geologiska Föreningens i Stockholm Förhandlingar 103, 17-25.

Skiöld, T. 1982. Radiometric ages of plutonic and hypabyssal rocks from the Vittangi-Karesuando area, northern Sweden. Geologiska Föreningens i Stockholm Förhandlingar 103, 317-329.

Skiöld, T. 1988. Implications of new U-Pb zircon choronology to Early Proterozoic crustal accretion in Northern Sweden. Precambrian Research 38, 147-164.

Skiöld, T. & Öhlander, B. 1989. Chronology and geochemistry of late Svecofennian processes in northern Sweden. Geologiska Föreningens i Stockholm Förhandlingar 111, 347-354.

Väänänen, J. 1984. Kolari. Geological Map of Finland 1 : 100 000, Pre-Quaternary Rocks, Sheet 2713. Geological Survey of Finland.

Väänänen, J. 1989. Kolarin alueen vulkaniitit. Lapin vulkaniittiprojektin raportti. Summary: Volcanic rocks of the Kolari area, western Finnish Lapland. Geological Survey of Finland, Report of Investigation 86. 79 p.

Väänänen, J. 1992. Kurtakko. Geological Map of Finland 1 : 100 000, Pre-Quaternary Rocks, Sheet 2731. Geological Survey of Finland.

Väänänen, J. 1998. Kolarin ja Kurtakon kartta-alueiden kallioperä. Summary: Pre-Quaternary rocks of the Kolari and Kurtakko map-sheet area. Geological Map of Finland 1 : 100 000, Explanation to the Maps of Pre-Quaternary Rocks, Sheet 2713 and 2731. Geological Survey of Finland. 87 p.

Appendix I. U-Pb mineral ages from the Muonio area, western Lapland.

Fraction	Weigth mg	U conc. ppm	Pb conc. ppm	$^{206}Pb/^{204}Pb$ measured	$^{208}Pb/^{206}Pb$ radiogenic	$^{206}Pb/^{238}U$	±2 SE (%)	$^{207}Pb/^{235}U$	±2 SE (%)	$^{207}Pb/^{206}Pb$	±2 SE (%)	Corr.	$T_{206/238}$	$T_{207/235}$	$T_{207/206}$
A142-Jalokoski gabbro															
A. +4.6	20.5	138.1	53.8	3050	0.2380	0.3293	0.65	5.190	0.65	0.1143	0.15	0.97	1835	1851	1869
B. +4.6/HF	20.6	127.6	49.4	7943	0.2447	0.3295	0.65	5.196	0.65	0.1144	0.15	0.97	1836	1851	1870
C. +4.2/M/HF	15.2	124.3	48.7	7329	0.2476	0.3325	0.65	5.237	0.65	0.1142	0.15	0.97	1850	1858	1868
A746-Haisuvuoma quartz monzodiorite															
A. +4.6	25.7	444.9	161.7	19528	0.1451	0.3347	0.89	5.314	0.89	0.1152	0.15	0.96	1860	1871	1882
B. 4.2-4.6	21.0	718.6	263.2	14771	0.1535	0.3346	0.65	5.309	0.65	0.1151	0.15	0.97	1860	1870	1881
C. 4.0-4.2	21.8	1101.1	404.7	19793	0.1602	0.3342	0.65	5.313	0.65	0.1153	0.15	0.97	1858	1870	1884
D. Titanite	31.0	110.1	40.0	988	0.1231	0.3250	0.75	5.018	0.76	0.1120	0.65	0.79	1813	1822	1832
A747-Härkimännikkö quartz monzonite															
A. +4.6	20.7	635.8	198.4	5336	0.1156	0.2865	0.74	4.480	0.74	0.1134	0.15	0.96	1624	1727	1854
B. 4.2-4.6	21.9	983.0	252.4	6512	0.1351	0.2380	0.75	3.612	0.75	0.1101	0.15	0.96	1376	1552	1801
C. +4.6/abr 3 h	10.2	600.8	200.2	15156	0.1468	0.3064	0.65	4.806	0.65	0.1138	0.15	0.97	1723	1789	1860
D. 4.2-4.6/abr 3 h	7.9	957.3	259.5	10461	0.1363	0.2517	0.65	3.834	0.65	0.1105	0.15	0.97	1446	1599	1807
A582-Kihlanki microcline granite (Lina type)															
A. +4.2/+200	22.4	595.3	187.1	5625	0.1367	0.2917	0.65	4.408	0.65	0.1096	0.15	0.97	1650	1713	1793
B. Titanite	40.6	99.0	74.4	189	1.3852	0.3103	1.78	4.688	1.82	0.1096	0.35	0.95	1742	1765	1792
C. 4.0-4.2/+150/abr 2 h	4.4	875.2	277.8	2218	0.1733	0.2843	0.65	4.268	0.65	0.1089	0.15	0.97	1612	1687	1781
D. +4.2/+200/abr 3 h	6.2	620.3	206.2	2223	0.1599	0.3006	0.65	4.542	0.65	0.1096	0.15	0.97	1694	1738	1792
E. +4.2/-200/abr 3 h	3.2	626.2	206.0	1270	0.1762	0.2912	0.65	4.399	0.65	0.1096	0.21	0.95	1647	1712	1792
F. +4.3/+200/abr 2 h	5.3	582.8	199.6	2870	0.1573	0.3112	0.65	4.713	0.65	0.1099	0.15	0.97	1746	1769	1797
G. 4.0-4.2/+200/abr 2 h	4.1	889.2	271.2	859	0.1842	0.2657	0.65	3.968	0.65	0.1083	0.16	0.96	1519	1627	1771
A893-Kiuaskero quartz diorite (porphyritic)															
A. +4.2	3.9	1598.0	303.2	2696	0.0698	0.1865	0.65	2.668	0.65	0.1038	0.15	0.97	1102	1319	1692
B. 3.8-4.0/+100	6.7	2894.7	375.2	1081	0.1284	0.1206	0.65	1.499	0.65	0.0901	0.15	0.97	734	929	1428
C. 3.6-3.8/+100	3.6	3876.1	391.1	1319	0.1385	0.0943	0.65	1.058	0.65	0.0813	0.15	0.97	580	732	1229
D. Titanite	33.8	78.5	37.2	150	0.6473	0.2662	0.65	4.045	0.80	0.1102	0.42	0.85	1521	1643	1802
E. 3.8-4.0/+100/abr 1 h	2.1	2926.1	355.9	2934	0.1001	0.1178	0.65	1.455	0.65	0.0896	0.19	0.95	717	912	1416
F. Titanite	9.4	74.4	38.3	97	0.8164	0.2412	0.70	3.676	0.99	0.1105	0.61	0.79	1393	1566	1808
A957-Saarenpudas mafic volcanic rock															
A. 4.0-4.2	9.6	220.4	120.4	1522	0.7158	0.3405	0.65	5.666	0.65	0.1207	0.20	0.96	1889	1929	1966

Isotopic ratios corrected for fractionation, blank and age related common lead
Corr. = Error correlation for $^{207}Pb/^{235}U$ vs. $^{206}Pb/^{238}U$ ratios.
SE = Standard error in the mean