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Preliminary REE potential mapping in the Puumala-Ruokolahti area, South-Eastern Finland

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Title of report Preliminary REE potential mapping in the Puumala-Ruokolahti area, South-Eastern Finland	
Abstract This report summarizes the results of preliminary REE potential mapping in the Puumala-Ruokolahti area. The study region belongs to the southern part of the Saimaa area which is rather unexplored regarding REE potential. REE minerals can incorporate uranium and especially thorium into their crystal lattices, and are therefore radioactive to varying degrees. Therefore, work was focused on the field checking of aeroradiometric gamma anomalies with REE potential review. This report is focused on the mineralogical studies of the Karhukoski monazite occurrence. The Karhukoski occurrence consists of three monazite-bearing, whitish granite dikes. Monazite is unevenly distributed and clustered particularly in biotite accumulations. The REE and thorium are incorporated into monazite which is the main host mineral for REE in Karhukoski. The biotite accumulations contain up to 1.7 % total REE and the occurrence is dominated by LREE.	
Keywords Rare earth elements, monazite, granite, thorium, mineralogy	
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1 INTRODUCTION

The objective of the Hi-tech-metals project of the Geological Survey of Finland is to map and study the potential for hi-tech-metals (Li, Ti, Ga, Ge, Nb, In, Te, Ta and REE) in the bedrock of Finland. This report summarizes the results of preliminary investigations in the Puumala-Ruokolahti area within five days in May, 2011.

1.1 Saimaa area

The study region belongs to the southern part of the Saimaa area (Fig. 1) which is mainly composed of Svecofennian turbiditic mica schists that grade into migmatitic mica gneisses and garnet-cordierite gneisses toward south. The supracrustal rocks of the Saimaa area were metamorphosed mainly at amphibolite facies conditions 1.88-1.86 Ga ago. Crosscutting 1.89-1.88 Ga synorogenic granitoids are found throughout the area. At 1.83-1.81 Ga, the rocks largely experienced a high-T event as the late Svecofennian granite-migmatite zone of southern Finland was formed (Lehtinen et al. 2005). The bedrock of the southern part of the Saimaa area has undergone granulite facies metamorphism 1.83-1.81 Ga ago. Late orogenic 1.85-1.79 Ga granites migmatize and crosscut the supracrustal rocks in the southern part of the Saimaa area.

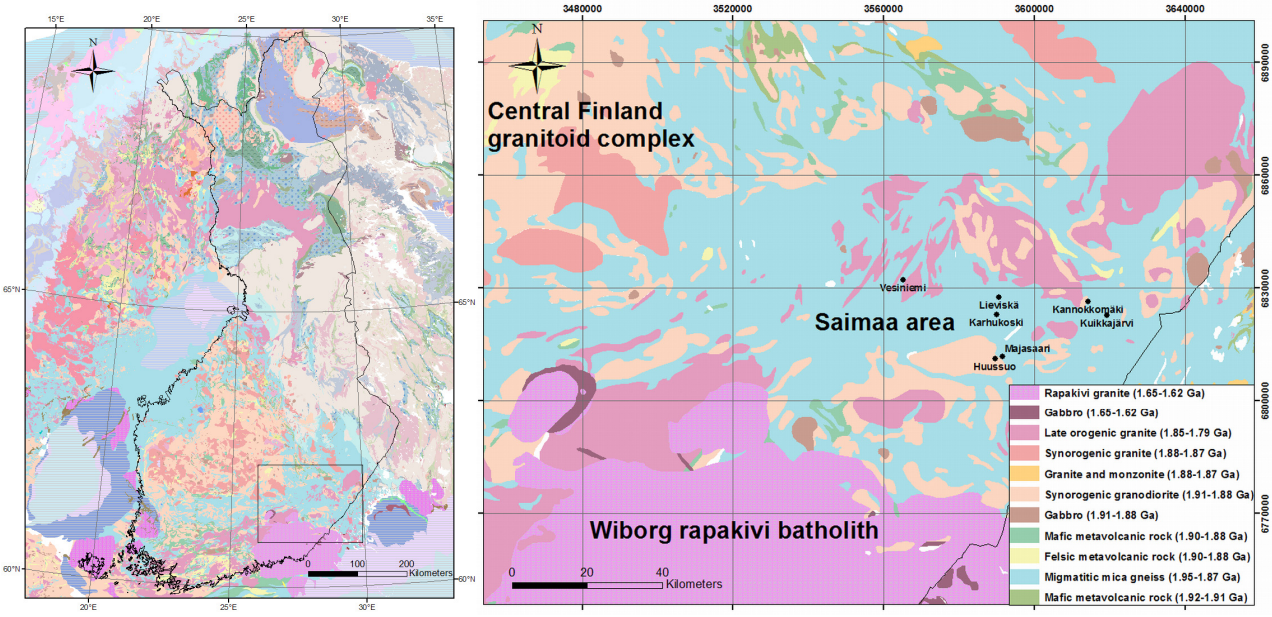

Figure 1. *Regional geological map of the Saimaa area showing field stops (modified after Geological Map of the Fennoscandian Shield).*

1.2 Previous data on the occurrence of hi-tech metals in the Saimaa area

The Geological Survey of Finland was exploring for radioactive rocks in the eastern part of Puumala in the late 1950s. A couple of occurrences were found, named as Lieviskä and Karhukoski. The Karhukoski monazite occurrence in Puumala was discovered by the Geological Survey of Finland by carborne radiometry in 1958 (Ervamaa 1960).

The Saimaa area is rather unexplored regarding REE potential. REE minerals can incorporate uranium and especially thorium into their crystal lattices, and are therefore radioactive to varying degrees. Therefore, work was focused on the field checking of aeroradiometric gamma anomalies with REE potential review.

2 FIELD TARGETS AND RESEARCH RESULTS

2.1 Karhukoski monazite occurrence

2.1.1 Geological setting

The bedrock of the Karhukoski area consists of three rock types: 1) migmatitic cordierite-garnet mica gneiss (cordierite-garnet gneiss), 2) whitish, medium-grained, strongly radioactive granite (monazite-bearing rock) and 3) reddish, weakly radioactive pegmatitic granite (pegmatite and granite). The area is mostly composed of migmatitic garnet-cordierite mica gneiss which is intruded by granites. Gneiss contains lots of garnet in places (Fig. 2).

Figure 2. *Garnet (red) and cordierite (violet) crystals in migmatitic mica gneiss in Karhukoski.*

2.1.2 Monazite-bearing granite dikes

The Karhukoski occurrence consists of three monazite-bearing granite dikes (Fig. 3) which are mainly located between the migmatitic cordierite-garnet mica gneiss (Fig. 4) and weakly radioactive, reddish granite (Fig. 5). The monazite-bearing granite is whitish (Fig. 6) compared

with the weakly radioactive, reddish granite. The dikes are called according to their location: the S dike (5-10 m x 60 m), the N dike (10 m x 70 m) and the W dike (1-5 m x 20 m). The most radioactive dikes are the S dike (Fig. 7) and the W dike. The monazite-bearing dikes belong to the late orogenic granites on the basis of U-Pb analysis of the Karhukoski monazite, 1801 Ma ± 20 (Nykänen 1988).

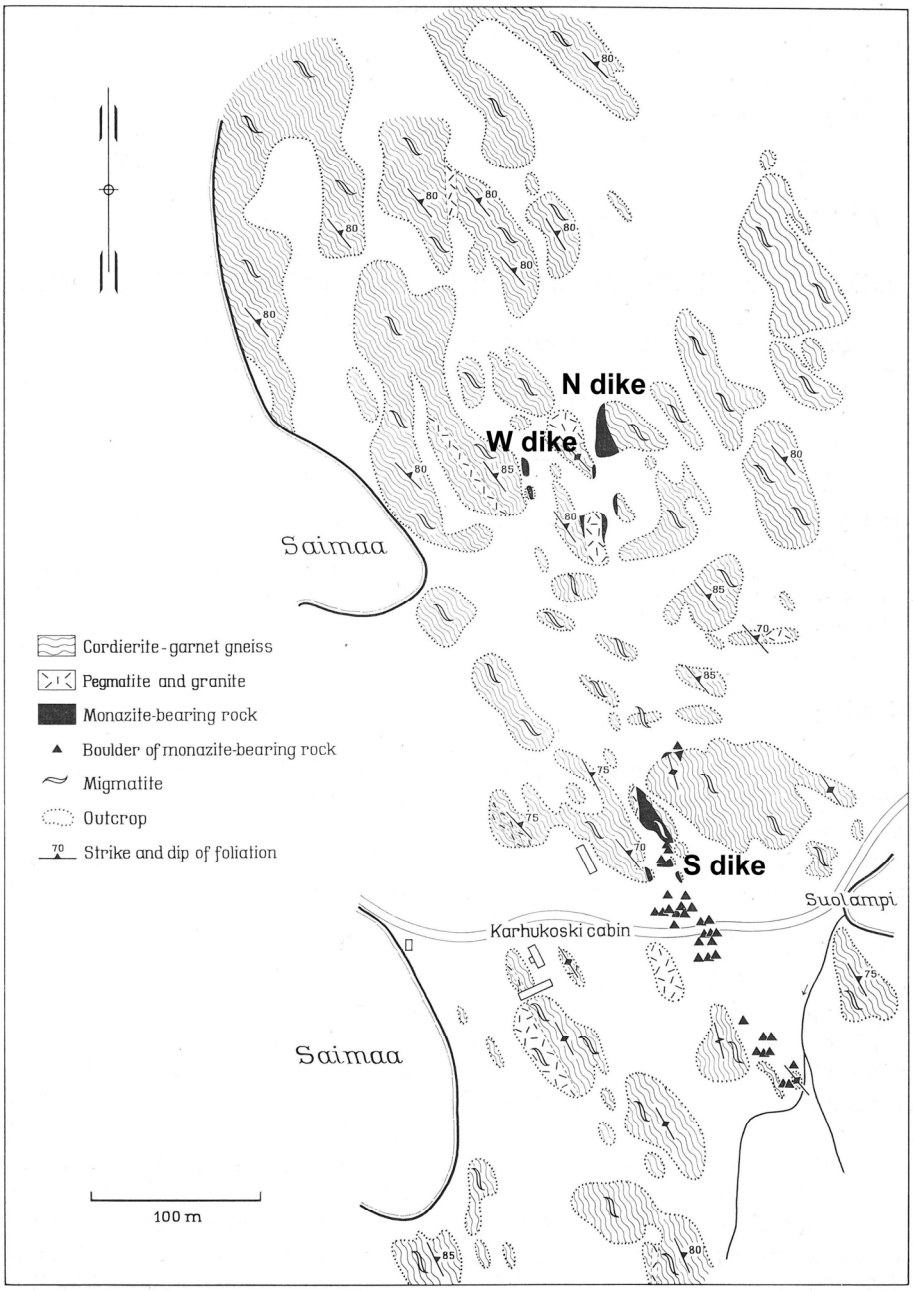

Figure 3. *Map of the outcrops in the Karhukoski area, Puumala. Radioactive boulders occur especially between the S dike outcrop and the road to the Karhukoski cabin. Mapped by Pentti Ervamaa (Modified from Haapala et al. 1969).*

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Figure 4. *Migmatitic cordierite-garnet mica gneiss which is the main rock type in the Karhukoski area (X = 6823679, Y = 3589715).*

Figure 5. *Reddish, weakly radioactive pegmatitic granite.*

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Figure 6. *Whitish, strongly radioactive, monazite-bearing granite showing a biotite accumulation at the bottom of the image (S dike).*

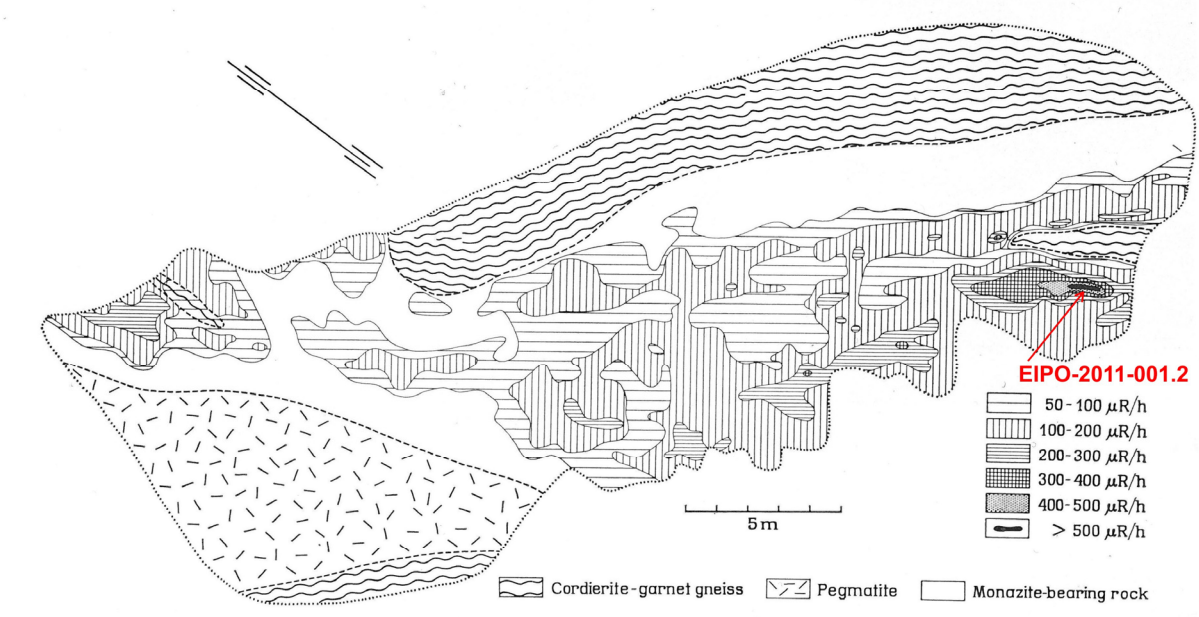

Figure 7. *Distribution of external gamma radiation on an outcrop of the S dike. Strike of the S dike is ca. 150° (Haapala et al. 1969). Coordinates of the sample EIPO-2011-001-2: X = 68222939, Y = 3589901.*

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2.1.3 Mineralogical studies

Two polished thin sections were prepared at the Geological Survey of Finland. One thin section from Karhukoski (EIPO-2011-001.2) and one thin section from Kovela (EIPO-2006-001.1) were analyzed by electron probe micro-analyzer (EPMA, analyzed by Lassi Pakkanen with Thair Al Ani) to characterize the REE-bearing minerals. Analyses were performed by wavelength-dispersive spectroscopy (WDS) using a Cameca SX100 instrument at the GTK. Analyzing conditions were as follows: accelerating voltage = 15 kV, beam current and diameter = 10 nA and 5 micrometer respectively. Natural minerals and synthetic metals were employed as standards. Analytical results were corrected using the correction program PAP (Pouchou and Pichoir 1986).

The main minerals of the monazite-bearing granite are plagioclase (An_{31}), quartz, biotite and microcline. Composition of plagioclase (andesine) was determined by microprobe. Accessory minerals are monazite, zircon, molybdenite, rutile, muscovite, magnetite, pyrite, sphalerite, chalcopyrite, apatite, goethite and bastnäsite.

The most radioactive spots are associated with biotite accumulations (Fig. 8) in whitish granite and radiation is mainly derived from thorium-bearing monazite. As the distribution and intensity of radiation of the rock is heterogeneous, also monazite is unevenly distributed and clustered particularly in biotite accumulations. The REE and thorium are incorporated into monazite (based on microprobe analyses) which is the main host mineral for REE in Karhukoski. The biotite accumulations contain up to 1.7 % total REE (based on whole rock analyses) and the occurrence is dominated by LREE.

Figure 8. *Biotite accumulation in whitish granite (S dike).*

Monazite [(Ce,La,Nd,Th)PO_4] occurs mostly as inclusions in biotite (Fig. 9) and at the grain boundaries of the biotite flakes. Monazite crystals are euhedral with grain size up to 0.5 mm. The crystals occur mainly as clusters, in many places with zircon and molybdenite (Fig. 10 and 11). The predominant rare earth element of monazite is cerium.

Figure 9. *Thin section image (XPL) of the biotite accumulation showing monazite crystals as inclusions in biotite (S-dike, X = 6822939, Y = 3589901). Photo: E. Pohjolainen.*

The rock also contains rather large rutile grains (Fig. 12 and 13), with grain size up to several millimeters. In places, bastnäsite [(Ce,La)(CO_3)F] grains occur as tiny, fibrous grains intergrown with rutile (Fig. 14). Bastnäsite grains were challenging to analyze due to small grain size and fibrous habit. Titanium in bastnäsite analysis results (Table 1) is probably derived from surrounding rutile.

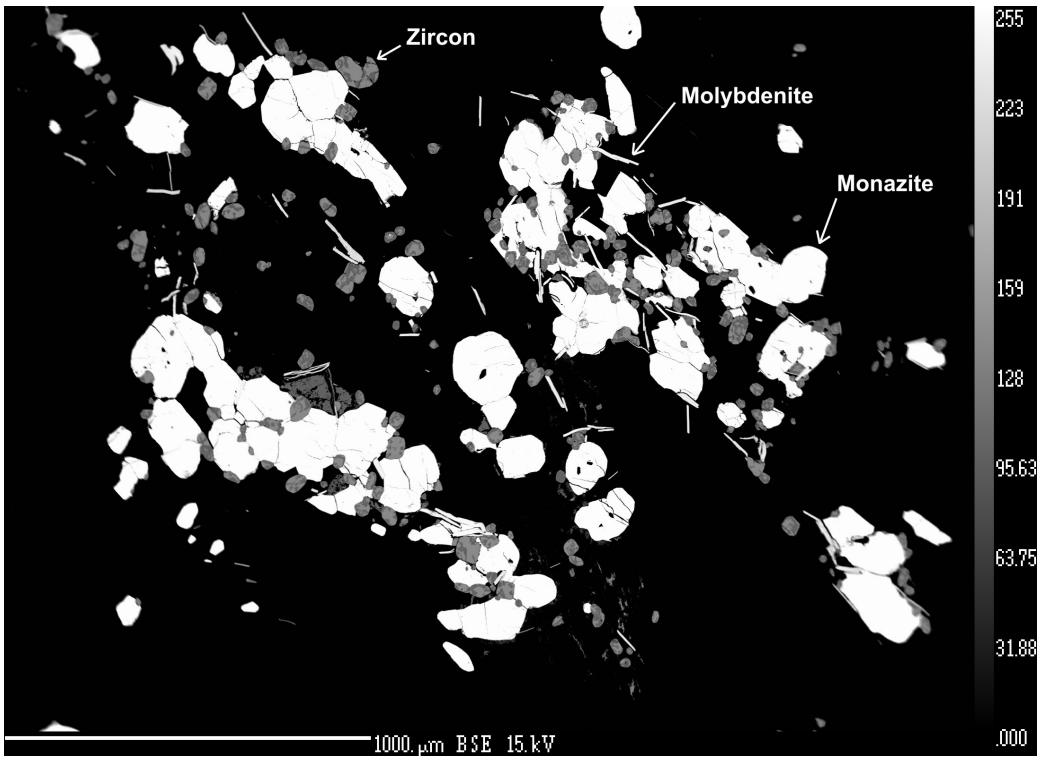

Figure 10. *BSE image of monazite crystals as clusters with zircon and molybdenite.*

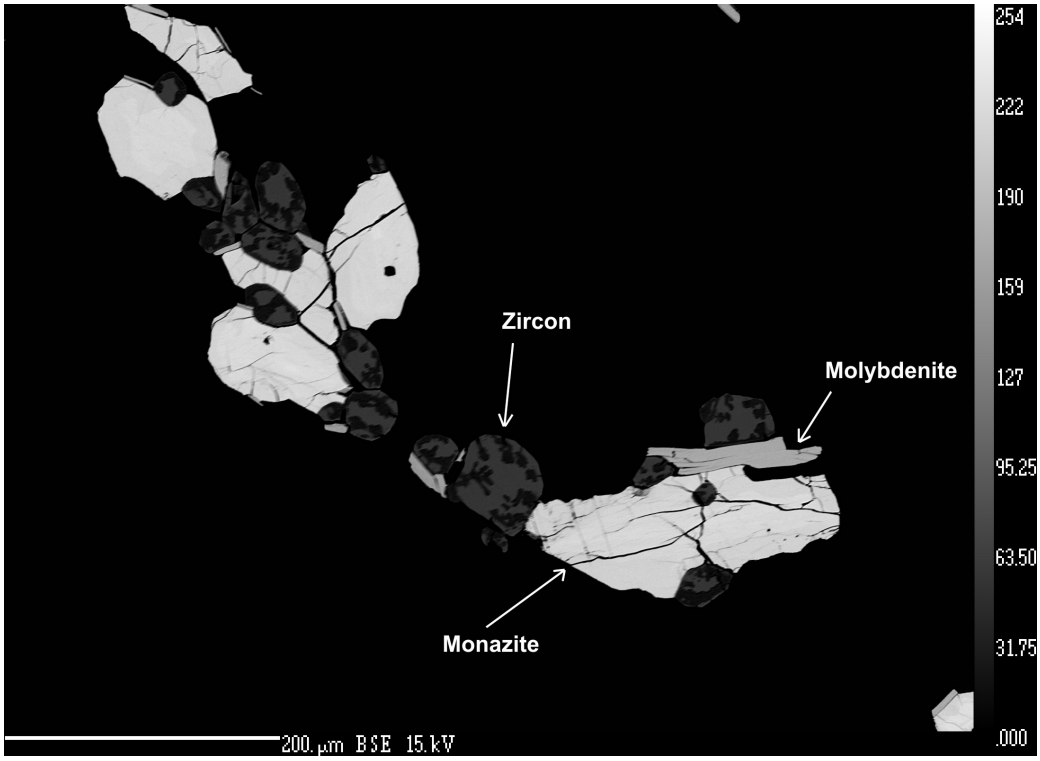

Figure 11. *BSE image of a cluster of monazite, zircon and molybdenite.*

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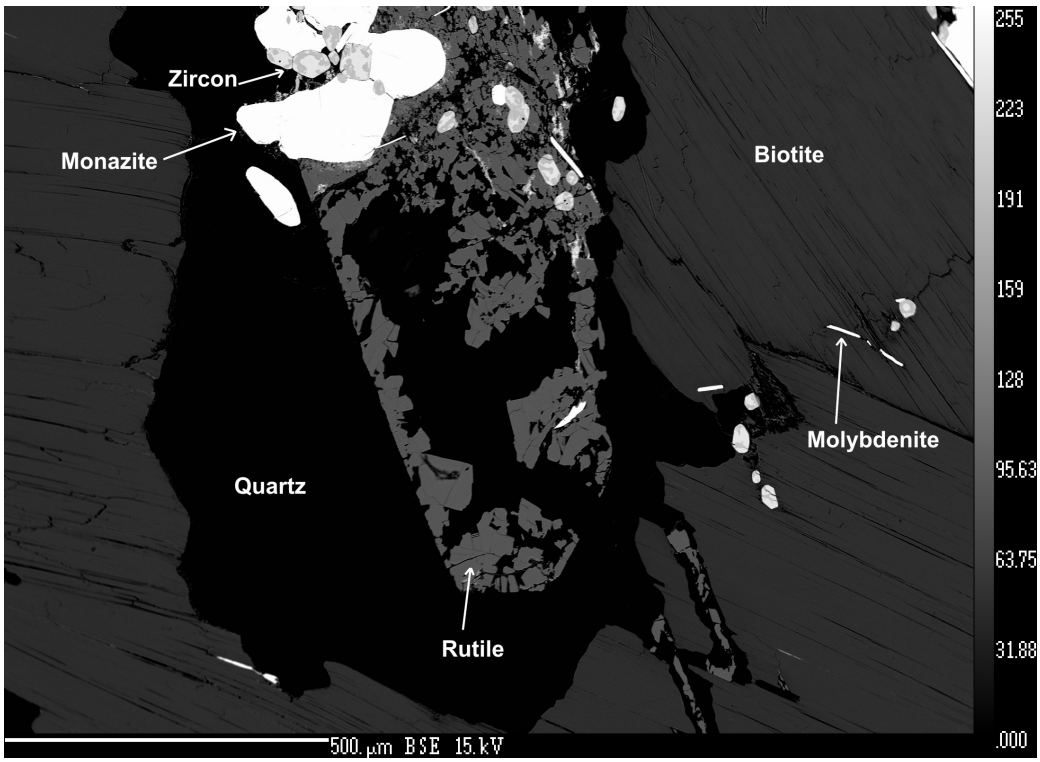

Figure 12. *BSE image of a large rutile crystal.*

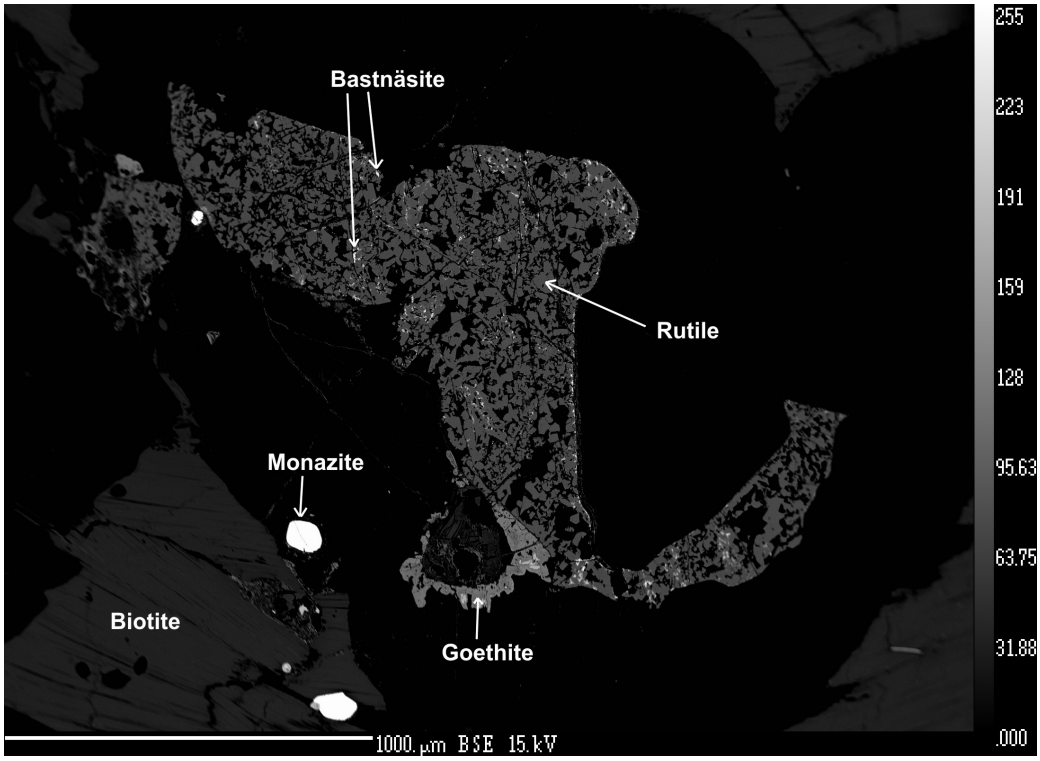

Figure 13. *BSE image of a large rutile grain containing very fine-grained bastnäsite.*

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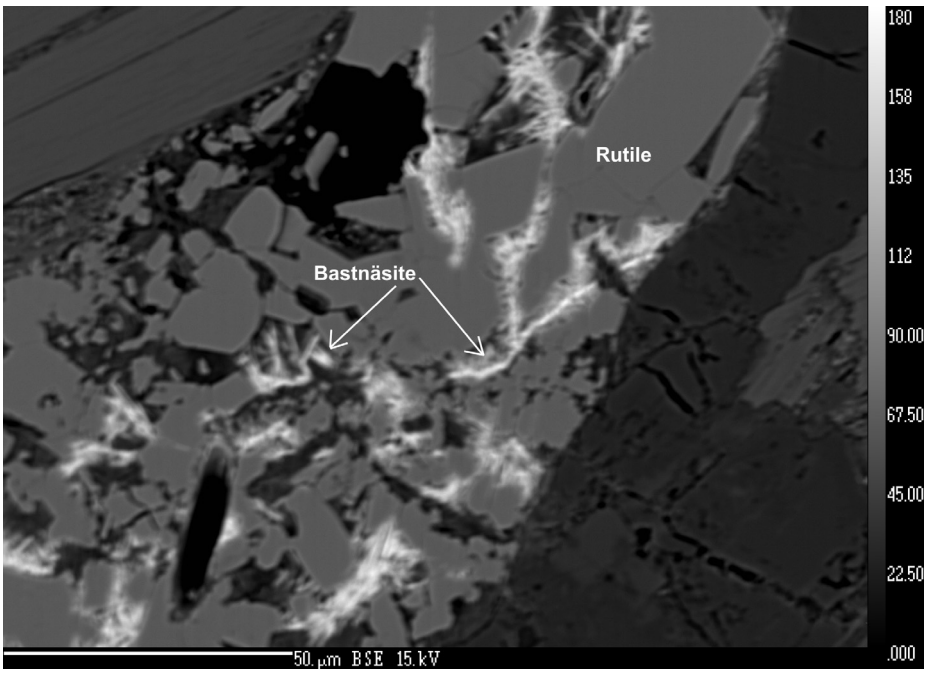

Figure 14. *BSE image of bastnäsite intergrown with rutile.*

Table 1. *Chemical analyses (by Lassi Pakkanen) of bastnäsites of the Karhukoski occurrence. Carbon dioxide content cannot be analyzed, so the microprobe analyses give a total of approximately 80 %.*

wt %	Bastnäsite 1	Bastnäsite 1	Bastnäsite 2	Bastnäsite 3	Bastnäsite 4
SiO_2	5.11	5.07	2.69	2.38	4.42
TiO_2	1.02	1.28	2.29	2.23	1.96
Al_2O_3	2.99	2.90	1.84	1.30	2.04
FeO	7.67	7.63	3.65	0.51	2.75
MnO	0.07	0.01	0.02	0.03	0.06
MgO	1.41	1.28	0.69	0.24	1.27
K_2O	0.07	0.08	0.07	0.05	0.03
Y_2O_3	1.47	1.43	1.74	1.48	1.38
CaO	2.20	2.25	2.39	2.52	2.44
Ce_2O_3	24.85	27.61	27.43	28.31	27.36
Nd_2O_3	9.81	10.57	11.12	10.94	10.77
La_2O_3	14.10	14.31	15.42	15.99	15.22
Pr_2O_3	4.00	4.07	4.39	4.51	4.08
PbO	0.05	0.14	0.17	0.12	0.21
ThO_2	0.01	0.11	0.13	0.13	0.17
Cs_2O	0.37	0.24	0.31	0.37	0.30
P_2O_5	0.55	0.65	0.50	1.94	0.40
SO_2	0.55	0.35	0.46	0.80	0.50
F	6.35	6.53	7.22	7.62	7.68
F = O	-2.67	-2.75	-3.04	-3.21	-3.23
Cl	0.09	0.07	0.05	0.12	0.11
Cl = O	-0.02	-0.02	-0.01	-0.03	-0.03
Total	80.04	83.83	79.55	78.34	79.90

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2.1.4 Comparison between Karhukoski and Kovela monazite occurrences

The Kovela monazite occurrence is located in Nummi-Pusula, southern Finland (Seppänen 1981). Like in Karhukoski, rare earth elements are included in monazite in a late orogenic granitoid. Monazite also accounts for high thorium content in the granitoids. Monazite is associated with biotite accumulations in Karhukoski, whereas monazite clusters occur in leucocratic and granitic-tonalitic parts of the granitoid in Kovela. The REE patterns (Fig. 15) of samples from the Karhukoski and Kovela occurrences are similar, because monazite is the main host mineral for rare earth elements in both occurrences. On the other hand, REE contents are higher in Kovela, up to 4.5 % total REE (Table 2).

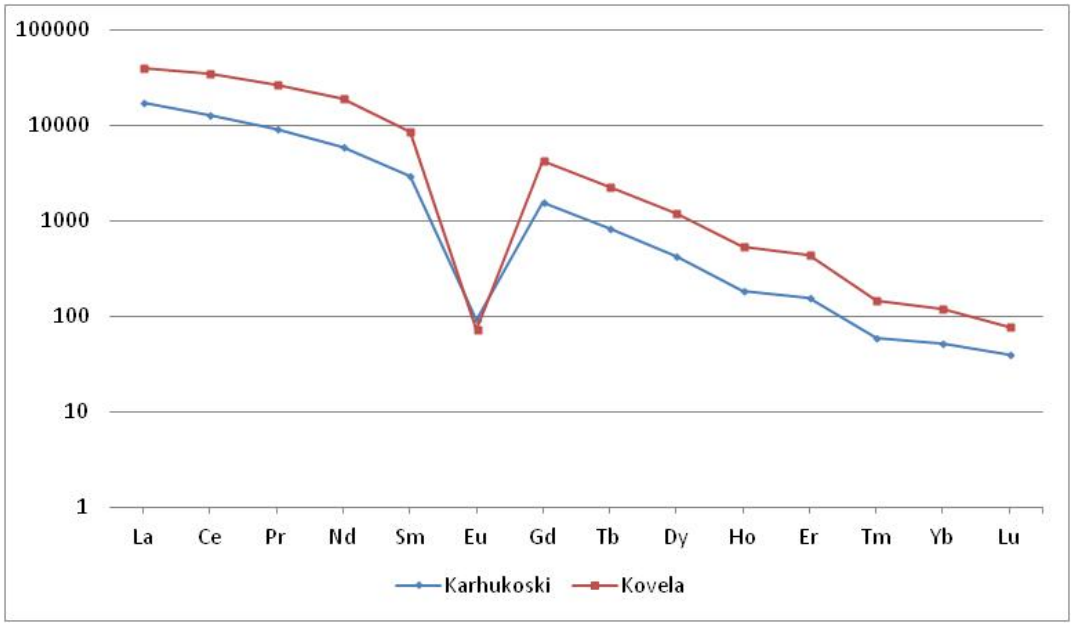

Figure 15. *CI chondrite normalized REE diagram of the Karhukoski and Kovela monazite occurrences showing strong negative Eu-anomaly. Normalizing values from McDonough and Sun (1995).*

The Kovela monazite occurrence contains less zirconium (160 ppm Zr) than Karhukoski (2460 ppm Zr). Karhukoski is clearly thorium dominated in comparison with uranium (Th/U-ratio ~ 20). The average Th/U ratio of the continental crust is ~ 4. The Kovela occurrence is even stronger enriched in thorium in comparison to uranium (Th/U ~ 38). In Kovela, monazite crystals also occur as clusters (Fig. 16 and 17) but grain size (up to 1 mm) is bigger than in Karhukoski.

The thorium and silicon contents of the Kovela monazite are remarkably higher in comparison with Karhukoski (Tables 3 and 4). Si replaces P in the crystal lattice of Kovela monazite. The Kovela monazite is exceptionally rich in Th (up to 18.7 % ThO_2) while the Karhukoski monazite is rich in Th as well (up to 13.2 % ThO_2). On the other hand, the contents of cerium, lanthanum, praseodymium, phosphorus and calcium are higher in the Karhukoski monazite.

The total content of rare earth oxides in monazite is 56.8 % in Karhukoski and 51.6 % in Kovela. Reason for the lower content of REO in the Kovela monazite is the higher substitution of REE by Th in the crystal lattice. In general, the total content of REO in monazites is lower in granitoids compared with black schists, e.g. monazite of the Talvivaara black schist ore contains 63.8 % total REO.

Table 2. *Chemical analyses of the single samples from the Karhukoski monazite occurrence (X = 6822939, Y = 3589901) and from Kovela monazite occurrence (X = 6702033, Y = 3326848).*

wt %	Karhukoski Biotite accumulation in granite	Kovela Tonalite
SiO_2	41.10	61.10
TiO_2	2.94	0.04
Al_2O_3	18.70	18.90
Fe_2O_3	15.00	0.54
MnO	0.02	0.02
MgO	4.49	0.10
CaO	2.05	4.07
Na_2O	2.31	6.05
K_2O	5.52	0.95
P_2O_5	0.90	2.32
Total	93.03	94.09
Trace elements (ppm)		
C	444.0	981.0
S	444.0	63.0
Sc	52.0	2.4
V	357.0	2.6
Cr	234.0	n.d.
Co	58.6	44.3
Ni	87.2	n.d.
Cu	37.2	2.9
Zn	412.0	44.6
Ga	31.0	27.0
Rb	498.0	17.6
Sr	134.0	126.0
Y	250.0	676.0
Zr	2456.0	157.0
Nb	47.0	n.d.
Ba	407.0	20.7
Pb	300.0	1240.0
Th	2830.0	14600.0
U	141.0	381.0
REE (ppm)		
La	4110.0	9550.0
Ce	7980.0	21600.0
Pr	850.0	2470.0
Nd	2680.0	8690.0
Sm	429.0	1260.0
Eu	5.2	4.0
Gd	308.0	855.0
Tb	29.9	80.1
Dy	104.0	290.0
Ho	10.1	29.2
Er	24.8	70.9
Tm	1.4	3.6
Yb	8.2	19.0
Lu	1.0	1.9
Total REE (%)	1.7	4.5

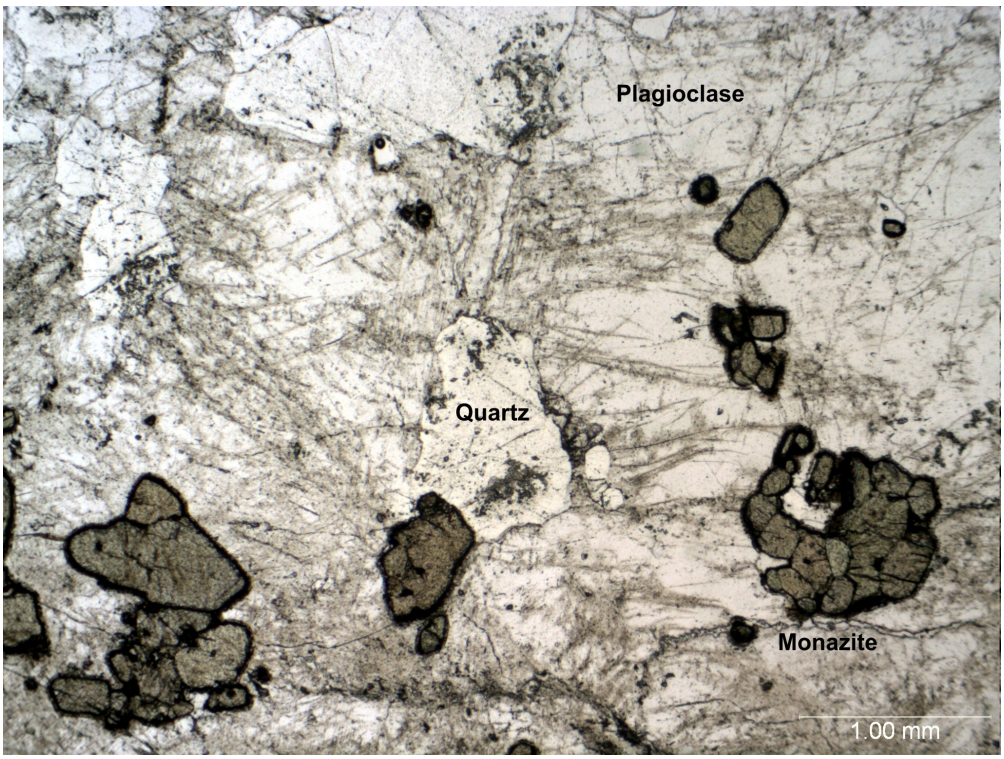

Figure 16. *Thin section image (PPL) of monazite clusters in the Kovela tonalite (X = 6702033, Y = 3326848). Photo: E. Pohjolainen.*

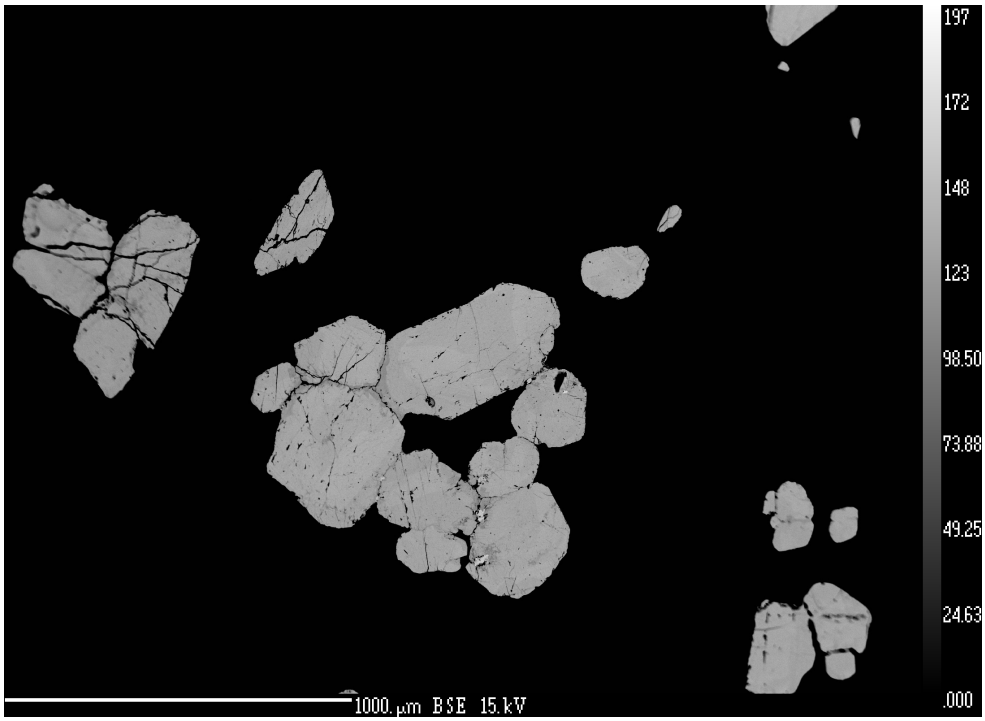

Figure 17. *BSE image of monazite clusters in the Kovela tonalite.*

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Table 3. *Chemical analyses (by Lassi Pakkanen) of monazites in the Karhukoski occurrence (sample EIPO-2011-001.2).*

wt %	Karhukoski 1	Karhukoski 2 (core)	Karhukoski 2 (rim)	Karhukoski 3	Karhukoski 4	Karhukoski 5	Karhukoski 6	Karhukoski 7	Karhukoski 8
P_2O_5	26.51	27.17	28.09	27.52	28.59	27.20	28.26	27.20	27.23
SiO_2	1.61	1.21	0.41	0.96	0.40	0.80	0.32	0.99	0.90
ThO_2	13.23	12.20	8.37	11.38	8.32	8.81	8.49	11.20	10.15
UO_2	0.91	0.54	0.76	0.73	0.93	0.47	0.95	0.66	0.48
Ce_2O_3	29.03	29.13	28.98	29.36	28.86	31.30	28.66	29.38	30.09
La_2O_3	13.76	13.39	12.35	12.72	12.15	13.33	12.26	12.83	13.23
Nd_2O_3	8.29	8.99	9.62	9.46	9.72	9.79	9.84	9.44	9.79
Pr_2O_3	4.06	4.05	4.28	4.16	4.14	4.34	4.17	4.15	4.32
Y_2O_3	0.38	0.52	1.51	0.44	1.84	0.26	1.81	0.39	0.40
CaO	1.42	1.56	1.57	1.67	1.63	1.28	1.79	1.59	1.43
FeO	0.09	0.05	0.05	0.00	0.00	0.09	0.03	0.05	0.04
MgO	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
PbO	1.41	0.90	1.14	1.02	1.13	1.01	1.05	1.43	1.44
F	0.63	0.44	0.51	0.56	0.57	0.57	0.58	0.59	0.56
F = O	-0.27	-0.19	-0.21	-0.24	-0.24	-0.24	-0.24	-0.25	-0.24
Cl	0.05	0.01	0.02	0.03	0.02	0.04	0.00	0.03	0.05
Cl = O	-0.01	0.00	0.00	-0.01	0.00	-0.01	0.00	-0.01	-0.01
Total	101.12	99.99	97.43	99.78	98.05	99.05	97.98	99.68	99.87

Table 4. *Chemical analyses (by Lassi Pakkanen) of monazites in the Kovela occurrence (sample EIPO-2006-001.1).*

wt %	Kovela 1	Kovela 2	Kovela 3	Kovela 4	Kovela 5	Kovela 6	Kovela 7	Kovela 8
P_2O_5	22.81	23.87	23.58	23.34	22.63	23.75	23.50	23.91
SiO_2	3.63	2.94	3.13	3.35	3.49	3.17	3.38	3.14
ThO_2	18.67	16.17	16.72	17.37	18.33	16.53	17.33	16.79
UO_2	0.91	0.77	0.87	0.94	0.75	0.77	0.95	0.79
Ce_2O_3	26.54	27.80	27.66	26.82	26.83	27.46	27.19	27.32
La_2O_3	9.83	10.34	10.55	9.71	9.90	10.36	10.30	10.59
Nd_2O_3	9.51	9.21	9.50	9.76	9.69	9.49	9.75	9.49
Pr_2O_3	3.73	4.08	3.82	3.85	3.83	3.78	3.84	3.87
Y_2O_3	0.79	0.72	0.73	1.03	0.72	0.82	0.90	0.87
CaO	0.79	0.82	0.85	0.82	0.78	0.80	0.75	0.74
FeO	0.03	0.00	0.00	0.00	0.00	0.05	0.00	0.00
MgO	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
PbO	2.56	1.46	1.77	1.73	2.21	1.79	2.18	1.72
F	0.48	0.40	0.49	0.46	0.52	0.52	0.47	0.47
F = O	-0.20	-0.17	-0.21	-0.19	-0.22	-0.22	-0.20	-0.20
Cl	0.02	0.02	0.01	0.01	0.02	0.02	0.03	0.00
Cl = O	0.00	-0.01	0.00	0.00	0.00	0.00	-0.01	0.00
Total	100.10	98.43	99.52	99.01	99.51	99.08	100.36	99.52

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2.1.5 Conclusions

Monazite-bearing granite in Karhukoski may have been generated by a low degree of partial melting of migmatitic mica gneiss on the basis of enrichment of incompatible elements (Th, LREE). The Karhukoski monazite occurrence is small, low-grade, Th-rich, fragmented, and thereby uneconomic.

REE minerals can incorporate uranium and especially thorium into their crystal lattices, and are therefore radioactive to varying degrees. Geophysical prospecting using aeroradiometrics with field follow-up of gamma anomalies can be utilized in exploration and e.g. in the identification of REE deposits. For instance, monazite can be rich in thorium as seen in Kovela.

Resistance of monazite to chemical weathering and its high specific gravity account for its association in placer deposits with other resistant heavy minerals. Globally, monazite resources are mainly related to heavy mineral placer deposits. Monazite is almost always only secondary, not primary valuable heavy mineral (Elsner 2010). Monazite is often considered as an impurity in placers because of its radioactivity and better REE supply options from other RE minerals. Global demand for monazite is expected to increase in the long term because of its abundant supply and its recovery from placer deposits as a low-cost by-product. However, granitoid-related (hard rock) deposit types including LREE-dominated Karhukoski and Kovela occurrences represent the high-cost category. As a further comment, possible concentration tests with material from the Karhukoski occurrence would generate a radioactive monazite concentrate which needs to be disposed of in a sustainable way.

2.2 REE potential mapping in the Puumala-Ruokolahti area

Ground checking of aerogeophysical gamma radiation and magnetic anomalies was carried out in the Puumala-Ruokolahti area. Thorium and magnetic anomalies were checked in the neighborhood of Karhukoski but nothing special was observed. Weak magnetic anomalies seem to be caused by disseminated magnetite in migmatitic mica gneisses. Th-anomalies are probably mostly artificial due to their locations in the extensively exposed bedrock regions.

Three lamprophyre dikes are mentioned in the bedrock map explanation of the Virmutjoki map sheet area by Nykänen (1988). Lamprophyres probably represent results of low degree partial melting and the process can also lead to the enrichment of incompatible elements (including REE) into melts. The field checking of these dikes was carried out in the areas of Huussuo and Kannokomäki in Ruokolahti and Kuikkajärvi (Fig. 1) in Rautjärvi but the dikes could not be found which is reasonable because these dikes are reported as extremely narrow (e.g. 20 cm in width in Huussuo). Granite in Huussuo was sampled and analyzed but the REE contents are low (147 ppm total REE).

GTK discovered the Lieviskä (Fig. 1) uranium occurrence in Puumala in the late 1950s (Ervamaa 1960). The host rock is strongly fractured and altered granite pegmatite with strongly radioactive spots (max. 5000 cps with SAIC GR-135 spectrometer). The rock contains lots of slickensided fractures which are coated mainly by chlorite; also hematite and malachite occur on the fracture surfaces. The main fracture direction is 200°/57° (strike 110°). The most radioactive points are associated with narrow quartz-rich veins. The occurrence is uranium dominated with Th/U-ratio ~ 0.7. The occurrence was observed and sampled but the REE contents are low (23-243 ppm total REE).

An aeroradiometric uranium anomaly (Fig. 18) in Majasaari, Ruokolahti was also checked. The bedrock in Majasaari consists mostly of granite, amphibolite, mica gneiss, granodiorite, hornblende gneiss, diorite and quartz-feldspar gneiss. The Majasaari uranium anomaly is caused by the strongly radioactive zone (strike ~ 130°) in granite (max. 18 000 cps with GR-135 spectrometer, Fig. 19). The radioactive zone is rather uniform and extensive. The most radioactive spots are associated with quartz and biotite accumulations in granite. The barren granite was sampled and analyzed but the REE contents are very low (69 ppm total REE) and the rock is uranium dominated with Th/U-ratio ~ 0.9. The Majasaari showing may be an interesting REE potential target for more detailed mapping and sampling although it is unlikely to be economically viable.

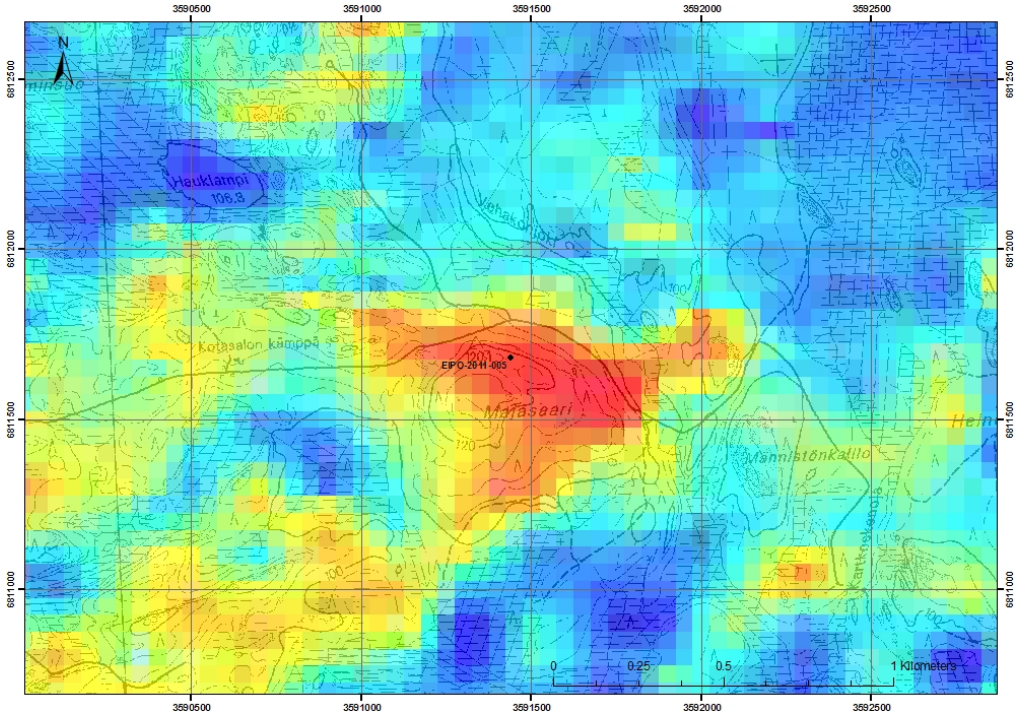

Figure 18. *The Majasaari uranium anomaly on U channel gamma radiation map (GTK aerogeophysical data). Base map © National Land Survey of Finland, licence 13/MML/12.*

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Figure 19. *Strongly radioactive spot in Majasaari (18 000 cps above coin) which is associated with a rusty biotite seam in granite.*

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Location	Karhukoski	Lieviskä	Lieviskä	Huussuo	Vesiniemi	Majasaari
X	6822939	6827426	6827432	6811111	6832183	6811760
Y	3589901	3590420	3590455	3589467	3565146	3591325
Sample	EIPO-2011-001.2	EIPO-2011-004.1	EIPO-2011-004.2	EIPO-2011-006.1	EIPO-2011-011.1	EIPO-2011-012.1
Rock	Biotite accumulation	Granite	Granite	Granite	Garnet mica gneiss	Granite
SiO_2 (wt %)	41.10	58.70	76.70	69.80	60.30	70.80
TiO_2	2.94	1.12	0.11	0.37	0.79	0.17
Al_2O_3	18.70	13.60	12.20	15.40	16.80	15.90
Fe_2O_3	15.00	12.20	0.79	2.82	8.69	1.59
MnO	0.02	0.16	n.d.	0.03	0.05	0.02
MgO	4.49	3.86	0.37	1.27	3.16	0.63
CaO	2.05	3.55	0.15	2.56	1.14	3.00
Na_2O	2.31	0.16	0.37	4.70	2.31	4.61
K_2O	5.52	1.61	8.68	2.55	2.97	2.82
P_2O_5	0.90	0.06	0.08	0.14	0.08	0.13
Total	93.03	95.03	99.45	99.64	96.29	99.68
Trace elements (ppm)						
C	444.00	0.03	0.02	0.04	0.24	418.00
S	444.00	0.01	n.d.	0.01	0.08	n.d.
Sc	52.00	35.40	n.d.	2.51	17.60	1.56
V	357.00	101.00	7.91	42.70	147.00	14.90
Cr	234.00	n.d.	n.d.	13.40	92.50	4.21
Co	58.60	18.00	10.30	15.80	8.94	44.90
Ni	87.20	10.80	n.d.	13.60	14.80	n.d.
Cu	37.20	393.00	7.91	5.76	72.40	7.44
Zn	412.00	211.00	25.00	41.00	254.00	41.80
Ga	31.00	n.d.	n.d.	n.d.	n.d.	20.00
Rb	498.00	29.00	n.d.	22.00	27.00	94.30
Sr	134.00	677.00	163.00	712.00	109.00	406.00
Y	250.00	69.60	3.83	7.37	15.50	6.03
Zr	2456.00	251.00	33.00	132.00	263.00	62.00
Nb	47.00	22.00	n.d.	n.d.	18.00	7.00
Ba	407.00	132.00	915.00	582.00	366.00	533.00
Pb	300.00	32.70	45.10	7.51	23.80	85.90
Th	2830.00	24.90	3.38	9.83	22.90	195.00
U	141.00	37.80	4.41	6.74	3.51	225.00
REE (ppm)						
La	4110.00	50.9	4.49	34.00	70.30	15.70
Ce	7980.00	79.3	8.94	68.20	144.00	30.70
Pr	850.00	13.1	1.04	7.26	16.80	3.31
Nd	2680.00	46.3	3.75	25.30	62.20	11.70
Sm	429.00	10.3	0.86	3.57	10.80	2.14
Eu	5.21	1.21	1.02	1.06	1.20	0.85
Gd	308.00	11.2	1.00	3.35	9.60	1.76
Tb	29.90	1.9	0.15	0.34	1.08	0.24
Dy	104.00	12.1	0.77	1.49	4.21	1.26
Ho	10.10	2.39	0.12	0.27	0.63	0.22
Er	24.80	7.010	0.37	0.84	1.75	0.65
Tm	1.44	0.89	0.04	0.10	0.20	0.08
Yb	8.23	5.85	0.26	0.69	1.41	0.59
Lu	0.98	0.84	0.04	0.11	0.23	0.10
Tot REE (ppm)	16542	243	23	147	324	69