

УДК 552.3:[553.49+553.81]

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“Magmatism of the Earth and related strategic metal deposits”. Proceedings of XXXIV International Conference. Miass, 4-9 August 2017/Editors V.A. Zaitsev & V.N. Ermolaeva.-M: GEOKHI RAS, 2017. 345 p. - ISBN 978-5-905049-21-7.

The mineral deposits of strategic metals are vulnerable to political and economic changes, and their availability is essential for high-technology, green energy, and other applications. The most of them are related to the deep-seated alkaline magmas.

This book offers a collection of papers presented at the 34th International Conference on Magmatism of the Earth and Related Strategic Metal Deposits held from August 4th to 9th 2017 in Miass, Russia. The conference articles are focused on understanding of the geological processes that produce high concentrations of critical metals in geological systems such as the transport of metals in the mantle and crust and enrichment processes, hydrothermal and metasomatic processes leading to the formation of such significant deposits. Papers in this book give a representative overview including mineralogy, geochemistry and origin of strategic metals deposits.

Supported by Russian Science Foundation (Agreement 15-17-30019 as of July 09, 2015)

ISBN 978-5-905049-21-7 © Vernadsky Institute of Geochemistry and Analytical Chemistry of Russian Academy of Sciences (GEOKHI RAS), 2017

The cover pictures are geological map of the Urals and «Ridges of Ural» of E.V. Nikolsky

Evgeny Vasilyevich Nikolsky (1917-1978) was a famous Russian artist who lived in Miass. The main theme of his artworks was Ural landscape. He had been making his paintings in different styles and techniques, but most of all he liked to paint with watercolours. In 1969 with this type of paint he had made an artwork “Ridges of Ural” which was painted in the mountains of Southern Ural. Nowadays, this artwork is being kept in local museum of Miass. This year we celebrate the centenary of the birth of this artist.

RARE-METAL MINERALIZATION IN SPHERULITIC PERLITES OF YAGODNINSKY ZEOLITIC DEPOSIT (SOUTH KAMCHATKA)

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For the first time ever, minerals containing rare, rare-earth and radioactive elements were identified in spherulitic perlites of extrusive-subvolcanic complex consisting of mainly acid composition enclosing rocks of Yagodninsky deposit of high quality zeolitic resources (South Kamchatka). It was established that the minerals of perrierite, pyrochlore, euxenite, monazite and xenotime group were the main concentrators of these elements. Monazite and xenotime whose formation is associated with potassic metasomatism processes occur most widely in spherulitic perlites.

Yagodninsky deposit of zeolitic resources, perlites and active mineral additives (full name (Nasedkin et al., 1988)) is situated in Banno-Karymshinsky geothermal (ore) district of South Kamchatka. The district is characterised by contrasted magmatism, wide development of alkaline pyroclastic rocks and formation of large multi-phase intrusive and extrusive-subvolcanic complexes (Rychagov et al., 2015). The deposit is confined to the extrusive-subvolcanic complex at elevation 1081 (Nasedkin, 1983). The enclosing rocks are rhyolitic and dacitic litho-vitroclastic tuffs, various composition perlites, rhyolitic lavas and extrusions, near-vent tuffs and tuffites (Boykova, 2015). Of special interest (owing to varied composition, structure and texture) are spherulitic perlites that form extrusions, short lava streams and separate blocks drawn to contacts of subvolcanic intrusions with tuffs and rhyolites.

Mineralogical studies of spherulitic perlites specified a chemical composition of rock-forming minerals as well as a group of accessory minerals containing rare, rare-earth and radioactive elements. The studies were conducted by means of VEGA 3 scanning electronic microscope equipped with energy-dispersion spectrometer (EDS) X-MAX 80 with AZtec firmware (Institute of Volcanology and Seismology of FED RAS, Petropavlovsk-Kamchatskii, research associates V.M. Chubarov and T.M. Phylosofova). The studies were conducted on 3 x 4 cm polished sections which were subjected to carbon coating. Base, rare, rare-earth and radioactive elements were detected by comparison with reference materials whose composition had been checked for homogeneity and content of elements.

Table. 1 Content of rare-earth minerals from spherulitic perlites of Yagodninsky zeolitic deposit based on data of energy-dispersion spectrometer (% wt.)

Oxides	Pyrochlore		Euxenite		Perrierite		Monazite		Xenotime	
	1	2	3	4	5	6	7	8	9	10
Al ₂ O ₃					2.12	2.80	8.50	8.66		
SiO ₂	2.15				19.80	20.45	26.82	25.01	9.35	4.81
P ₂ O ₅							17.36	15.95	14.12	13.15
Na ₂ O	0.47	0.49								
K ₂ O							2.33	2.16	1.35	0.69
CaO	11.98	11.51			4.37	4.66	3.14	2.45	0.59	0.83
V ₂ O ₅									1.69	1.11
TiO ₂	21.97	22.67	32.12	26.95	14.53	15.09				
MnO	1.95	2.23								
FeO	2.81	2.71	1.02	0.99	8.79	9.09	0.98	1.87		
As ₂ O ₅							6.01	5.64	18.03	19.71
Y ₂ O ₃	2.39	1.81	14.66	17.40	2.30	1.49	3.96	3.24	35.96	38.59
ZrO ₂					0.90	1.57				
Nb ₂ O ₅	18.38	20.08	15.54	24.33						
Ta ₂ O ₅	7.14	3.31	3.14	4.31						
La ₂ O ₃					8.58	7.97	8.62	8.10		
Ce ₂ O ₃	2.20	2.17			19.81	19.58	15.12	16.69		2.13
Pr ₂ O ₃		0.63			2.50	3.00		1.79		
Nd ₂ O ₃	1.15	1.75			7.48	7.85	4.79	6.96	1.32	2.63
Sm ₂ O ₃					1.63	1.65				
Dy ₂ O ₃		0.67	2.11	2.82					3.07	3.03
Er ₂ O ₃			2.17	1.76					2.09	2.84
Yb ₂ O ₃			2.54	2.99		0.57			4.63	3.86
∑REE			2.17		1.77	0.70			1.38	2.07
ThO ₂	1.42				0.37	0.73	0.94	1.56		
UO ₂	23.97	24.39	19.83	10.04						
∑	97.98	94.42	95.30	91.59	94.94	97.20	98.57	100.08	93.58	95.45

Note. ∑REE – (Pm, Eu, Gd, Lu)₂O₃.

The texture of perlitites in studied samples is massive, brecciated, finely banded, fluidic; the structure is spherulitic, porphyritic or microfelsitic. The perlitites contain a small amount of inclusions – 2–3 % of rock volume. The inclusions are presented with barium-containing potassium-sodium feldspar, acid plagioclase, biotite, titanomagnetite (up to 5.1 % wt TiO₂) and ilmenite. Apart from inclusion, they have spherulites of feldspathic composition and feather-like quartz-feldspathic aggregates. In terms of alkalis content, perlitites are referred to the moderate alkaline type (6-8 wt% of Na₂O + K₂O). In unaltered glasses, Na₂O (4.6-5.7 wt%) dominates over K₂O (1.2-3.3 % wt.).

Two types of hydrothermal-metasomatic alteration are typical for spherulitic perlitites: zeolitization and K-feldspathization. Zeolitization of glass starts along concentrically-zonal perlite fissures without displacement with formation of a metacolloidal matter. The quantitative analysis of such zones demonstrates that their aluminium content is approximately the same as in the original glass. At the same time, silicon content significantly decreases, sodium content drops almost to zero, K₂O increases by approx. 1 % wt., CaO increases by 3.5 wt%. Sum deficit in assays is 13-24 % wt., which is, most probably, due to presence of water.

K-feldspathization develops along transverse rock fissures, along contacts of porphyritic minerals and spherulites with glass, and along intermittent bands in fluidized perlitites. The sections of K-feldspathized glass, as compared to alkaline feldspar of inclusions, do not have sodium and barium, aluminium content slightly decreases, silicon content increases, potassium content increases (up to . % wt. of K₂O). Sum deficit in assays is on the average 4-5 % wt. Along with K-feldspar, secondary quartz and hydromica are formed.

The minerals of perrierite, pyrochlore, euxenite, monazite and xenotime group are the main concentrators of these elements. Minerals-concentrators are complex multicomponent solid solutions which makes it difficult to classify them definitively. The typical chemical constituents of the minerals are shown in the table. Rare earth metals are also observed as trace elements in zircon (Hf), apatite (Y, Nd, Yb), fluorite (Yb, Lu), haematite (Ce), rutile (Zr, Nd) and sphene (Y, Nb, Ta, Nd).

Uranium-containing titanate - tantalate-niobates. This group of minerals is characteristic for alkaline syenites, alkaline granites, pegmatitic granites etc. (Geochemistry..., 1964; Rikhvanov et al., 1989 et al.). Pyrochlore and euxenite were detected in spherulitic perlitites in the form of irregularly-shaped inclusions in ilmenite (Fig. 1, b). Ilmenite is associated with oligoclase, barium-containing potassium-sodium feldspar, biotite, titanomagnetite (up to 5.1 % wt TiO₂), zircon, apatite and sphene. In inclusions, pyrochlore and euxenite form concretions with distinct smooth-line boundaries. In euxenite, zonality is observed which is caused by fluctuation of base elements – Ti, Y, Nb and U.

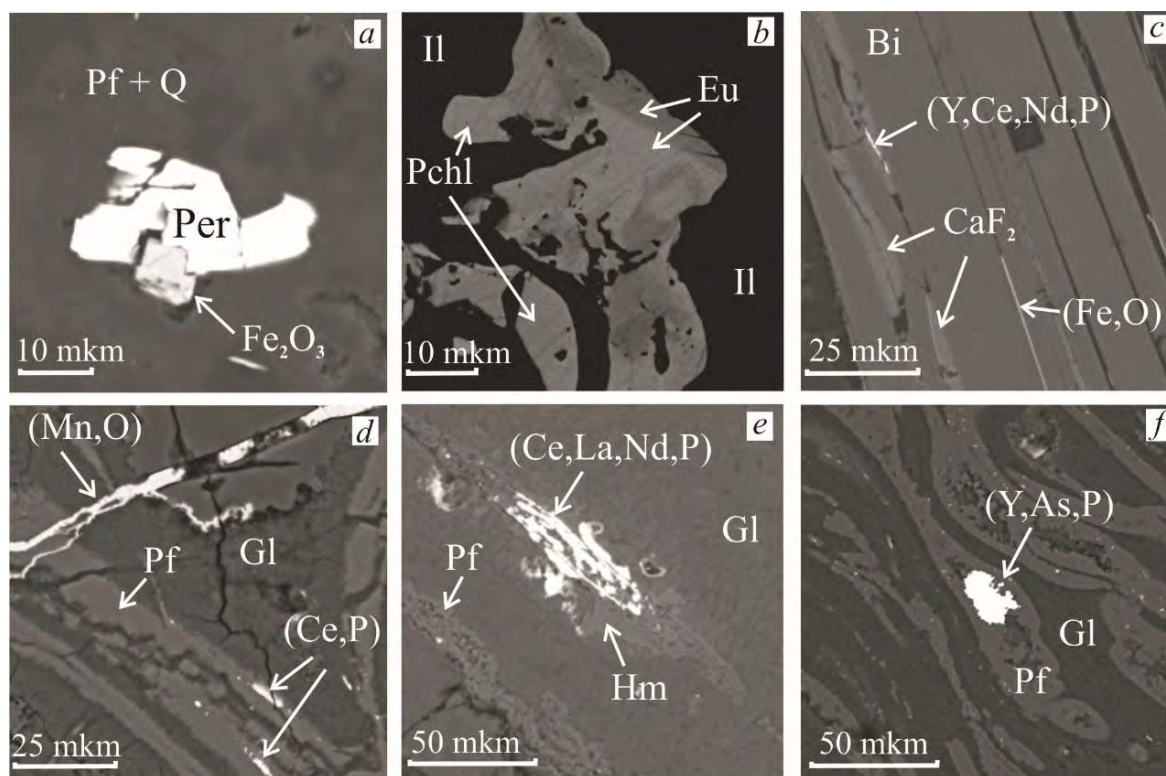


Fig. 1. Rare-metal minerals in spherulitic perlitites of Yagodninsky zeolitic deposit:

a – Perrierite (Per) in concretion with haematite in the aggregate of quartz-feldspathic (Q + Pf) composition; *b* – pyrochlore (Pchl) in concretion with zonal euxenite (Eu) in ilmenite (Il); *c* – fluorite with cerous phosphate along cleavage planes in biotite (Bi); *d* – cerous phosphate in K-feldspathized (Pf) glass along perlite fissures; *e* – cerous phosphate along the fissure in glass (Gl) in association with hydromica (Hm); *f* – xenotime with arsenic in schliers of K-feldspathized glass of fluidized perlite.

Titaniumsilicate perrierite occurs rarely. It is known that this mineral was found in granite pegmatites, alkaline metasomatites, quartz-feldspathic veins, apatite ores and in other rocks as well as in volcanic sediments of different origin (Bonshtedt-Kupletskaia, 1972; Andreyev, Ripp, 1995). Perrierite in spherulitic perlites is confined to quartz-feldspathic areas of decrystallization of glass (Fig. 1, a). It forms rhomboid crystals or irregularly-shaped grains up to 30 μm in size; sometimes it forms concretions with haematite. The main components present in the mineral are as follows: SiO_2 (20–21%), TiO_2 (14,5–18,4 %), Ce_2O_3 (19,6–21,6 %), FeO (7,1–9,5 %), La_2O_3 (8-9,7 %), Nd_2O_3 (5,9-7,9 %).

Phosphates of rare earths are widely spread. They are confined to zones of K-feldspathized glass where they are observed as concentrations of numerous fine grains less than 3 μm in size, as linearly extended uniform masses; spongy, needle-like or nodular formations the size of which does not exceed 50 μm (Fig. 1, c-f). Phosphates are also deposited along fissures in the crystals of potassic feldspar and in albite, together with fluorite they develop along cleavage planes in biotite and form concretions with rutile. Two groups of phosphates are distinguished – ceric and yttrium ones. By composition, they are closer to monazite and xenotime. Water is often present in phosphates, which is evidenced by the sum deficit in assays. Xenotime contains a significant amount of As and, most probably, have the form of a solid solution with minerals of the chernovite series. Elevated content of arsenic in the rhyolites of the deposit may be associated with this mineral.

Conclusion

A large group of accessory minerals containing rare, rare-earth and radioactive elements was found in the spherulitic perlites of extrusive-subvolcanic complex enclosing Yagodninsky zeolitic deposit. It is known that confinedness of elements to one or another group of minerals depends on the acidity-alkalinity of environment and on ion activity of sodium and potassium. Probably, an important role of sodium in crystallization of the acid melt promoted the formation of uranium-containing titanate-tantalate-niobates, whereas at the stage of hydrothermal-metasomatic transformation of rocks, when the role of potassium incoming with deep-level metal-bearing hydrothermae increased (Serezhnikov, Zimin, 1976; Rychagov et al., 2015), titanosilicates and cerous phosphates as well as yttrium phosphates were deposited. Thus, rare-metal mineralization in the rocks of the extrusive-subvolcanic complex of Yagodninsky zeolitic deposit says in favour of the fact that both the original melt and the ascending hydrothermal fluid flow are enriched with rare earth and other elements.

This work was done with a financial support from Russian Foundation for Fundamental Research (project 16-05-00007a) and Far East Department of Russian Academy of Sciences (FED RAS) (project 15-I-2-065).

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A ROLE OF DEFORMATION-INDUCED PROCESSES IN THE OPHIOLITE ULTRAMAFIC ROCK AND CHROMITITE ORIGIN. AN EVIDENCE FROM KRAKA OPHIOLITE, THE SOUTHERN URALS

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The Kraka ophiolite is located in the northern part of Zilairskaya megazone (megasynclorium) of the Southern Urals western slope. Geological and structural features of these ultramafic rocks as well as relationships with surrounding rocks were considered in previous works (Kazantseva, Kamaletdinov, 1969; Senchenko, 1976). The internal structure of