ISSN 1028-334X, Doklady Earth Sciences, 2009, Vol. 425, No. 2, pp. 231–234. © Pleiades Publishing, Ltd., 2009.
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GEOLOGY

Granitization of the Basic Volcanic Rocks in the Contact Aureole of the Gabbronorite Intrusion (Ganal Ridge, Kamchatka)

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Presented by Academician A.A. Marakushev March 17, 2008

Received April 3, 2008

DOI: 10.1134/S1028334X09020123

Granulite-like metamorphic rocks found by Tikhomirov in 1956 in the Ganal Ridge of Kamchatka [1] opened a long discussion on their origin and facies affiliation. Most researchers ascribed these rocks to the ancient complex of the sialic basement of East Kamchatka [2, 3], while others suggested their contact-reaction formation [4–6]. Therefore, establishment of the nature of the granulite-like rocks is of importance for understanding not only their genesis and facies affiliation, but also the origin of the crystalline basement of all East Kamchatka.

This work reports new data in support of the contact-reaction nature of the granulite-like rocks and their formation during hornfelsing, metasomatism, and magmatic replacement of primary basic volcanics and intercalated sedimentary rocks of the Vakhtalkinskaya Sequence of the Ganalskaya Group in the contact aureole of the Yurchikskii gabbronorite intrusion.

The Vakhtalkinskaya sequence (800–900 m thick) occupies the base of the Ganalskaya Group and consists of metamorphosed basic volcanics: amphibole and clinopyroxene–amphibole schists with boudinaged interlayers of metaterrigenous rocks represented by garnet–biotite–cordierite plagiogneisses from 10–20 cm to 10–15 m and thicker silicic (dacite) metavolcanic rocks, quartzites, and rare marbles.

The Yurchikskii intrusion cutting across the deposits of the Ganalskaya Group is a phacolithlike body up to 22 km long. The most intense magnetic field found beneath its northern termination indicates a notable thickness (up to 1500 m) of the intrusion. The insignificant thickness of caprocks over the northern part of the massif and their penetration by gabbronorite apophyses provided intense hornfelsing, metasomatism, and magmatic replacement of the initial deposits (Fig. 1).

The Yurchikskii intrusion is made up of early gabbronorites and later (postmetamorphic) rocks varying in composition from lherzolites, wehrlites, and troctolites to clinopyroxene–amphibole melanocratic gabbro [7]. In the margins, the gabbronorites are gneissose, cataclased, and diaphthorized (up to gabbroamphibolites) owing to superimposed regional amphibolite-facies metamorphism, which spanned even hornfels aureole and sedimentary–volcanogenic rocks of the Ganalskaya Group. According to Sm–Nd and U–Pb-SHRIMP data, the gabbronorites were emplaced in the Eocene (about 31 Ma ago [8]), while late gabbroids based on $^{40}Ar/^{39}Ar$ and U–Pb-SHRIMP determinations were formed in the Early Miocene (personal communication of E.G. Konnikov).

The basic volcanics of the Vakhtalkinskaya Sequence in the inner parts of the contact aureole were converted into fine-grained amphibole, clinopyroxene–amphibole, and two pyroxene–amphibole hornfelses consisting of brownish green magnesio-hornblende or ferroan pargasite ($X_{Mg} = 0.60–0.67$), plagioclase ($X_{An} = 0.80–0.45$), clinopyroxene ($X_{Mg} = 0.68–0.77$), and more rarely orthopyroxene ($X_{Mg} = 0.70–0.72$). The maximum temperature of contact metamorphism calculated from clinopyroxene–orthopyroxene equilibria reached 700–800°C.

Hornfelses locally suffered metasomatic alterations of widely varying intensity depending on the presence of fracture zones permeable for metamorphosing fluids.

The initial stages of metasomatic alteration in hornfelses were marked by formation of individual small crystals and chains of orthopyroxene, which corroded and replaced amphibole of primary rocks (Fig. 2). All hornfelses of the northern part of the contact aureole (distinguished by specks in Fig. 1) were variably overprinted by metasomatic processes, which caused the replacement of their assemblages by orthopyroxene

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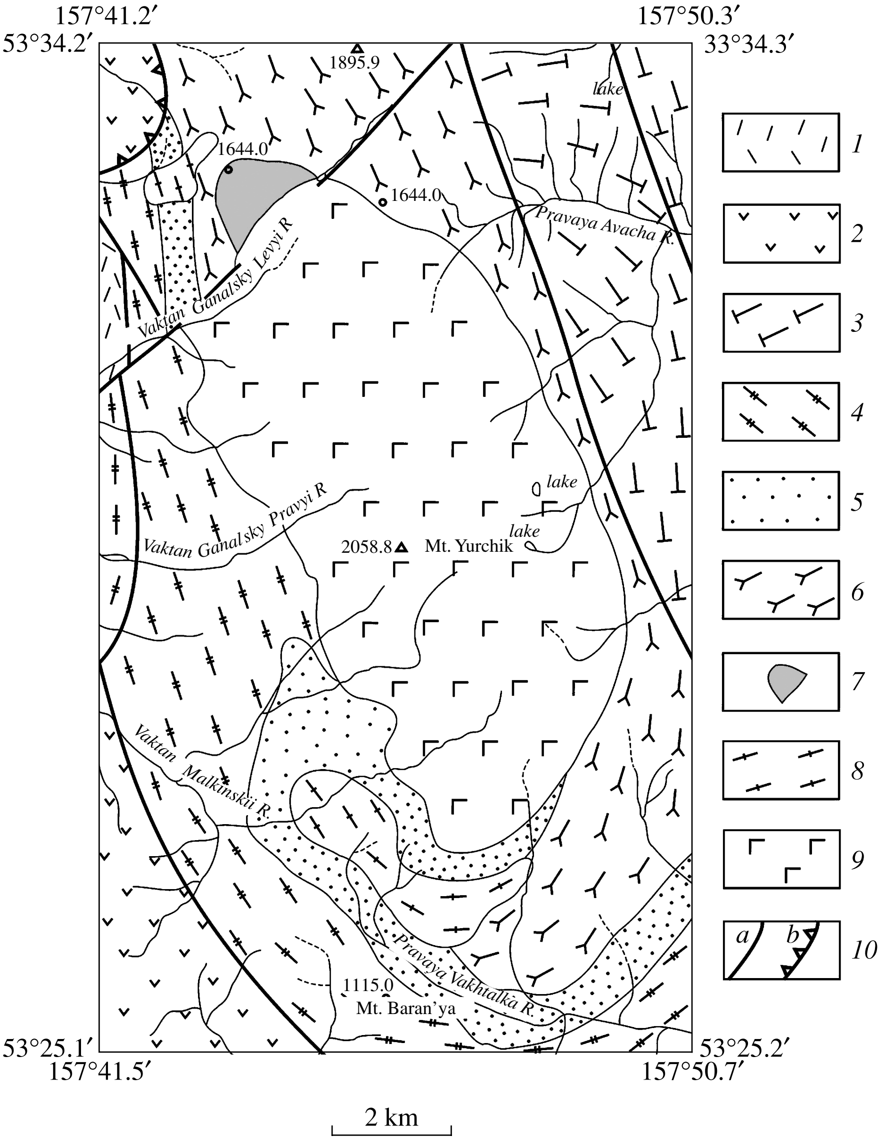

Fig. 1. Schematic geological map of the central part of the Ganal Ridge. (*1*) Neogene tuffs and volcanics; (*2*) pyroclastic complex (Iruneiskaya Formation); (*3*) terrigenous–volcanic–pyroclastic complex (Stenovaya Group); (*4*–*6*) Ganalskaya Group: (*4*) D'yavolskaya Sequence, (*5*) Voevodskaya Sequence, (*6*) Vakhtalkinskaya Sequence; (*7*) zone of intense hornfelsing, metasomatism, and magmatic replacement of the rocks of the Vakhtalkinskaya Sequence; (*8*) gneissose gabbronorites and postmetamorphic gabbroids of the Yurchikskii intrusion (undivided); (*10*) faults (*a*) and thrusts (*b*).

(X_{Mg} = 0.58–0.63, with more rare Fe varieties X_{Mg} = 0.45–0.56), sodic plagioclase An_{45}, and variable amounts of biotite, apatite, and Fe–Ti oxides.

With intensification of metasomatic processes, all mafic minerals in hornfelses were almost completely corroded and replaced by a fine-grained metasomatic biotite–orthopyroxene–plagioclase assemblage, and penetrated by thin leucocratic migmatite veinlets and patches of biotite–orthopyroxene–plagiolcase ± garnet composition, which are characterized by a coarser grained (up to 1–2 mm and more) hypidiomorphic magmatic texture.

The formation of biotite–orthopyroxene–plagioclase ± garnet leucocratic veinlets and patches resembling leucosomes in typical migmatites indicates a local melting (magmatic replacement) of preliminarily metasomatized hornfelses. A characteristic feature of metasomatites and migmatite veinlets and patches is the sharply elevated contents of apatite, which points to the high content of volatiles (water, phosphorus, chlorine, and fluorine) in fluids.

Escalation of metasomatic alterations of hornfelses coupled with local magmatic replacement caused intense debasification of the initial basic volcanics, which is expressed in an increase in the amount of leucocratic minerals (mainly plagioclase) at the expense of mafic minerals in the newly formed assemblages. For instance, sample 427-I (fine grained biotite–orthopyroxene–pla-

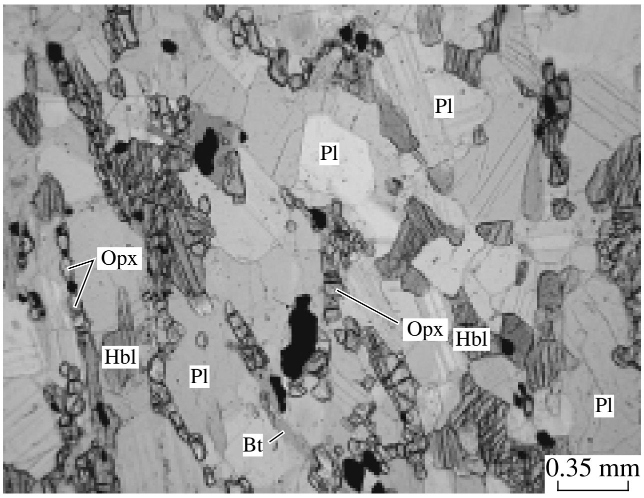

Fig. 2. Metasomatic replacement of hornblende by orthopyroxene in the pyroxene–amphibole hornfels. Sample 537-C-1.

gioclase metasomatite) contains about 28 vol. % orthopyroxene, up to 1 vol. % biotite, 69 vol.% plagioclase, and 2 vol. % apatite and ore minerals, while the magmatic veinlet contains 10 vol. % orthopyroxene, 83 vol. % plagioclase, 5 vol.% biotite, and 2 vol.% ore mineral and apatite. The increase of plagioclase in the migmatite veinlets and patches is associated with formation of anthiperthites of potassium feldspar (up to 1–5 vol%) and an increase of the Fe mole fraction in mafic minerals and the Al mole fraction in orthopyroxene.

Subsequent intensification of metasomatic processes and magmatic replacement of hornfelses caused even greater debasification of primary basic volcanics and the appearance of rare thin veinlets of garnet enderbite consisting of orthopyroxene, biotite, plagioclase, quartz, cordierite, garnet, and occasionally K feldspar in the metasomatites. Large bodies of garnet enderbites are formed during magmatic replacement of boudinaged sedimentary beds among basic volcanic rocks of the Vakhtalkinskaya Sequence. The thermodynamic conditions of the formation of garnet enderbites determined from the garnet–orthopyroxene geothermobarometer [9] correspond to 700–800°C and 3.2–4.8 kbar.

The comparison of the chemical composition of primary basic volcanics of the Vakhtalkinskaya Sequence and their transformation products indicates that metasomatic alteration and magmatic replacement chemically correspond to siliceous–alkaline metasomatism (granitization) and cause sequential and uneven influx of SiO_2, Al_2O_3, Na_2O, K_2O, Rb, Ba, Zr, Nb, and Cl into the replaced rocks and removal of FeO, MgO, CaO, and some trace elements (Cr, Co, Ti, Y, and S) (Fig. 3).

Thus, the study of altered rocks of the Vakhtalkinskaya Sequence in the contact aureole of the Yurchikskii gabbronorite massif indicates that their transformation was caused by high-temperature contact hornfelsing coupled with metasomatic alteration of hornfelses and their local magmatic replacement. All these alterations occurred almost simultaneously, were tightly related in space and time, and were determined by the extent of the attack of percolating fluids on the primary rocks.

The possibility of granitoid formation during granitization of the basic rocks under the effect of highly mineralized deep-seated fluids was theoretically shown by D.S. Korzninskii [10] and confirmed by numerous experimental studies [11–14]. According to these conceptions, granitization was caused by magmatic

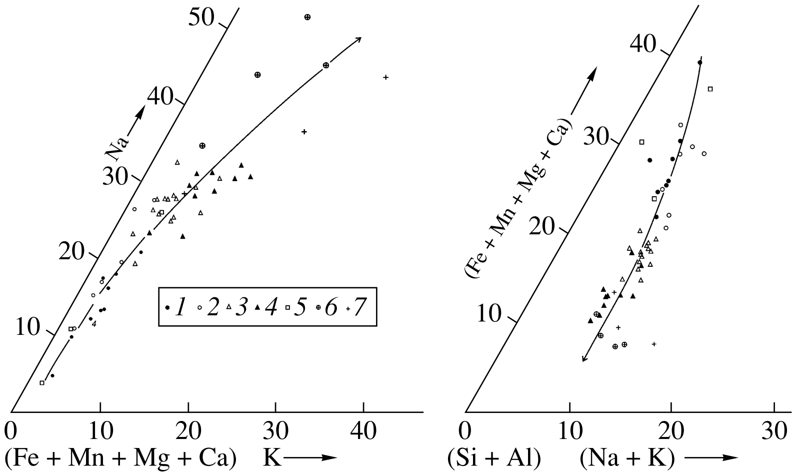

Fig. 3. Petrochemical diagrams characterizing metasomatic transformation and magmatic replacement of hornfelsed basic volcanic and sedimentary rocks of the Vakhtalkinskaya Sequence at the contact aureole of the Yurchikskii gabbronorite intrusion. (*1, 2*) hornfelses: pyroxene–amphibole–plagioclase (*1*) and amphibole–plagioclase (*2*) compositions; (*3*) biotite–orthopyroxene–plagioclase metasomatites; (*4*) garnet enderbites and plagiogneisses; (*5*) xenoliths of basic hornfelses in garnet enderbites; (*6*) charnokitoids; (*7*) metamorphosed volcanics (metadacites). Arrows show the trend of compositional change of metabasic volcanic rocks of the Vakhtalkinskaya Sequence during granitization and magmatic replacement.

replacement of primary rocks under the effect of alkaline–silicic transmagmatic subcrustal fluids, which caused debasification and bleaching of the rocks in parallel with increasing partial melting (formation of shadow and banded migmatites).

Experimental data indicate that highly mineralized aqueous-hydrocarbonic fluid is formed in the mantle to incongruently dissolve silica, alkalis, and some lithophile elements (Rb, Li, REE) in mantle rocks. With ascent to the upper crustal levels and a corresponding decrease in temperature and pressure, the solubility of alkalis and silica in mantle fluids decreases, causing a metasomatic change and nonisochemical partial melting of the crustal protolith. According to [12], these processes require strong heating of the fluid influence zone (the temperature in the zone of fluid discharge must be no lower than that of the granite solidus) and a sufficient thickness of the crustal protolith (about 15 km), which provides for the high solubility of mantle material by fluids.

The factual material presented shows that strong heating of the crustal protolith and its significant thickness at the Ganal Ridge of Kamchatka led to hornfelsing, metasomatism, and magmatic replacement (granitization) of primary basic volcanics and intercalated sedimentary rocks in the contact aureole of the large Yurchikskii gabbronorite intrusion. It is suggested that these metamorphic processes and magmatic replacement were assisted by highly mineralized mantle fluids which filtered along the magmatic channel, the pathway for the ascending gabbroid melt.

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