

MELT AND FLUID INCLUSIONS IN THE RHYOLITE XENOLITH FROM THE NEOVOLCANIC BASALTS OF THE JUAN DE FUCA RIDGE

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Two aspects of rhyolites: (1) their peculiar position as final products of crystallization differentiation of basic melts in magma chambers or lava flows (Walker, 1958), and (2) their role in driving explosive or other eruptions in andesitic and andesite-dacite volcanoes mostly attract attention of petrologists. In this paper we present first results of investigations of melt and fluid inclusions in rhyolite xenolith from the covering neo-volcanic basalts of the Kleft segment of the Juan de Fuca ridge, dragged during the 1986 cruise of the "Academician Vinogradov" research ship. Judging from the available information on the MORB compositions and their xenoliths in the MOR series adjacent to the American continent (Dixon *et al.*, 1986, Smith *et al.* 1994), no "final" products of crystallization differentiation of MORB have been identified there thus far. The rhyolite sample discussed in this paper provides possibly the first evidence indicating that a complete series of the crystallization differentiation of MORB could be present under the axial valley of the Juan de Fuca ridge.

Doubly polished plates (100-150 μm) were used for optical investigations of the melt and fluid inclusions under the transmitted light. Melt homogenization experiments were carried out by means of an optically controlled heating stage. The chemical composition of minerals, glasses and melt inclusions was measured on a Camebax-Micro microprobe and on the ion microanalyzer IMS-4f in the standard regime.

The xenolith is composed of a light-gray taxitic groundmass in which 1-3 mm-sized light-colored spots are composed of the relic crystals of quartz and plagioclase. The latter are rimmed by brownish gray-banded vesicular glass. The chemical composition of the plagioclase (in wt. %) is: SiO_2 - 63.46; Al_2O_3 - 23.17; FeO - 0.28; CaO - 5.22; Na_2O - 8.02; K_2O - 0.29. Other minerals and phase segregations in the xenolith comprise titanomagnetite, zircon, drop-like sulfide and sulfide-oxide vesicular segregations, rare small crystals of green clinopyroxene as well as the banded glass hosting abundant gas and silicate-salt inclusions. The chemical composition of central part of crystal of clinopyroxene (in wt. %) is: SiO_2 - 50.42; TiO_2 0.71; Al_2O_3 - 1.86; FeO - 13.69; MnO - 0.34; MgO - 12.35; CaO - 19.2; Na_2O - 0.41; K_2O - 0.01.

The relic crystals of plagioclase, clinopyroxene, and titanomagnetite commonly possess the rim composed of the dendritic microcrystals related to partial melting and quenching of the parent crystals. Similar dendrites are commonly present in glass, as well as on the surface of gas vesicles. The vitric phase in the xenolith exhibits characteristic banding with alternating light- and dark-colored glassy layers. The bands, varying in width, are represented by translucent light-colored glass and dark-brown opaque mass, composed of the fine intergrowths of plagioclase and magnetite dendrites with glass. The light- and dark-colored bands occur in roughly similar proportions; boundaries between them may be either sharp or diffuse.

Another peculiarity of the xenolith structure is the quite complex vesicularity, substantially different from that of the host basalt. The basalt contains evenly scattered rounded gas bubbles 0.1 to 0.5 mm in diameter (less than 10 vol.%); one order of magnitude smaller gas pores with irregular shapes are present along the boundary of varioles. Several bubble populations can be distinguished in the rhyolite xenolith. (1) Unevenly scattered gas pores in the light-colored glass; typical concentration is about 10 bubbles (1-10 μm in diameter) per the area of $10^4 \mu\text{m}^2$; there are spots containing 20-30 bubbles (average diameter of 2 μm). (2) Garlands of gas bubbles are present on the surface of partially melted quartz crystals (2-3 μm in size). (3) Garlands of gas bubbles (0.2 to 1 mm in diameter) occur along the upper boundary of the xenolith; some large bubbles reach 2 to 3 mm in size. (4) Anomalously large gas cavities with irregular shape (3 to 15-mm-long and 1 to 5-mm-wide) in the areas of the maximum melting of the xenolith.

Both large gas cavities and most small gas bubbles in light-colored glass are "empty" (i.e., they do not contain solid phases). Vacuoles with complex phase composition are also observed in the glassy part of the sample. The vacuoles may host different solid phases. The degree of filling differs significantly in adjacent cavities (magnetite, clinopyroxene, apatite, and readily sublimated compounds of Na, K, Fe, Ca and Cl, F, and S). These cavities may be classed as "silicate-salt" inclusions.

The chemistry of the glassy part of the rhyolite xenolith is rather complex. Several types of vitric formations can be distinguished there. These are: (1) light- and dark-colored bands in zones of the complete or almost complete melting of rhyolite at the contact with host basalt and inside the xenolith (neither zones of intermixing of the basaltic and acidic material, neither zones of diffusion have been noted at the rims of the xenolith); (2) vitric mesostasis between the dendrites of clinopyroxene, plagioclase and magnetite; (3) zones of partial melting at the contacts between quartz and plagioclase. According to the results of the microprobe and ion probe, chemical composition of the variably colored bands differs in terms of the contents of the petrogenic components and some volatiles (in wt.%): SiO_2 - 74.38 vs. 62.31; TiO_2 - 0.18 vs. 1.71; Al_2O_3 - 11.43 vs. 12.87; FeO - 3.99 vs. 10.38; MgO - 0.36 vs. 1.62; CaO - 1.48 vs 4.66; Cl - 0.76 vs. 1.9; F - 0.13 vs. 0.1; and H_2O - 2.6 vs. 1.84 (in light- and dark-colored glass, respectively). The chemical composition of basaltic glass (in wt. %) is: SiO_2 - 50.05; TiO_2 - 1.69; Al_2O_3 - 13.48; FeO - 12.01; MnO - 0.17; MgO - 6.97; CaO - 10.6; Na_2O - 2.75; K_2O - 0.17; Cl - 0.01, F - 0.02; H_2O - 0.28.

Quartz occurs as idiomorphic crystals 0.05 to 0.25 mm in size containing abundant primary melt inclusions ranging from several μm to more than 30 μm . Chains of gas bubbles (2-3 μm in size) are present on the surface of partially melted quartz

crystals. Heterogeneous distribution of petrogenic and volatile elements near individual quartz crystals is observed; the width of such zones may reach 10 to 15 μm .

Thermometric investigations have been conducted on the quartz crystals, in which three types of inclusions have been distinguished: (1) primary silicate glassy inclusions, (2) secondary silicate-salt inclusions, and (3) secondary salt inclusions. The primary inclusions occur as individual vacuoles 10 to 35 μm in size and as groups of such vacuoles, erratically distributed in the crystals. Each inclusion is composed of a gas bubble and glassy mass. The primary inclusions contain one gas bubble and show consistent gas-to-solid ratio with gas occupying ca. 5 vol.%. Upon heating, glass starts to soften in normal inclusions at about 580-600 $^{\circ}\text{C}$. Inclusions homogenize into the melt phase at 880-900 $^{\circ}\text{C}$. The chemical composition of glass from unheated melt inclusion in quartz (in wt. %) is: SiO_2 - 78.7; TiO_2 - 0.21; Al_2O_3 - 8.05; FeO - 3.15; MnO - 0.06; MgO - 0.09; CaO - 0.92; Na_2O - 1.88; K_2O - 1.33; Cl - 0.82; H_2O - 3.1.

Some primary inclusions contain several bubbles or one bubble, showing greater gas-to-solid ratio than "normal" inclusions. Such inclusions have visible interior rim, enriched in silica (up to 82.73 wt.%) but depleted in chlorine (ca. 0.51 wt.%) as compared to the central part of inclusions (SiO_2 - 78.12 wt.% and Cl - 0.74 wt.%). It is likely, that the host mineral (quartz), around inclusions, has been partially melted during the transport of the xenolith by basaltic melt. The temperature of the latter, assessed from the homogenization temperatures (T_h) of inclusions in olivine and clinopyroxene, exceeded 1160-1190 $^{\circ}\text{C}$ (Smirnov 2003, pers. comm.). Homogenization of such "overheated" inclusions occurs between 930 and 960 $^{\circ}\text{C}$; some of the inclusions failed to homogenize at $T > 1050$ $^{\circ}\text{C}$.

Partially healed cracks host chains of the silicate-salt inclusions, with relatively high content of the fluid phase (>10 vol.%) residing in a glassy mass. In such combined inclusions the fluid part typically consists of saturated salt solution, commonly containing 3, 4 or more solid phases, and a gas bubble. The volumetric glass-to-fluid ratios are variable. On heating, the solid phases dissolve in the fluid at about 600 $^{\circ}\text{C}$, after which glass starts to melt. The gas bubble dissolves at 780-800 $^{\circ}\text{C}$. Further heating (up to 1000 $^{\circ}\text{C}$) induces no changes in the volumetric relations between the silicate and the salt liquids. These inclusions, most likely, have formed through entrapment of the heterogeneous silicate-salt liquids and, thus, may be classed as "combined" inclusions.

From the presence of the combined silicate-salt inclusions in quartz and in silicate glasses of the rhyolite xenolith, it may be concluded that, at the final stages of vitrification following the partial melting of the xenolith, the rhyolite liquid split into the immiscible silicate and the salt fractions.

The pattern of distribution of trace elements in basaltic and rhyolitic glasses, as well as in melt inclusion in quartz from rhyolite (Figure) suggests that the rhyolite is, most likely, a product of the "final" crystallization differentiation MORB in the low-level chambers under the rift valley of the Kleft segment. The finding of rhyolite in the neo-volcanic MORB of the Kleft segment of the Juan de Fuca ridge suggests that the "standard" sequence of crystallization differentiation has taken place.

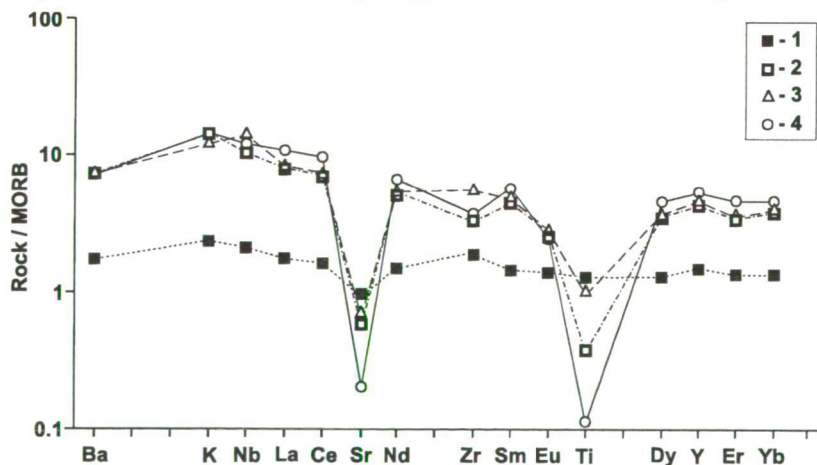


Figure. Spider diagram for trace elements in vitric rocks and melt inclusion in mineral of the Juan de Fuca ridge. SIMS data. 1 – basaltic glass; 2 – light rhyolitic glass; 3 – dark rhyolitic glass; 4 – melt inclusion in quartz.

References

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