PLACE AND ROLE OF AMPHIBOLE IN PROCESSES OF LARGE-SCALE SILICEOUS VOLCANISM IN ISLAND ARCS: CASE STUDY OF LATE PLEISTOCENE CALDERA ERUPTIONS OF THE ITURUP ISLAND (KURILE ISLANDS)

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Dacitic pyroclastic rocks at the Iturup Island. Thick, sometimes more than 200 m, siliceous pyroclastic (tuff, pumices) strata on the Iturup Island cover Vetrovoy (Windy), Dozornyi (Lookout) and Roka isthmuses. 20 Ka Vetrovoy Isthmus (VI) tuff was erupted from caldera which center could be located either in the center of isthmus or in the Prostor Bay of the Sea of Okhotsk. The erupted volume is estimated by (Melekestsev et al., 1988) at 100 $км^3$. Tuff strata overlaying Dozornyi and Roka isthmuses belong to similarly large eruption of Lvinaya Past' (Lion Mouth) (LP) caldera, which, by different estimations, erupted about 70 – 170 km^3 of magma (Bazanova et al., 2016), and dated at 13.0 – 12.3 Ka (Degterev et al., 2015).

Important feature of both eruption centers, which are divided by 120 km distance, is almost total similarity in major and trace element compositions. Their pumices represent low-Al_2O_3, low-K_2O ferrous dacites of normal alkalinity. Typically to subduction related rocks they show pronounced depletion in Ta, Nb and Ti. Chondrite normalized REE patterns are flat with moderate Eu/Eu*.

The pumices are white porous (~60 vol. %) rocks with plagioclase, quartz, augite, hypersthene, and Fe-Ti oxides. LP pumices contain abundant amphibole phenocrysts, which are absent in VI pumices. This difference, coupled with similarity of the rock chemistry, stimulated us to study the role of amphibole in the generation of siliceous melts and development of reservoirs for violent explosive eruptions.

Amphibole in dacites. Amphibole in LP pumices forms well shaped black almost opaque crystals. It contains inclusions of plagioclase, augite, hypersthene, magnetite, ilmenite, and apatite. The association of the earliest minerals comprises plagioclase, two pyroxenes and Fe-Ti oxides. Amphibole appears at intermediate stages of crystallization. This is associated with the sharp increase in Ca-content of contemporary plagioclase up to An85.

LP amphiboles are compositionally homogeneous and belong to Mg-hornblende with relatively low Al_2O_3 6.19 – 7.81 wt. % and Na_2O 1.46 – 1.61 wt (Fig. 1). Volatiles are represented by hydroxyl group and Cl (0,08 – 0,13 wt. %). Fe^{3+}/Fe^{2+} ratio is high ~ 5. This is the reason for unusually high $Mg^{2+}/(Fe^{2+}+Mg^{2+})$ ~0.98 at MgO/(FeO+MgO)~0.55.

Amphibole phenocrysts contain abundant vitreous naturally quenched melt inclusions (MI). They have metaluminous low-K_2O rhyolitic compositions, similar to MIs in other minerals of the LP pumices. However amphibole-hosted MIs differ from those in pyroxenes in lower A/CNK, which resemble more to the A/CNK of MIs in quartz. It supports the idea that amphibole began its crystallization later than other mafic minerals. MIs are rich in H_2O, which contents vary between 2.3 and 6.5 wt. % (SIMS data). H_2O contents in MI in mafic minerals and plagioclase tend to be slightly higher than in quartz.

The earliest mineral assemblage in VI pumices includes phenocrysts of plagioclase, augite and Fe-Ti oxides. Magma degasses at the early stages and this is documented by abundant H_2O-CO_2 fluid inclusions and dramatic increase of Ca-contents (up to An95) in the plagioclase. Simultaneously to degassing, hypersthene and apatite contents increase in the phenocrystal assemblage with decrease of augite fraction. Similarly to LP rocks, quartz is the last mineral joined to crystallization process and form together with latest plagioclase of intermediate composition.

VI pumice mineral assemblage does not contain amphibole. Nevertheless, it was found as inclusions of intricate shape, sometimes intergrown with hypersthene, in augite phenocrysts. In augite from two-pyroxene-palgioclase clusters it associates with Ca-rich plagioclase, which from mirmecitic texture in clinopyroxene. Amphibole was also found as inclusion in hypersthene, where it have more regular, usually rounded shapes and is often combined with vitreous MIs.

In contrast to LP amphiboles, those from VI pumices vary in a wide range of compositions. The most part of inclusions belongs to tschermacitic hornblende, smaller one – to Mg-hornblende, and single inclusions have edenite-pargasite-Mg-hastingsite compositions. Generally VI amphibole inclusions are rich in Al_2O_3 (8.11 – 13.08 wt.%) and Na_2O (1.60 – 2.26 wt.%) compared to LP phenocrysts (Fig. 1). On the other hand, they have lower Fe^{3+}/Fe^{2+}, varying from 0.05 to 3.98 (average ~1.5), which explains lower and more common for dacitic mafic minerals $Mg^{2+}/(Mg^{2+}+Fe^{2+})$ 0.64 – 0.92. The lowest Fe^{3+}/Fe^{2+} have edenite-pargasite-Mg-hastingsite inclusions in augite.

VI pumice phenocrysts contain abundant vitreous naturally quenched MIs, which compositions are similar to MIs in LP minerals. MIs in the early minerals show wider range of alumina/alkali (A/CNK) variations, within the field of peraluminous compositions. Mis in latest plagioclase and quartz become closer to metaluminous compositions. Glasses of the hypersthene-hosted naturally quenched MIs, combined with amphibole, have peraluminous compositions and thus differ from the amphibole-hosted MIs from LP pumices. H_2O contents in MIs of the VI pumice minerals are similar to those from LP. For example, plagioclase-hosted MIs in VI pumices contain 2.3 – 5.3 wt. % H_2O (SIMS data), like in inclusions in the LP plagioclases (2.7 – 5.9 wt. % H_2O (SIMS data)).

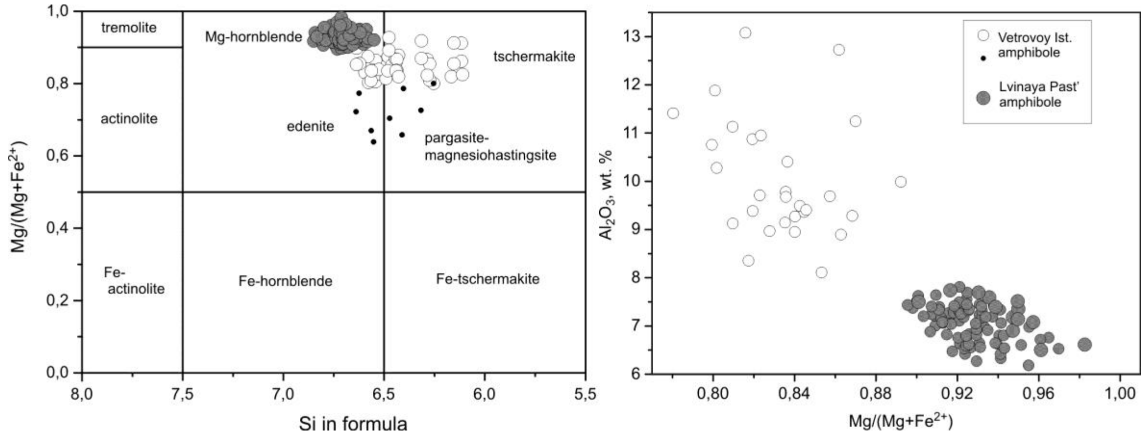

Fig. 1. Compositions of amphiboles from Vetrovoy Isthmus and Lvinaya Past'dacitic pumices.

Behavior of amphibole in evolution of dacitic magma reservoirs at Vetrovoy Isthmus and Lvinaya Past' calderas. Major and trace element compositions of pumices evidence that magmas of both caldera eruption centers have similar nature and compositions. Evolution of both magma reservoirs resulted in similar large-scale explosive eruptions.

The origin of silica-rich melts in arc settings is believed to be a result either of fractionation of deep basic and intermediate magmas or of crustal rock partial melting. The stability of amphibole in both types of processes is constrained primarily by volatile, e.g. H_2O, contents and pressure. H_2O behaves as incoherent component and usually is accumulated at fractional crystallization or saturates early portions of melts at partial melting.

Our study demonstrates that minerals from both centers have crystallized from hydrous rhyolitic melts, which, most probably, were formed on partial melting of metabasitic crust of the Iturup Island. Slight HREE/LREE enrichment and peraluminous A/CNK ratios of these melts evidence for shallow depths of partial melting. Melt compositions vary slightly in the course of crystallization. Gradual decrease of CaO and FeO contents with decrease of Al_2O_3 from early to late phenocryst assemblages can be explained by predominant crystallization of plagioclase and magnetite.

Phenocrysts of both centers grew almost isothermally within 830-880°C. Crystallization pressures in the LP reservoir were estimated at 1.4 – 2.2 kbar (4.5 – 7.0 km) by amphibole-bearing mineral barometers. Similarly, pressures, at which amphibole included into pyroxenes of the VI pumices, could be in equilibrium were estimated at 2.8 – 3.7 kbar (9-12 km). On the other hand degassing pressure in the VI reservoir was estimated at 0.8 kbar through the fluid and melt inclusion study and can be assumed as an approximation of lithostatic pressure (2.5 km).

Amphiboles, which now form inclusions in the VI pyroxenes, most probably originated due to contact metamorphism of previously erupted basic or andesitic lavas and tephra that form the melting substrate. Most likely partial melting began at ~10 km as it was documented by inclusions. The resulted crystal laden mash containing restitic and reactional minerals migrated upward to the depths where amphibole became unstable. Its breakdown gave predominantly plagioclase and clinopyroxene with subordinate orthopyroxene. Moreover, dehydration of amphibole and probably other hydrous minerals provided significant amount of H_2O, which could stabilize magmatic amphibole. This did not happen because the magma was stored at depths less than 3 km and saturation in water triggered intensive degassing. Degassing accompanied reaction of early augite with the melt. This reaction reduced augite and increased hypersthene fractions.

Excess of Ca, which was produced by the reaction, caused increase in Ca content in plagioclase (up to An95) and possibly appearance of apatite.

Similarities between VI and LP pumices in bulk rock, melt, and pyroxene compositions suggest that early augite and hypersthene of LP pumices were also produced due to breakdown of amphibole in the melting substrate. In contrast to VI reservoir the LP magma was stored under higher pressure (> 1 kbar) and favored crystallization of magmatic amphibole. This process should be controlled by partial pressure of water, which, similarly to VI reservoir, probably also increased. When saturation was attained reverse reaction of Mg-hornblende formation at the expense of two pyroxenes occurred. Similarly to VI reservoir excess of Ca, released in this reaction, was consumed by increase of Ca in plagioclase and formation of calcic amphibole.

Conclusions. Magmas of voluminous Late Pleistocene eruptions of the Vetrovoy Isthmus and Lvinaya Past calderas have originated by dehydration partial melting of metabasic rocks, which contained amphibole and probably other hydrous minerals and composed the Iturup Island crust. Breakdown of hydrous minerals resulted in saturation of melts by water. This could be the major factor, which governed high explosivity of eruption of both caldera centers. Different styles of volatile saturation are explained by different pressures of the magma storage. H_2O-CO_2 fluid released on degassing in the shallow VI reservoir, while saturation of LP magma in the deeper reservoir resulted in crystallization of amphibole without fluid saturation.

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