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ABSTRACTS**

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COMPOSITIONAL TRENDS OF AMPHIBOLE IN 2001-2013 YOUNG SHIVELUCH ANDESITES AS EVIDENCE OF MAGMA CHAMBER REPLENISHMENT AND SUBSEQUENT CONVECTION

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Hornblende-plagioclase andesites of the Young Shiveluch volcano erupted from 2001 to 2013 show minor variations of whole rock and matrix glass compositions but large variations of mineral phenocryst compositions. We focused this work on the composition of amphiboles in andesites from the growing Shiveluch lava dome, pumiceous rocks from pyroclastic flows and rare mafic inclusions. We propose that the shallow magma chamber was replenished during this time that enhances magma convection and caused more frequent eruptions.

2001-2013 eruptive dynamics and whole rocks compositional variations

Intensive growth of the lava dome alternating with episodes of its destruction was observed in 2001-2013. During this period Young Shiveluch had five paroxysmal explosive eruptions (May 2001 and May 2004, February and September 2005 and in October 2010). In the course of these eruptions extensive pyroclastic flows covered the valleys on the southern volcano slopes at a distance of 20-25 km from the eruptive center. In 2007, 2008, 2009 and 2013 more moderate explosions also occurred and were accompanied of small-volume pyroclastic flows. The volume of material erupted during 2001 - 2012 appears to be close to 0.8 km^3 (Shevchenko et al., 2015) even if lavas erupted in 2013 and tephra placed outside of the volcanic edifice are not taken into account.

SiO_2 content in lava dome samples and pumice fragments from pyroclastic flows is 60.5–64.0 wt.% and varies unsystematically over time. The andesites contains 15-20 to 45 vol.% phenocrysts which are represented by plagioclase with An in cores ranging from 30 to 83-88 mol. %, low- and high-Al amphiboles, and rare orthopyroxene and clinopyroxene with Mg# 69-74. Rare olivine (Fo_{80-88}) with reaction rim of orthopyroxene, Fe-Ti oxides and amphibole are presents in most samples. Groundmass is composed by plagioclase, subordinate pyroxene, magnetite and rare amphibole microliths. Matrix glasses are rhyolitic (SiO_2 =74 - 80 wt.%) in all samples. Mafic inclusions, which were found in a block in pyroclastic deposits of 2005 eruption (Gorbach, 2006) are olivine-hornblende basaltic andesite (SiO_2 = 56.3 wt. %).

Amphibole texture and chemistry

Phenocrysts, microphenocrysts and rare microliths of amphiboles in the 2001-2013 eruptive products show a wide range of major element compositions (in wt.%: SiO_2=40.46-50.13; TiO_2=0.56-3.54, Al_2O_3=6.18-14.06, FeO*=6.07-15.24, MgO=11.56-19.31, CaO=10.62-12.59, Na_2O=1.19-3.67, K_2O=0.09-0.75). This compositional range corresponds to masnesiohornblende (*Mg-Hbl*), pargasitic (*Prg*) and magnesiogastingsitic (*Mg-Hst*) amphibole after Leake et al. (1997). Most crystals are idiomorphic. Opacitized amphiboles are rare in 2001-2013 andesites. Two main amphibole generations have been distinguished on the basis of their textural and chemical features: 1) Middle-sized phenocrysts of *Mg-Hbl* (≥1-1.2 мм) with simple chemical zoning (Al, Fe, Na decrease, Si and Mg increase from core to rim); 2) Large phenocrysts (≥1.5-2 mm) with patchy, chemically very heterogeneous, especially with regard to Al and Mg, core compositions containing abundant inclusions of melt, plagioclase and magnetite. In addition to these generations, subphenocrysts (0.3-0.5 mm) and microlites (0.1-0.2 mm) of *Prg* and *Mg-Hst* hornblende were found in some samples erupted in 2004, 2007 and

2013. Amphiboles phenocrysts and microliths from mafic inclusions correspond mainly to *Mg-Hst* composition.

The most of zoned phenocrysts studied exhibit inverse correlation between Mg, Si (on the one side) and Al, Ti, Fe, Na (on the other side), corresponding to edenite - Al-tschermakite substitution. However, this correlation is disrupted in some crystals. For example, simultaneous increase of Al and Mg is observed in amphiboles from mafic inclusions and on the crystal rims at the contact of a host andesite with the inclusion, in some crystals from 2001, 2004, 2007 and 2013 eruptions. The positive trend of Al and Mg (or of Al_{IV} and Mg#, Fig.1) is interpreted in a series of papers as trend magma replenishment (e.g., Sato et al, 2005; Kiss et al., 2014).

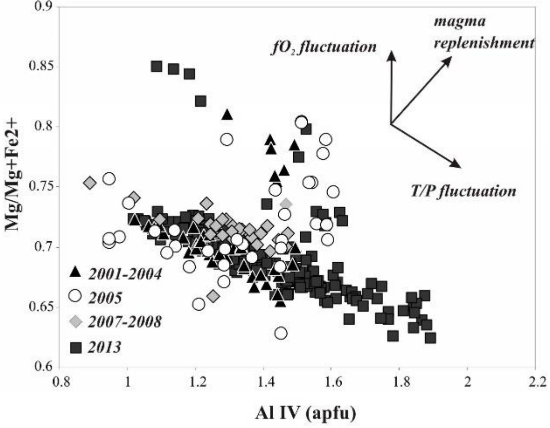

Fig. 1. Al_{IV} (a.p.f.u.) vs. Mg# variations in amphiboles from 2001-2013 Young Shiveluch rocks.

In result of mafic magma replenishment, the silica content in magma decreases that leads to increasing Al_{IV} values in amphiboles. Mafic input also increases $Mg/Mg+Fe^{2+}$ ratio in the mixed magma. Thus, simultaneous increase in Al_{IV} and Mg# of amphibole is expected to reflect magma replenishment (Kiss et al., 2014).

Dirksen et al. (2006) proposed on the basis of olivine reaction rim study that mafic replenishment preceded two months to four years the 2001 eruption. The data on amphibole compositions are consistent with this conclusion and indicate that a part of the crystals of amphiboles from 2001-2013 Young Shiveluch andesites crystallized from hotter magma. According to Ridolfi et al. (2010) and Holland, Blundy (1994) thermometers, the predominant association of *Mg-Hbl* and plagioclase An_{40-50} crystallized at temperature of 847 ± 18 °C and pressure of about 150 MPa (~5 km depth). Some amphibole phenocrysts crystallized under higher temperature conditions (T av. = 917° ± 23 °C, T max = 970 °C). The temperature increase is identified not only in the cores of complexly zoned crystals but also in the rims of individual crystals and microphenocrysts, more rarely microliths (e.g., from andesite pumice of 2013 eruption).

Heterogeneity of amphibole composition and crystallization conditions, the varies of the crystals amount with small variations in bulk rocks and matrix glasses composition in 2001-2013 andesites are in good agreement with the mechanism of convective mixing. Mafic magma replenishment should result in the formation of heated boundary layer in the lower levels of shallow magma chamber and cause convection in its upper levels (Sparks et al., 1977). As a result, portions of magma with different contents of crystals having a contrasting thermal history and different amount of dissolved volatiles can reach the surface (e.g., Couch et al. 2001). Convective processes in a shallow magma chamber also may explain the Young Shiveluch eruptive dynamics in 2001-2013. The overpressure in the magma chamber due to the mafic magma input and intense emission of volatile components may cause an increase in volume and frequency of eruptions.

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