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TIME CONSTRAINS FOR MAGMA SUPPLY IN BEZYMYANNY AND SHIVELUCH VOLCANIC SYSTEMS

Pavel Plechov[1], Vasily Shcherbakov[1], Alexandra Tzay[1], Madeleine Humphreys[2]
[1]*Geological Department, Moscow State University, Moscow, Russia.*
[2]*Department of Earth Sciences, University of Cambridge, United Kingdom.*

The width of reaction rims between phenocrysts and surrounding melt represents incomplete mineral-melt reactions; we used these widths for determining time constrains on magma supply in hybrid volcanic systems (Bezymyanny and Shiveluch). Opacitic rims around hornblende from Bezymyanny (March 1956 eruption) and complex rims around olivine from Shiveluch (2001-2004 eruption) allowed estimations of 1) time between magma chamber supply and eruption, and 2) frequency of new magma intrusion into the shallow level magma chamber.

According to the proposed model [1], the generation of the hornblende opacitic rims is the result of Hb disequilibrium with surrounding melts that occurs due to the magma mixing or to abrupt changing of P-T-x conditions. There are two stages in the generation of the reaction rims.

1. During the first stage, minerals attain equilibrium with the surrounding melt by diffusion exchange of the components. If equilibrium is attained then a polymineral rim is not present and a zonal outer rim is formed as a result of reequilibration. If the stability limit of the mineral has been reached, phenocrysts are replaced with polymineral aggregates and a reaction rim starts to form.

2. In the second stage, the reaction rim spreads to the center of the grain. Diffusion exchange between hornblende and melt proceeds through the newly-formed polymineral rim.

The thickness of the rim is a function of the time of reaction between hornblende and melt [1]:

$$x(t) = \sqrt{D(t - t_0)} \qquad (1),$$

where x = thickness of the rim, t = period of time during which the mineral reacts with the surrounding melt, t_0 = "rest time" during which rim is not generated, and D = coefficient of proportionality which characterises the speed of the process.

"Rest time" (t_0) reflects the duration of the first stage of disintegration; it is controlled by the velocity of diffusion in mineral. t_0 for olivine, characterized by the high-speed diffusion of Fe and Mg, is close to 0 [2], but for hornblende t_0 may reach a few days [3].

The experimentally defined coefficient D [2,3] is greater by two orders of magnitude than coefficients of diffusion in hornblende and olivine and corresponds to the rates of diffusion in melt within one order of magnitude. Growth of the opacitic rim in hornblende is controlled by diffusion in the interstitial melt within the rim. The reaction of replacing hornblende with a plagioclase – pyroxene – magnetite aggregate leads to a 5% decrease in volume. Interstices formed as a result of hornblende breakdown are filled with melt, which creates an environment for component transportation. Diffusion in rim interstitial melt is slower than diffusion in surrounding melt because: 1) there is a nonlinear path inside the reaction rim, 2) some channels are not permeable to components throughout their length, and 3) small channel dimensions could produce an additional interaction of components with channel walls.

We determined the maximum range of D for hornblende breakdown (2.7×10^{-16} to 2.0×10^{-15} m^2/s) and t_0 (2–5 days) from experimental data [3]. The time required for developing the hornblende breakdown rims (Fig.1a) during the March 30, 1956 eruption of Bezymyanny Volcano was calculated using the maximum and minimum possible t_0 and D values and evaluated to be 4–37 days. This evaluation allowed us to revise the interpretations of the events preceding this eruption. The hot magma injection into the chamber that induced hornblende opacitization could have taken place in February or March 1956, while the eruptive activity of the volcano occurred on October 22, 1955, and a series of eruptions associated with ash falls continued until late November. Hence, the volcanic events in 1955 were not directly related to processes in the chamber before the March 30, 1956 eruption and required a separate butch of the magma supply before October 22, 1955, i.e. magma supply frequency could be estimated for the 1955-1956 period as 2 times per year. This estimate is consistent with estimations from plagioclase zoning study (Shcherbakov et al., this volume) for the 2000-2007 eruptions.

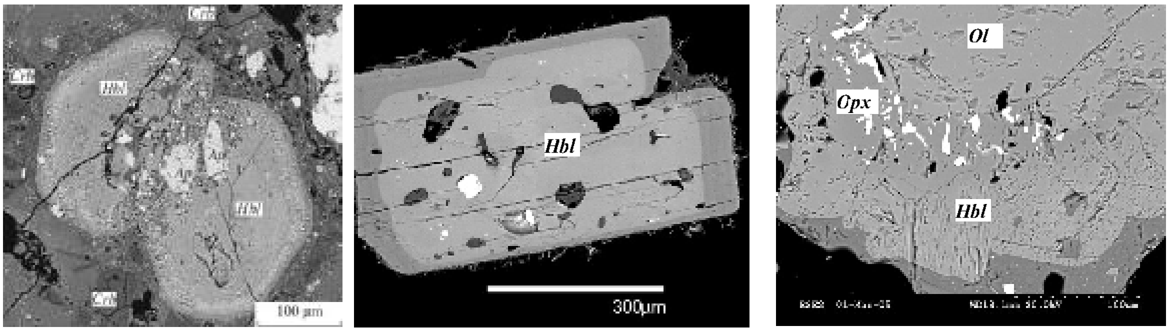

Fig. 1. Rims around phenocrysts in Bezymyanny and Shiveluch lavas. a) An opacitic rim around hornblende (Bezymyanny, March 1956)[1]; b) a Mg-rich rim around hornblende without breakdown (Shiveluch, 2001)[4]; c) a complex reaction rim around olivine. The rim consists of two parts. The external part of the rim consists of hornblende; the internal part is made up of orthopyroxene-magnetite aggregates. The width of the internal rim is constant, whereas the external rim width is more variable (Shiveluch, July 2002)[4]. Mineral symbols: Hbl—hornblende, Ol- olivine, Opx – orthopyroxene, Ap—apatite, Crb—cristobalite.

In products of the 2001-2004 eruption of Shiveluch Volcano there is no evidence for hornblende breakdown (Fig. 1b). Moreover, hornblende is present in the reaction rim around olivine (Fig. 1c). Possibly the magma supply under Shiveluch Volcano is more similar to the magma of the shallow chamber than is the supplying magma beneath Bezymyanny Volcano.

We obtained timescales of 13–50 days for formation of the inner rim and 61–1361 days for formation of the whole reaction rim [4], using an experimentally determined coefficient for a rhyodacitic melt at T =885°C and P =150MPa (1.02μm^2/h) as a minimum estimate, and the growth rate of olivine reaction rims in Arenal Volcano (2.95μm^2/h) as a maximum value [2]. The value of 13–50 days obtained from internal rim widths could reflect the length of time for which the olivine–amphibole interface was unstable, though it is not clear whether the experimentally obtained growth rate is appropriate for this solid–solid reaction. This timescale is consistent across all samples, and might represent the time of magma ascent below the amphibole stability limit (approximately 50–100 MPa) [4]. The estimate of 2 months to >4 years based on total rim widths reflects the residence time of the olivine xenocrysts in the system, i.e. the time between injection of basalt and eruption, under either mechanism. Rim widths from this sample indicate magma influx 470–1361 days prior to eruption (i.e. approximately August, 1997 to February, 2000). Samples shv202002 and PK-02/3a were erupted a year later, in June 2002. Rim widths from these samples indicate magma influx 9 weeks to 1 year previously (i.e. during the same extrusive episode, June 2001 to May 2002). Thus, frequency of magma recharge for the Shiveluch volcanic system is estimated as 0.3-1 times per year.

References

1. Plechov P., Tzay A., Scherbakov V., and Dirksen O. (2008) "Horblendes in andesites of 30 March 1956 Bezymyanniy eruption and conditions of their opacitization", Petrology, 16(1),19-35.
2. Coombs M.L. and Gardner J.E. (2004) "Reaction rim growth on olivine in silicic melts: Implications for magma mixing," Am. Mineral. 89, 748–759.
3. Rutherford M.J. and Hill, P.M. (1993) "Magma ascent rates from amphibole breakdown: An experimental study applied to the 1980–1986 Mount St. Helens eruptions," JGR, 98, 19667–19685.
4. Dirksen O., Humphreys M.C.S., Plechov P., Melnik O., Demyanchuk Y., Sparks R.S.J., and Mahony S. (2006) "The 2001-2004 dome-forming eruption of Shiveluch Volcano, Kamchatka: Observation, petrological investigation and numerical modelling", JVGR, 155(3-4), 201-226.