# CHEMICAL COMPOSITION AND PARAMETERS OF CRYSTALLIZATION THE SOUTHERN TRACHYBASALTS: EVIDENCE FROM AND FLUID INCLUSIONS

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The southern Baikal volcanic region is the largest area of Late Cenozoic volcanism in the Baikal rift system. Its development was associated with the formation of a system of three grabens (Tunkin, Khubsugul, and Oka) and mountain ranges separating them and multistage volcanic activity, which resulted in the appearance of numerous volcanic fields over an area of 600 x 400 km. The development of this region was related to the influence of a mantle plume (mantle hot spot) on the lothosphere. This influence is recorded in the specific structural framework of the region and compositions of its volcanic products. The latter are strongly dominated by subalkali basalts (hawaiite) and alkaline basaltoids (tephrite, basanite, and tephriphonolite). These rocks are rich in titanium, phosphorus, alkalis, and lithophile elements. Thus, both geological and geochemical features of the Late Cenozoic volcanic rocks of the southern Baikal volcanic region suggest a mantle plume source of their melts. This allows us to consider the physicochemical conditions of formation, compositions, and differentiation paths of initial melts that generated in the environment of intracontinental intraplate activity on the basis of the investigation of melt inclusions in the phenocrysts of volcanic rocks.

We have studied lavas from eastern Tuva highland and Dzhida volcanic field which are characterizrd by most active volcanic processes. The regions are located each from other in 400 km. The rocks are slightly differentiated: their phenocrysts are dominated by olivine (up to 2-3 mm) and, occasionally, clinopyroxene. The groundmass and consist of plagioclase microlites, small grains of pyroxene, olivine, and opaque minerals sulfide globules, and apatite needles. The rock chemical composition is presented in Table 1.

Table 1. The composition of rocks and melt inclusions in olivine from Southern Baikal volcanic field

| Component (wt %) | Eastern Tuva (I) | | Dzhida (II) | | Component (ppm) | (I) | (II) |
|---|---|---|---|---|---|---|---|
| | rock | inclusions | rock | inclusions | | inclusions | inclusions |
| $SiO_2$ | 47.22 | 49.47 | 47.44 | 48.79 | Li | 8.53 | 7.87 |
| $TiO_2$ | 2.33 | 2.57 | 2.58 | 2.78 | Be | 1.75 | 2.36 |
| $Al_2O_3$ | 14.38 | 16.54 | 14.74 | 18.12 | B | 3.43 | 3.37 |
| FeO | 11.09 | 7.75 | 11.90 | 5.42 | Sr | 706 | 770 |
| MnO | 0.15 | 0.12 | 0.14 | 0.10 | Ba | 305 | 317 |
| MgO | 9.45 | 7.49 | 8.15 | 6.23 | Y | 17.8 | 21.4 |
| CaO | 8.35 | 8.01 | 8.41 | 8.62 | Zr | 180 | 196 |
| $Na_2O$ | 3.62 | 4.87 | 4.02 | 5.27 | Nb | 41.7 | 54.8 |
| $K_2O$ | 1.86 | 2.10 | 2.27 | 3.05 | La | 20.6 | 24.1 |
| $P_2O_5$ | 0.53 | 0.73 | 0.73 | 0.86 | Ce | 47.4 | 53.0 |
| $H_2O$ | - | 0.46 | - | 0.28 | Nd | 24.2 | 28.9 |
| Cl | - | 0.04 | - | 0.03 | Sm | 6.46 | 7.08 |
| F | - | 0.07 | - | 0.08 | Eu | 1.73 | 2.07 |
| S | - | 0.09 | - | 0.02 | Gd | - | 7.27 |
| Total | 98.98 | 100.31 | 100.38 | 99.65 | Er | 1.91 | 2.29 |
| Fo | - | 82 | - | 81 | Yb | 1.49 | 1.81 |
| T, °C | - | 1220 | - | 1200 | Th | 1.67 | 2.22 |
| n | 3 | 16 | 1 | 9 | U | - | 0.72 |
| | | | | | n | 3 | 2 |

The melt inclusions are composed of glass, varying amount of daughter crystals, and a fluid bubble. Their experimental investigation was carried out at atmospheric pressure using Sobolev-Slutsky heating stage. In order to prevent olivine oxidation, pure helium atmosphere was maintained at high temperature. The samples were quenched by shutting off heating power and simultaneous complete opening of gas flow through the stage. The quenching rate was at least 300°C/s.

The chemical compositions of the quenched glasses of melt inclusions are shown in Table 1. The basaltic melts contain from 48.8-49.5 wt % of $SiO_2$ and shown high contents of alkalis (4.9-5.3 wt % $Na_2O$, 2.1-3.1 wt % $K_2O$). These melts show elevated $TiO_2$ contents ranging from 2.6 to 2.8 wt %. With respect to other components, the trachybasalt melts show normal contents of FeO, MgO, CaO, and $P_2O_5$ (Table 1). The concentrations of volatile components in the melts are not high and average at (wt %) 0.03-0.04 Cl, 0.02-0.09 S (electron microprobe analysis), 0.28-0.46 $H_2O$, and 0.07-0.08 F (ion microprobe data).

In addition to melt inclusions, the olivine phenocrysts contain $CO_2$ fluid inclusions, which suggest that the melts were saturated in $CO_2$ during olivine crystallization. The primary fluid inclusions are homogenized at 9.2-24.0°C into a liquid phase, which corresponds to a $CO_2$ density of 0.73-0.87 g/cm$^3$ (Table 2). Given the most probable temperatures of olivine crystallization of 1200-1300°C, $CO_2$ fluid pressure is 4.3-6.6 kbar corresponding to a depth of 16-24 km at a lithostatic pressure gradient of 275 bar/km. It is necessary to note that these pressure estimates are the lowest constraints, because fluid aureoles were often observed around the melt inclusions, which suggests inclusion decrepitation at the eruption of the lavas onto the surface.

Table 2. Fluid pressure and depth of olivine crystallization in trachybasalts from Southern Baikal volcanic field

| Sample | Type of inclusion | Temperature of homogenization $CO_2$, °C | $CO_2$ density, g/cm$^3$ | $CO_2$ pressure at 1200-1300°C, kbar | Depth of crystallization, km |
|---|---|---|---|---|---|
| Kd - 1 (I) | Primary | 21.6 (l) | 0.76 | 4.7 - 5.0 | 17 - 18 |
| | Primary | 22.3 (l) | 0.75 | 4.5 - 4.9 | 16 - 18 |
| Xz -3/2 (II) | Primary | 17.7 (l) | 0.80 | 5.2 - 5.6 | 19 - 20 |
| | Primary | 20.7 (l) | 0.77 | 4.8 - 5.1 | 18 - 19 |
| | Primary | 21.6 (l) | 0.76 | 4.7 - 5.0 | 17 - 18 |
| Dzh - 14/6 (II) | Primary | 24.0 (l) | 0.73 | 4.3 - 4.6 | 16 - 17 |
| Dzh - 14/8 (II) | Primary | 9.2 (l) | 0.87 | 6.2 - 6.6 | 22 - 24 |
| | Secondary | 23.9 (g) | 0.23 | 0.77 | 2.8 |

Note: l - homogenization in liquid phase, g - in gas phase; gradient of the lithostatic pressure is equal to 275 bar/km.

The ion microprobe analyses of the melt inclusions show a narrow range of trace element contents (Table 1). The concentrations of Ba, K, Sr, Zr, P, and Ti in the inclusions are similar to those of the rocks. Together with the major-element systematics, this suggests obvious genetic relationships between the primitive melts that crystallized olivine phenocrysts and the rocks representing the ultimate products of magma evolution.

The analysis of a great number of trace elements in the melt inclusions allowed us to characterize in detail the geochemistry of the primitive melts of the Baikal rift and constrain a number of specific features of their source. In general, the melts show an increase in the normalized content of trace elements with increasing degree of incompatibility in the processes of mantle melting. The normalized ratio $[La/Yb]_N$ of the melts is close to 10. The highest enrichment relative to the primitive mantle composition was obtained for K and Nb (60-80). In contrast, the normalized contents of other highly incompatible elements (Th, B, and, to a smaller degree, Ba) are somewhat lowered relative to Nb and K. An intriguing feature of the Baikal rift melts is high $[Ba/Th]_N$ = 2.1-2.3, $[K/La]_N$ = 2.1-2.2, $[Nb/La]_N$ =1.9-2.1, $[Sr/Ce]_N$ = 1.2-1.3, and $[P/Zr]_N$ = 1.7-2.2. This can be described in general as a selective enrichment of Ba, K, Nb, Sr, and P in the melts relative to Th and REE. These element ratios practically do not fractionate in the processes of mantle melting and crystal fractionation of mafic magmas. Consequently, their departure from typical mantle values can be regarded as evidence for either a specific composition of the mantle source or magma contamination by usual rocks.