Evolution of parental melts of alkali ultrabasic intrusive masses of Maimecha-Kotui Province (Polar Siberia)

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Abstract. Computational modeling based on data on the compositions of melt inclusions in chrome-spinelids using the COMAGMAT [12] and PETROLOG [11] programs indicates the similarity of the parent melt of meimechites [4] with the picritic magma of the Gulinsky massif. Experimental data on the inclusions confirm this conclusion, showing the reliability of the actually calculated trends in the fractionation of ultrabasic melts. In general, the calculations showed that the crystallization of olivine from the high-magnesium pyrite melt occurred in the temperature range of 1510–1260 °C, mainly at a pressure of 6–7 kbar. At the same time, the melt evolves and approaches its composition to olivine basalt, from which, starting from 1200 °C, clinopyroxene mainly crystallizes with enrichment of the residual melt with alkalis, rare and rare-earth elements. The similarity of the compositions of the parental melts for meimechites and Gulinsky pluton rocks and the proximity of P – T parameters of their evolution indicates a possible genetic relationship of these magmatic formations.

In the north of the Siberian platform, alkaline-ultrabasic intrusive complexes and effusive formations are widely developed, which are a part of the Maimecha-Kotui province. Among the intrusive complexes, the Guli pluton is distinguished in terms of the size and diversity of its constituent rocks, the bulk of which is ultramafic and mafic (dunite and pyroxenite). In the structure of the volcanic stratum, a special place is occupied by the Maimechensky formation, composed of ultrabasic lavas, meimechites, spatially associated with the massif. Many researchers have noted the similarity between meimechites and Guli pluton ultramafites [1-8]. At the same time, the issues of interrelation and evolution of deep melts, ancestors for meimechites and alkaline-ultrabasic massifs, remain controversial, and it is very difficult to find it out using only petrologic-mineralogical and geochemical methods. To solve this problem, data on melt inclusions in minerals and calculation methods were used.
Earlier it was shown, that the parental high-temperature melt of meimechites, calculated on the basis of data on melt inclusions in olivine, contains 24 wt.% MgO (table 1, № 1) [4]. Subsequently, studies of inclusions in chrome spinelids served as the basis for estimating the composition of picritic magma (table 1, № 2), from which the dunites of the Guli pluton [6, 9, 10], which are similar in chemistry to the original meimechites, crystallized. The study of homogenized inclusions (figure 1) in chrome-spinelids [9] made it possible to trace the changes in the composition of melts from ultrabasic to basic, close to olivine basalt (table 1, № 3).

### Table 1. The composition of melts (mass. %), from which the rocks of the Gulinsky massif and the meimechites of Maimecha-Kotui province were formed.

|   | SiO₂ | TiO₂ | Al₂O₃ | FeO* | MnO | MgO | CaO | Na₂O | K₂O | P₂O₅ |
|---|------|------|-------|------|-----|-----|-----|------|-----|------|
| 1 | 40.97| 3.30 | 4.26  | 14.78| 0.15| 24.00| 8.16| 1.77 | 1.26| 0.47 |
| 2 | 42.71| 2.88 | 5.87  | 5.40 | 0.00| 25.11| 8.24| 1.55 | 2.03| 0.56 |
| 3 | 47.21| 3.37 | 7.95  | 13.03| 0.20| 9.77 | 10.55| 2.13 | 2.04| 0.87 |

Remark. 1 - composition of the parental melt of meimechites [4]. 2 - the calculated gross composition of olivine-containing melt inclusion in dunite chrome-spinelid [9]; 3 - the composition of glass of the heated and homogenized melt inclusions in dunite chrome-spinelid [9]. FeO* - total iron.

Taking into account the similarity of ultrabasic melts noted above and the close spatial relationship of meimechites and intrusive hyperbasites, the ancestral meimechite melt (being a source of olivine cumulates) can serve as the initial magma for dunites and other rocks of the Gulinsky massif.

In this regard, when modeling the processes of crystallization of the initial magma for the rocks of Gulinsky massif, the composition of the parent melt of meimechites was taken as a basis [4]. Calculations based on PETROLOG [11] showed, that the temperatures of liquidus crystallization of olivine from this melt in the presence of water (up to 0.5 wt.%, [9]) depending on the pressure, could be the following: 20 kbar - 1600 ° C, 14 kbar - 1570 ° C and 10 kbar - 1550 ° C. Taking into account the previously established liquidus crystallization temperatures of olivine from dunites of the Gulinsky massif (about 1520 ° C [9]), for calculations using the COMAGMAT program [12], pressure values of 10 kbar were taken, corresponding to the intermediate magmatic chamber at a depth of 30 km at the base of the crust.

Modeling of decompression (from 10 to 2 kbar) crystallization of the parent melt of meimechites showed that olivines (Fo90-91), similar in composition to minerals from dunites of Gulinsky massif.
were formed at pressures of 6-7 kbar, and clinopyroxenes, which correspond in composition to pyroxenes from inclusions, crystallized at lower pressures (3.9-5.4 kbar).

Because of this, calculations using the COMAGMAT [12] program of fractional crystallization of the initial melt for the Guli pluton rocks, which corresponds to picrite in composition (Table 2), were carried out in an isobaric system (6.5 kbar) in the presence of water ~ 0.5% by weight, QFM buffer. Calculations showed that olivine starts to crystallize at around 1510 °C. Its quantity is growing rapidly (up to 38%) when the temperature drops to 1260 °C, when clinopyroxene begins to accumulate intensively (up to 20%). It should be noted that the results of crystallization of olivine and the corresponding changes in the composition of melt to 1260 °C, obtained on the basis of data on the melt of picrite composition and on the parent melt of meimechites, almost coincide (figure 2).

Figure 2. Fractional crystallization of ultrabasic melts.
Parental melt of meimechites (decompression model, from 10 to 2 kbar): crystallization of olivine (1), clinopyroxene (2), ilmenite (3) and a change in the content (wt.%) MgO (4), the sum of alkali (5) in the residual melt. Picritic melt in melted inclusions in chrome-spinelid (isobaric model, 6.5 kbar): crystallization of olivine (6), clinopyroxene (7), ilmenite (8) and a change in the amount (wt.%) of MgO (9), the amount of alkalis (10) in the residual melt.

On diagrams TiO₂, CaO – MgO (figure 3) one can see, that the calculated crystallization trends of the initial melts for meichmechites and picrites are close, and the composition points of melt inclusions in chrome spinelides are close to them. In our opinion, this confirms the accuracy of the calculations performed and it is the evidence of the formation of Guli pluton rocks from the melt, which is close in its composition to the parent meimechite melts.

As a result of evolution of the initial picrite melt during fractional crystallization of olivine, the melt loses a large amount of MgO and approaches the composition of olivine basalt, which can be traced in the study of melt inclusions in chrome spinelides. Calculations of similar isobaric crystallization of such a melt (table 1, No. 3), corresponds in composition to homogeneous glasses of the quenched inclusions, were carried out using the COMAGMAT program [12]. The pressure was set in accordance with the results of modeling the crystallization of clinopyroxene from the
Parental melt of meimechites — 4 kbar, QFM buffer, and water — 0.5% by weight. Calculations showed that olivine from this melt starts to crystallize at around 1245 °C and its amount reaches 6.5%. Starting from 1200 °C, clinopyroxene crystallizes intensively (up to 59% at 1070 °C), then ilmenite joins it at 1165 °C (up to 4.5% at 1090 °C). At the same time, the composition of the melt changes dramatically - an increase in the amount of aluminum and alkali occurs with a decrease in the contents of calcium, magnesium and titanium.

Figure 3. The evolution of ultrabasic melts composition.
Parental melt of meimechites (decompression model, from 10 to 2 kbar): a change in the content (wt.%) of TiO$_2$ (1) and CaO (2). Melt inclusions in chrome-spinelids from dunites of Gulinsky massif: content (wt.%) of TiO$_2$ (3) and CaO (4) [6]. Picritic melt (isobaric model, 6.5 kbar): a change in the content (wt.%) of TiO$_2$ (5) and CaO (6).

Considering the features of geochemistry of rare-earth elements, we see that as a melt of the basic composition evolves with decreasing temperature, there is an accelerated accumulation of light lanthanides (figure 4). At the same time, the initial composition of melt, which corresponds to the composition of glass of the melt inclusion in chrome-spinellid from dunits of Gulinsky massif, practically coincides with the data on melt inclusions in olives from meimechites [4], which once again confirms the genetic similarity of these two ultrabasic complexes.

Summing up the research, it should be noted that as a result of using experimental and computational methods, the physicochemical parameters of deep evolution of the original high-magnesium ultrabasic melt for the Guli pluton rocks were established. It turned out that at a pressure of 6-7 kbar and in the temperature range 1510-1260 °C, mainly olivine crystallizes. Subsequently, with a decrease in temperature from the melt of the basic composition, pyroxene and a small volume of ilmenite crystallize. At the same time, the residual melt is enriched in alumina, alkalis, rare and rare-earth elements. The ratios of mineral phases established as a result of computational modeling are close to natural for the rocks of Guli pluton. In general, it should be emphasized that the study was based on the results of the study of melt inclusions in chrome-spinellides, which, thanks to the stability of these minerals, allow not only to decipher the crystallization conditions of ultrabasic
arrays, but can provide information on the indigenous sources of sedimentary complexes important from a practical point of view [14].

Figure 4. Evolution of peculiarities of rare-earth elements’ distribution in the melts of Gulinsky massif.

Content of rare-earth elements: 1250 °C - in the initial basalt melt at 1250 °C. 1070 °C - in the final melt at 1070 °C. Computational modeling using the COMAGMAT program [12] based on data on the glass composition of homogeneous melt inclusions of magnesia basalt composition in the chrome-spinel from the dunites of the Gulinsky massif - marked with letters St on figure 1. The shading shows the field of rare-earth elements in melt inclusions in olivine from meimechites (according to data from [4]). The contents of elements are normalized to the composition of chondrite according to [13].

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