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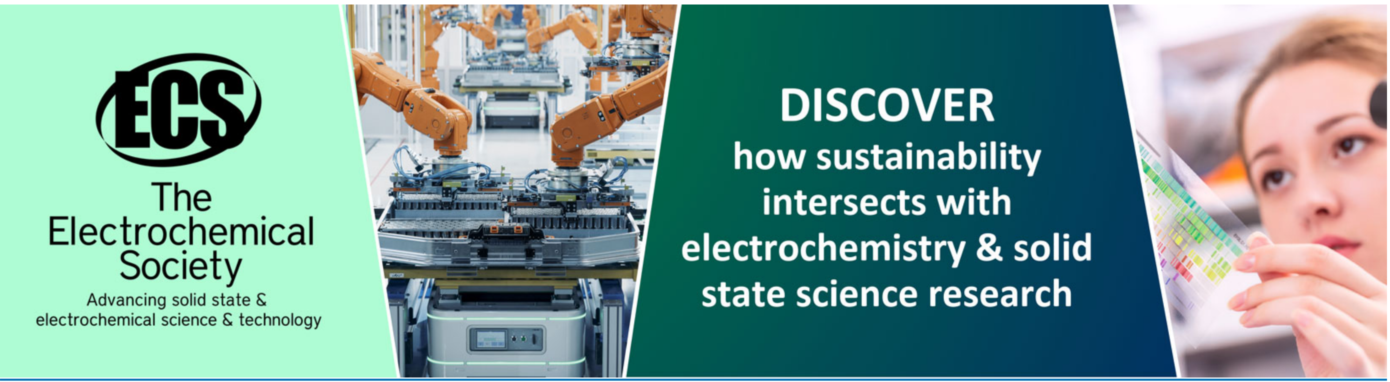

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Petrology of Ortsog-Uul peridotite-gabbro massif in Western Mongolia

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Abstract. The Ortsog-Uul mafic-ultramafic massif of Western Mongolia is located in a tectonic block with overturned bedding. The massif hosts two intrusions: a rhythmically-layered peridotite-gabbro association (Intrusion 1) and massive Bt-bearing amphibole-olivine gabbro (Intrusion 2). Intrusions 1 and 2 have different petrology features. Early Intrusion 1 (278±2.5Ma) is characterized by lower concentrations of alkalis, titanium and phosphorus than late Intrusion 2 (272±2Ma). The chondrite-normalized REE and primitive mantle-normalized rare elements patterns of Ortsog-Uul intrusions have similar curves of elements distribution. However, Intrusion 2 is characterized higher contents of REE and rare elements. High concentrations of incompatible elements are indicative of strong fractionation process. It has been suggested that Intrusions 1 and 2 derived from compositionally different parental melts. Model calculations (COMAGMAT-3.57) show that parental melts of two intrusions were close to high-Mg picrobasaltic magmas. The concentration of MgO in melt is 16.21 (Intrusion 1) and 16.17 (Intrusion 2). Isotopic data of Ortsog-Uul magmatic rocks exhibit different values of εNd (positive and negative) for Intrusion 1 and 2, respectively.

1. Introduction

Many mafic-ultramafic layered sulfide-bearing intrusions of the southeastern Siberian Region [1,2], the Vietnam [3], the China [4], and the Mongolia [5] is studied recently. A brief summary of the Ortsog-Uul massif based on previous geological reports in Russian by Izokh et al. [6]. The massif located on the northern slope of the Khangai uplands, on the left bank of the Tamiryn-Gol River (figure 1) in Western Mongolia. The Ortsog-Uul massif (S=5 km^2) as the adjacent Dulan-Uul mafic-ultramafic intrusion belongs to the Tamir Complex and it intrudes the metamorphic rocks, quartzites, gneisses, schists and amphibolites (figure 1). A more representative collection of samples was obtained by us in recent years to identify the genesis of the Ortsog-Uul massif. Our research also motivated by recent findings of Ni-Cu-PGE minerals included in the rocks. The data confirmed that Ortsog-Uul massif consists of two intrusions [7]. The identification of differences in the conditions of formation of these intrusions is the good prerequisite for understanding of the petrological processes.

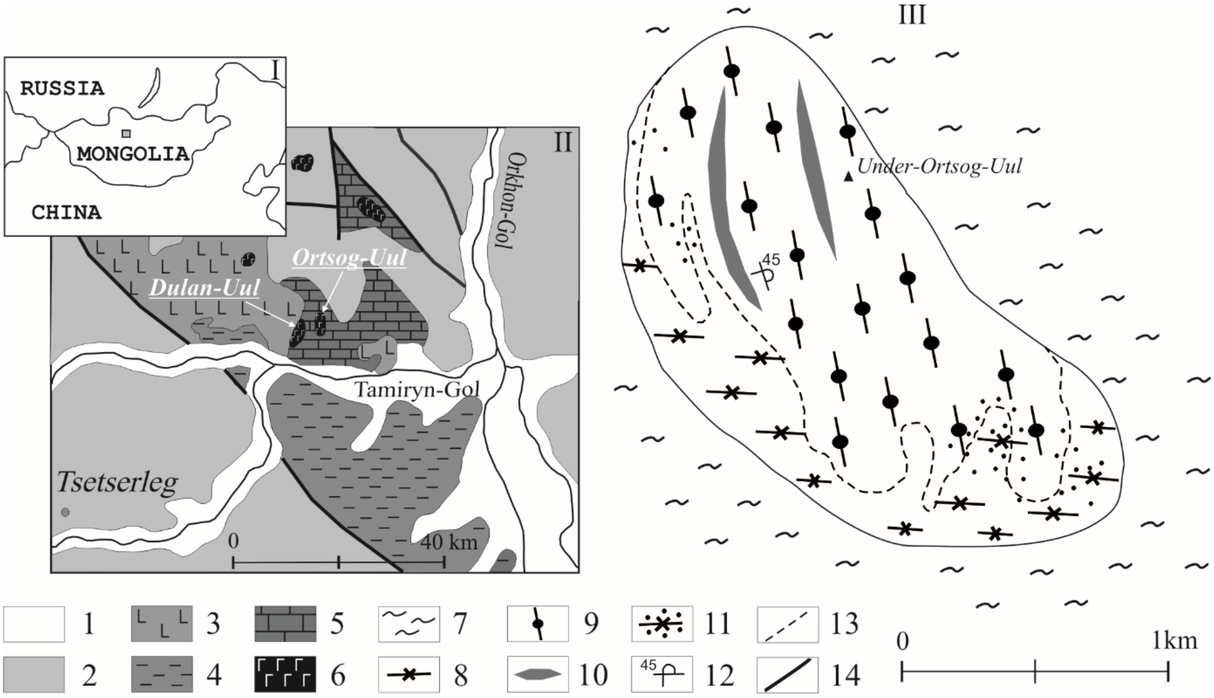

Figure 1. Simplified geological map of the Khangai uplands and the Ortsog-Uul massif: 1 – quaternary deposits; 2 – sedimentary terrigeneous rocks (PZ_3- MZ_2); 3 – basaltic rocks (PZ_3); 4 – green schists (R_3-Є$_1$); 5 – carbonaceous rocks (R_3- Є$_1$); 6 –Tamir Complex (PZ_1); 7 – host rocks (crystal slates and gneisses); 8 – Intrusion 2 gabbroids; 9-10 – Intrusion 1: 9 – olivine gabbro, gabbronorite and troctolite; 10 – melanotroctolite and plagioclase peridotite; 11 – sulphide mineralization; 12 – overturned layering; 13 – contact between Intrusions 1 and 2; 14 – fault.

2. Analytical methods

Following types of analysis were carried out in the Institute of Geology and Mineralogy in Novosibirsk, Russia. Major element oxides were determined by XRF using an ARL 9900. Trace elements and REE were estimated by ICP-MS using an Element-I Finnigan MAT. Electron microprobe analyses of all minerals were analyzed by Cameca Camebax Micro and Jeol JXA8100 electron microprobes (WDS). Argon isotope ratios of biotite were measured using a GV Instruments ARGUS. SHRIMP-II zircon dating was carried out in VSEGEI's Centre of Isotopic Research (St. Petersburg). Sm-Nd isotopic analyses of whole rock samples were determined using TIMS method in Geological Institute Kola Science Centre (Apatity).

3. Results

The Ortsog-Uul massif hosts two intrusions separated by a NW-SE distinct contact: a rhythmically-layered peridotite and gabbro (biotite-free) which is located north of the contact (Intrusion 1) and a massive biotite-bearing amphibole and olivine gabbro, south of the contact (Intrusion 2). The both intrusions are Permian in age. The Ar/Ar age of Intrusion 1 (Mg-hornblende from olivine mezogabbro) is 278.7 ± 2.5 Ma. A U-Pb zircon age of Intrusion 2 determined for olivine mezogabbro is 272 ±2 Ma (SHRIMP II) that is similar to Intrusion 1. However, the Ar/Ar age of Intrusion 2 (biotite from Bt-bearing olivine mezogabbro) is 257 ± 6.5 Ma.

The concentrations of SiO_2 and alkalis positively correlate suggesting progressive accumulation in residual melt during fractional crystallization. These are increase with decrease of MgO contents. The MgO versus Al_2O_3 plot (figure 2) shows the compositional variations of both intrusions due to olivine and plagioclase fractionation. The MgO ranges from 4 wt. % (plagioclase peridotite) to 33 wt. % (gabbronorite) in rocks of Intrusion 1 during fractional crystallization. The MgO range (17-25 wt. %)

is not extended in gabbro of Intrusion 2, while contents of alkalis, in particular, K_2O (up to 0.8 wt. %) are high. Samples of Intrusion 2 show a discrete vertical compositional field at 20 wt. % MgO in the plot of MgO versus (Na_2O+K_2O). The rocks of intrusion 2 are enriched in TiO_2 and P_2O_5 (up to 0.5 wt. % and 0.06 wt. % respectively) compared to Intrusion 1 resulting the presence of accessory titanomagnetite and apatite in the rocks of Intrusion 2.

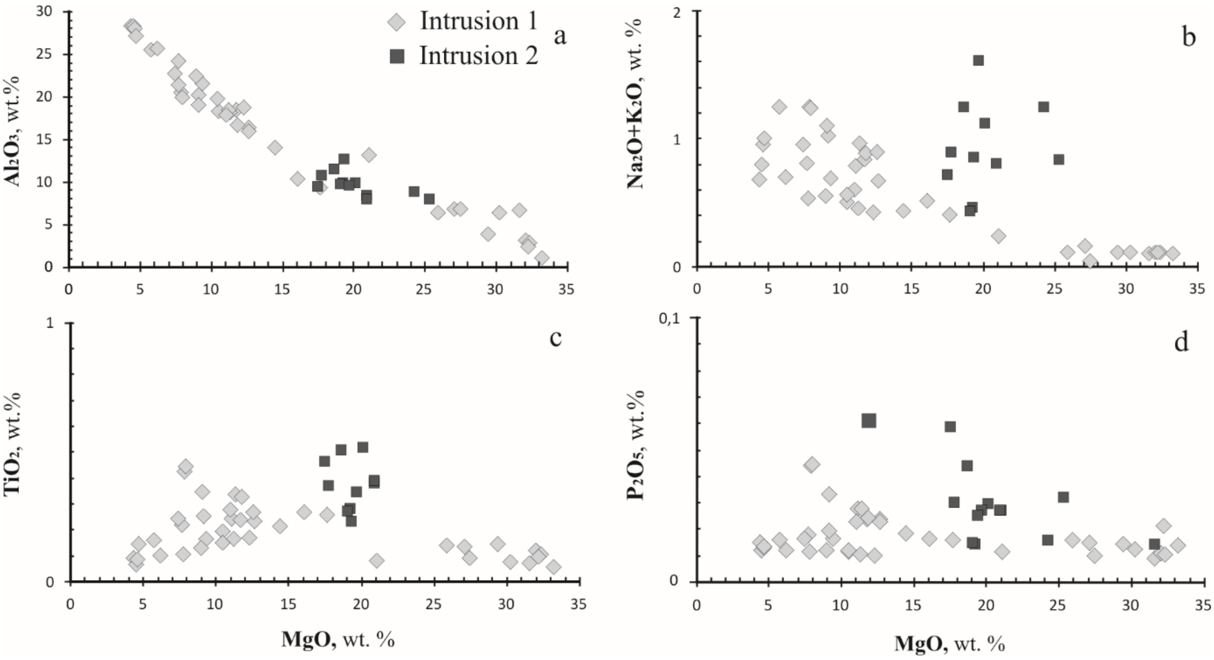

Figure 2. MgO versus Al_2O_3 (a), Na_2O+K_2O (b), TiO_2 (c), and P_2O_5 (d) plots of Intrusions 1 and 2.

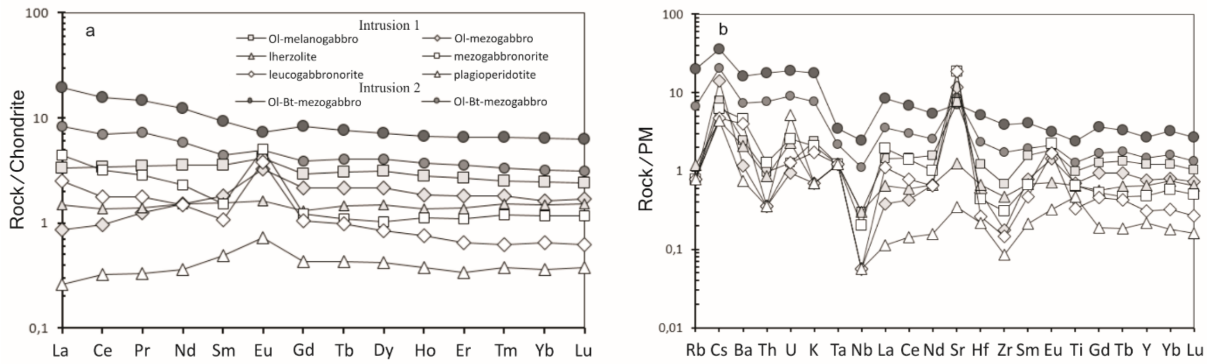

Figure 3. Chondrite-normalized [8] rare earth element (a) and primitive mantle-normalized [9] trace element (b) patterns of the Ortsog-Uul massif.

All Ortsog-Uul rocks have similar chondrite-normalized REE patterns [8] with slightly LREE enrichment ($(La/Yb)_N$ = 2.24−3.05), and weak positive Eu anomalies (figure 3 a). The Layered Series of Intrusion 1 displays a general increase of trace element contents from plagioclase peridotite to olivine melanogabbro. Most of the rocks of Intrusion 2 are characterized by higher concentrations of REE, HFSE and LILE normalized on the primitive mantle [9] than the Intrusion 1 as shown on the spidergrams. Gabbros from Intrusion 2 are REE-rich suggesting their derivation from a source which has the higher degree of fractionation compared to Intrusion 1 rocks. Both intrusions show positive anomalies of Sr and Eu (Eu/Eu^* = 1.2 to 3.8), and negative anomalies of HFSE (figure 3 b). The εNd is determined as positively (13.5; 270 Ma) and negatively (−4.3; 270 Ma) by isotopic analyzes for Intrusion 1 and 2, respectively.

Using the COMAGMAT-3.57 [10] software, we have found the compositions of the parental melts of the Ortsog-Uul intrusions, which might have crystallized at 2 kbar and the oxygen activity controlled by the QFM buffer. The initial melts estimated for both intrusions relate to high-Mg picrobasaltic magmas. The calculated concentration of MgO in melt is 16.21 (Intrusion 1) and 16.17 (Intrusion 2).

4. Discussion and conclusion

The age of the Ortsog-Uul massif is debatable. The age of Intrusion 2 determined by U-Pb method (SHRIMP II) is 272 ± 2 Ma whereas the Ar/Ar age of this intrusion is 257 ± 6.5 Ma. The both dating are disagree with the PZ_1 age shown on the geological map [11,12]. Nevertheless, the dating of Intrusion 2 by different methods has range 7-15 Ma. There are two explanations for this range. Firstly, closing time of isotope systems was possible various during slow cooling of massif or repeated warming up of the massif up to lower temperatures [13]. Secondly, zircon grains were probable xenogenic (trapping from the host rocks). In the latter case, the age of zircons will show the age of early crystallization of Intrusion 2 (not ancient, than 272 ± 2 Ma). Thus, the obtained data indicate the formation of the Ortsog-Uul massif in the Permian Period. In addition, the Nomgon massif (256±2.1 Ma) and a few basic rocks of the Selenga complex [5] are a similar age. The Nomgon massif and the Selenga complex are enriched in platinum group elements (PGE) [14,15]. This suggests that the Ortsog-Uul, Nomgon and Selenga massifs belong to the same PGE-enriched magmatic province. All aforementioned intrusions are located in common structure of the Central Asian Fold Belt (CAFB).

The each rhythm of Layered Series consists consistently of gabbro, troctolite, melanotroctolite and plagioclase peridotite from bottom to top. Such rhythmic sequence in the Ortsog-Uul massif disagrees with those of layered intrusions showing a normal-type stratification with mafic layers at the base and more leucocratic layers in the top in agreement with crystal fractionation process [16,17]. Consequently, it can be assumed that the Ortsog-Uul massif is included an overturned tectonic block. The overturned bedding of Ortsog-Uul rocks agrees with earlier geological data. The folded surface with elements of overturned bedding is shown at Early Proterozoic, at Triassic and Cretaceous systems of Early Mesozoic on the geological map L-48-I,II [11]. It confirms that studied region, including the Ortsog-Uul massif, have been involved in folding.

The MgO content smoothly decreases usually into the each cyclic unit of layered intrusions. The content of MgO increases abruptly during the transition to the next cyclic unit [18,19]. While it was revealed that the MgO contents gradually increases in each separate cyclic unit of Ortsog-Uul Layered Series up a section. This could be the case if plagioclase crystallizes earlier than olivine, but the euhedral crystals of plagioclase have not been observed in melanocratic rocks. Consequently, the overturned bedding of the tectonic block including Ortsog-Uul massif is the only reason for the reverse sequence.

Intrusions 1 and 2 have close MgO contents and different contents of incompatible elements. Firstly, rocks of Intrusions 1 and 2 form two separated trends (figure 2) on the MgO versus Na_2O+K_2O plots. The high contents of Na_2O+K_2O (up to 1.8 wt. %), TiO_2 (up to 0.6 wt. %), P_2O_5 is observed in rocks of the Intrusion 2 resulting the presence biotite, Ti-bearing clinopyroxene, titanomagnetite and apatite. Rocks of the Intrusion 2 are characterized by the high contents of REE, LILE and other rare earth element (except Sr, Eu) compared with Intrusion 1 (figure 3). It has been suggested that intrusions were formed from different portions of melt witch have not the equally processes of fractionation [20]. The isotopic data show positive εNd for Intrusion 1 and negative εNd for Intrusion 2. It confirms impossibility of sequential crystallization of both intrusions rocks from single melt [21,22]. Different contents of incompatible elements with the same concentration of MgO prove the various mantle sources of parental melts for these two intrusions. Based of isotopic data of Ortsog-Uul magmatic rocks have been determined that Intrusion 1 was formed from the depleted mantle source (εNd = 13.5; 270Ma) and Intrusion 2 was formed from the enriched mantle source (εNd= −4.3;

270Ma) [23]. The rocks of Ortsog-Uul massif are result fractionating of the picrobasaltic melts with the different content of alkalis and TiO_2 by COMAGMAT-3.57

From geological, mineralogical, geochemical and isotopic data, we can conclude that:

1) The Ortsog-Uul massif is located in the large Tamir Complex hosted within an overturned tectonic block;

2) There are two intrusions: an early [278.7 ± 2.5 Ma] layered Intrusion 1 and a late [272 ±2 (257?) Ma] massive Intrusion 2;

3) The wide difference of incompatible element contents shows that intrusions of Ortsog-Uul massif derived from compositionally different parental melts: Intrusion 1 from depleted source and Intrusion 2 from enriched source;

4) MgO contents in melts were estimated as 16.21 (Intrusion 1) and 16.17 (Intrusion 2); this proves that magma has the high-Mg picrobasaltic composition.

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