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PETROGENESIS OF ULTRAMAFIC CUMULATE ROCKS FROM DITRĂU ALKALINE MASSIF

Theses of PhD dissertation

Author

ENIKŐ ESZTER ALMÁSI

Supervisor

Dr. Elemér Pál-Molnár

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I. INTRODUCTION AND RESEARCH OBJECTIVES

The results of early investigations of the ultramafic cumulate rocks (hornblendites) from Ditrău Alkaline Massif [DAM] shows that these rocks originate from the early stage of the massif evolution. However, the conditions of their formation is not yet clarified. According to Streckeisen (1938) the hornblendites from the massif were generated from alkaline gabbro melts. Also, Streckeisen (1960) reported the formation of hornblendites which were the first differentiated component of the fractional crystallisation of primary alkaline syenite magma. According to Kräutner and Bindea (1995, 1998) the development of hornblendites can be related to olivine-pyroxenites. The olivine-pyroxenites are xenolites from the upper mantle. The upwelling magma delivered these rocks in the crust, where they suffered a partial hydratation. In these conditions the xenoliths were altered metasomatically and transformed in hornblendites. According to Pál-Molnár (1998, 2000) the hornblendites were within-plate alkaline-subalkaline rocks which in the last process were enriched in Na resulting a strongly alkaline (miascitic) character.

The aim of the research was to investigate the petrogenesis of ultramafic cumulate rocks from the Ditrău Alkaline Massif, to identify the parental magma of the ultramafic series and to specify/determine the ratio of ultramafic cumulate rocks in the massif.

II. METHODS APPLIED

For the petrogenetic investigations I carefully analysed the following parameters: texture of the ultramafic cumulate rocks, textural and chemical features of the rock-forming minerals and the major/trace element geochemical signature of the rocks.

Samples of ultramafic cumulates were collected at Jolotca, Csibi-Jakab, Pietrăriei de Jos, Pietrăriei de Sus, Tarniţa de Jos, Tarniţa de Sus, Ascuţit and Filep Creeks. From the 120 collected samples 45 thin sections were made. The rock-, as well the mineral textures and zoning patterns were examined with a Brunel-SP-300-P and Olympus BX 41 polarizing

microscopes at the Department of Mineralogy, Geochemistry and Petrology, University of Szeged. The in situ analysis of the mineral phases (point and line measurements) were determined using a CAMECA SX100 electron microprobe equipped with four wavelength-dispersive X-ray spectrometry (WDS) and one energy-dispersive X-ray spectrometry EDS at the University of Bern of 15 kV accelerating voltage and 20 nA beam current.

The trace and rare earth element (REE) analysis of minerals (16 amphibole, 12 clinopyroxene, 4 titanite and 2 olivine grains) were carried out on a New Wave Research UP213 Nd-YAG 213 nm UV laser system coupled to a Thermo X Series 2 ICP-MS at the School of Earth and Ocean Sciences, Cardiff University. All measurement were made using Thermo Elemental PlasmaLab time-resolved analysis mode. The laser beam diameter was 40 μm, with a frequency of 10 Hz and a power of ~3.5 J cm^{-2}. Ablations were carried out under a pure helium atmosphere. Acquisitions lasted about 90 s, including a 20-s gas blank prior to the start of the analysis and a 10-s washout at the end. BIR, BHVO and BCR standards were used as external standards. Si were used as internal standards to correct concentration values. Si concentrations were quantitatively measured prior to LA-ICP-MS using EPM. Subtraction of gas blanks and internal standard corrections were performed using Thermo Plasmalab software.

Whole-rock major-, trace- and rare-earth element X-ray fluorescence analyses (XRF) were carried out on a Panalytical PW2404 wavelength-dispersive sequential X-ray spectrometer at the School of Geosciences, University of Edinburgh, U.K. (8 samples). Additional major, trace element and REE of bulk rock analyses were obtained by ICP mass spectrometer (Finnigan MAT Element) and ICP atomic emission spectrometry using a Varian Vista AX spectrometer at the Department of Geological Sciences, University of Stockholm, Sweden (6 samples) and at the ACME Analytical Laboratory (http://acmelab.com/), Vancouver, Canada (3 samples).

III. THESIS POINTS HIGHLIGHTING THE MOST IMPORTANT RESULTS

The following new scientific results have emerged in the course of these investigations:

1. Based on the observations made at the samples' location (field), textural/geochemical investigation of the rocks and mineral phases showed that the ultramafic rocks (so named yet hornblendite) are ultramafic cumulate rocks. These cumulates originated from fractional crystallization and accumulation processes. Three types of ultramafic cumulate rocks were identified: olivine-pyroxene hornblendite, plagioclase-bearing pyroxene hornblendite and plagioclase-bearing hornblendite. The mineral composition of these rock types were similar, but the modal ratios were different.

2. Amphiboles were the main rock-forming minerals in the ultramafic cumulates of the Ditrău Alkaline Massif, where they appeared both as cumulus and intercumulus phases. The intercumulus amphibole surrounded the olivine and pyroxene crystals, crystallized in the intergranular spacing, while the cumulus amphibole directly crystallized from the melts. The crystallization of the two types of amphiboles were different as follows: the cumulus amphibole was formed by fractional crystallization and accumulation, while the intercumulus amphiboles were obtained by a reaction involving early formed minerals (olivine, pyroxene) and hydrous melts/fluids.

I have shown for the first time the presence of orthopyroxene (enstatite) in the ultramafic cumulate rocks from Ditrău Alkaline Massif. The orthopyroxene contains enstatite with the following chemical composition: $Fe^{2+}_{0.49\text{-}0.59}Mg^{2+}_{0.35\text{-}0.46}$ $Ca^{2+}_{0.04\text{-}0.05})(Fe^{3+}_{0.00\text{-}0.07}$ $Mg^{2+}_{0.93\text{-}0.97}$ $Al^{VI}_{0.00\text{-}0.02})(Fe^{3+}_{0.00\text{-}0.03}Al^{IV}_{0.02\text{-}0.05}Si_{1.92\text{-}1.96})O_6$.

I pointed out that, the orthopyroxene is a xenocryst while the upwelling magma fall from the surrounding rocks, probable in the mid-lower crust region. The composition was similar to the orthopyroxene crystals from crustal granulite xenoliths (mid-lower crust or crust/mantle boundary).

3. I applied the chemical composition values of the amphiboles to estimate the pressure and temperature of their crystallization. The best results were given by the oxo-hygro-thermobarometer provided by Ridolfi and Renzulli (2012) which was calibrated for alkaline systems. Amphibole barometry indicated a 6±1 kbar (600±100 MPa) pressure during the crystallization, which corresponded to middle-lower crust conditions. With an average crustal density this pressure range corresponds to ~25 km depth. The majority of the ultramafic cumulate rocks were formed in this region. Amphibole thermometry indicated 900-1050°C as the crystallisation temperature of the amphiboles from Ditrău Alkaline Massif ultramafic cumulate rocks.
Intercumulus and cumulus amphiboles were formed under the same crystallization conditions.

4. Through the detailed petrogenetic investigations of the ultramafic cumulate rocks from Ditrău Alkaline Massif a new point of view emerged concerning the formation of these rocks. The large amount of hydrous minerals (amphibole, apatite) in the cumulate rocks, the mineral composition, the enriched content of the high field strength elements (HFSE)/large ion litophile (LIL) elements in the minerals and rocks shows that the melts which formed the Ditrău Alkaline cumulate rocks were hydrous alkaline basaltic melts. These melts were rift related and originated in the upper mantle from partial melts of the metasomatic vein.

5. I determined that the ultramafic cumulate rocks are co-genetic with gabbroitic rocks and lamprophyres from the massif. Probably these rocks had the same primary alkaline hydrous magma. Mineralogy, major-trace and rareearth elemental composition of gabbroitic rocks and lamprophyres were very similar with the values from ultramafic cumulate rocks. According to Batki et al. (2014) the composition of lamprophyres in Ditrău Alkaline Massif were the closest in chemical composition to the primary magma. The formation of these rocks were generated by 1–4% partial melting of an enriched garnet and lherzolite mantle source containing 4% of pargasitic amphibole. The source enrichment was attributed to a sub-

lithospheric metasomatic zone consisting from a variable amphibole-rich ± carbonate ± oxides ± apatite ± clinopyroxene-bearing veins, which originates from the hydrous alkaline melts.

I measured the parental magma composition based on the estimation of the liquid in equilibrium with the most primitive cumulate minerals' (e.g. clinopyroxene) chemical composition. This conclusion was based on in situ (LA-ICP-MS) trace element data of the cumulus phases and trace element partition coefficients. It was pointed out that these melts' composition was similar to the lamprophyres compositions from the massif.

6. Taking in count the petrological and geochemical data and their direct petrogenetic implication I established a hypothetical petrogenetic model for the Ditrău Alkaline Massif ultramafic cumulate rock.

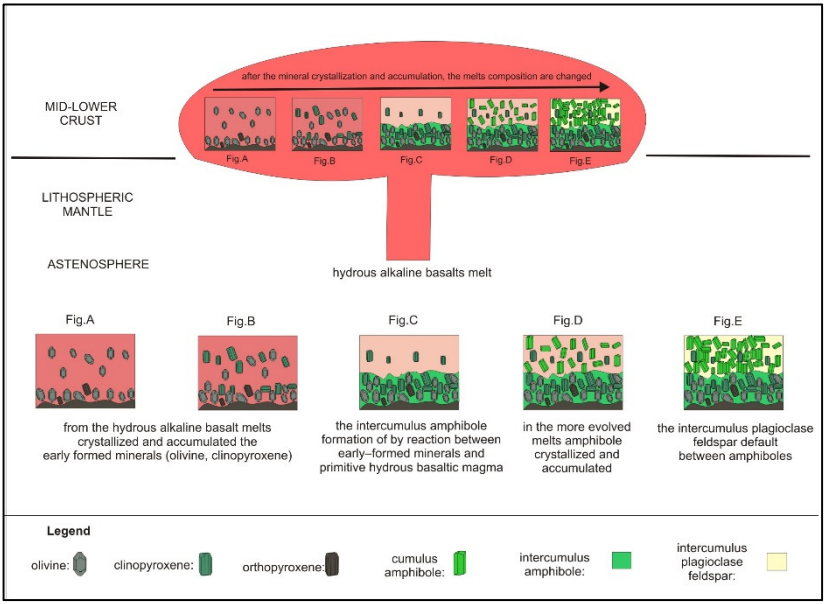

Fig. 1. Hypothetical petrogenetic model for ultramafic cumulate rocks from Ditrău Alkaline Massif

The crystallization of ultramafic cumulate rocks starts in the mid-lower crust or crust/mantle boundary of the hydrous alkaline basalt melts. From these melts crystallized and accumulated the early-formed minerals (olivine, clinopyroxene) (Fig 1 A, B). The intercumulus amphibole was formed by the reaction between early –formed minerals, primitive hydrous basaltic magma, or with more evolved melts (Fig.1. C)

After the crystallization of Fe-Mg rich minerals, the melt's composition changed. The cumulus amphibole crystallized the more evolved melts (Fig. 1. D). After the formation of cumulus amphibole, the melt's composition was different compared to the primary magma. From these types of melts crystalized the intercumulus plagioclase (Fig. 1. E).

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