Petrogenesis of the Csomád dacite: implications for the structure and processes of the magma storage system

SUMMARY OF THE DOCTORAL (PHD) DISSERTATION

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I. Introduction, objectives

During the last 20 million years in the Carpathian-Pannonian Region - due to a diverse volcanic activity – various types of magmas reached the surface (e.g. (pl. Pécskay et al., 2006; Harangi & Lenkey, 2007). Volcanologically the Middle Miocene was the most intensive period, however lots of volcanoes were active in the Quaternary and eruptions took place in three areas of the region in the last 500 thousand years. This means that we cannot obviously declare the present calm state of volcanoes as an evidence of the end of volcanic activity in the area and the renewal is impossible. Many researchers drew people's attention, like Szakács et al. (2002): *"We could not rule out the possibility of a future magmatic activity accompanied by volcanism in the areas of last volcanic activity in the Carpathian-Pannonian Region…further research and permanent monitoring are needed to reveal the volcanic hazard more precise"*. Harangi (2007) collected available scientific data and determined (based on e.g. the temporal and spatial distribution of the volcanism and the possible melting in the upper mantle) that: *"A renewal of volcanic activity in the Carpathian-Pannonian Region is not only a scpeculation" now, but this idea is supported by scientific data"*. Last eruptions took place south from Hargita-mountains at the Csomád volcano 30-40 ky ago (e.g. Harangi, 2007), which volcano is the youngest member of the Kelemen-Görgény-Hargita volcanic arc. This arc – which had a continuous volcanic activity in the last 12 My – shows a younging towards south accompanied by the decreasing amount of erupted magma (e.g. Mason et al., 1998). The Csomád is a dacitic lava dome complex with two explosion craters, the Mohos and the St. Anna. Besides more lava domes can be found nearby the volcano (e.g. Kis-Haram, Bálványos), which are part of the Csomád in a broader view. Based on the available age dataset (e.g. Pécskay et al., 1992, 1995; Szakács et al., 1993) the Csomád is a long-lived dacitic volcano. Its activity might have begun even one million yers ago divided by long breaks. Repeated age measurements on the material of the tuff pit near Tusnádfürdő (Pécskay et al., 1995; Moriva et al., 1996) draw attention to the uncertainty of the existing data, because the results from different methods differ in orders of magnitudes. More and more data suggest that the today's calm state of the volcano does not mean that it is extinct. Vasile Lazarescu proposed in the 1980s a possible hot magma chamber beneath the volcano. This suggestion was published by Rădulescu et al. (1983) based on heatflow measurements (this area has the highest heatflow in Romania, 85-120 mW/ m^2) and on a deep drilling, in which case they measured 78 °C at the depth of 1140 m. Latter investigations of gas-geochemistry (e.g. Vaselli et al., 2002) and geophysics imply to a magmatic body with melt content beneath the volcano. To describe the magma storage system two different types of geophysical investigations were used recently, and their conclusions were similar to the former ones: there is supposedly a vertical magma storage beneath the Csomád which may have a continuation towards south-east. Analyses of the seismic data covered the investigation of earthquakes beneath the volcano.

Popa et al. (2012) determined that beside the Vrancea-zone even the Csomád's area has seismic activity. Furthermore, under the Csomád loci of hypocenters appears along a seismically slow, vertical zone from the depth of 8 km towards the mantle. The magma storage are located in this depth range, between 8 and 20 km. Based on 1D and 2D inversion method of the magnetotelluric survey data it is observable a low resistivity (<10 Ωm) zone between ~5-15 km depth. However the upper part of this zone might be a hydrothermally altered body, the deeper part can be a magmatic body with certain amount of melt (Novák et al., 2012).

All these observations give the importance to recognize the Csomád's behaviour as precise as possible. To infer the behaviour of seemingly inactive volcanoes the best way is to reveal the magma storage processes which preceded the former eruptions. To understand these processes a petrogenetic investigation of volcanic and occasionally plutonic rocks is needed. Tools of cognition are the integrated petrographical and mineral textural – mineral chemical analyses. Using these methods it is possible to resolve the pre-eruption processes of the magma and in many cases its conditions (temperature, pressure, redox state, composition and fluid content). To estimate the duration of the system's build-up and to reveal the triggering mechanism of the eruption are possible in this way too. To reveal these processes and conditions detailed analyses of the phenocrysts of the Csomád were carried out.

In my investigations amphiboles have a specific role. They provide detailed information about the processes and conditions of a magmatic system beneath a volcano and they carry information with respect to the dynamics of the system (e.g. Bachmann & Dungan, 2002; Rutherford & Devine, 2003; Sato et al., 2005; Humphreys et al., 2009b), so using them we can get an amphibole-perspective about the magma storage system of the volcano (Thornber et al., 2008). Another aim of my research was to determine the age of the volcanic activity more accurately. In this investigation zircon geochronology were used.

II. Analytical methods

For the petrogenetic investigations, I carefully analysed the textural and chemical features of the phenocrysts of the dacite with special emphasis of the amphibole crystals. In the first step, the zoning and textural characteristics of the phenocrysts were examined in detail with a Nikon YS2-T petrographic microscope and an AMRAY 1830 I/T6 scanning electron microscope (using 20 kV accelerating voltage toward better BSE images) at the Department of Petrology and Geochemistry, Eötvös Loránd University. For the determination of the tiny mineral phases, qualitative chemical analyses were performed with the PU9800 type ED-spectrometer. The in situ analyses (point and line measurements) of the phenocrysts were carried out using a CAMECA SX100 electron microprobe equipped with four WDS and one EDS at the University of Vienna, Department of Lithospheric Research (Austria). I used 15 kV accelerating voltage and 20 nA beam current. Trace elements of amphibole phenocrysts were measured by LA-ICP-MS at the Utrecht University (from 100 μm thick polished thin sections). Ca was used as an internal standard element, the applied ablation crater diameter was 40-60 μm, depending on the size of the given mineral grain.

For the zircon geochronological investigations, I prepared zircon separates from the studied rocks with heavy liquid separation. Following this, the necessary analytical measurements were performed with the contribution of István Dunkl at the Georg-August University in Göttingen, and in addition in the LCPU geochronological laboratory of the Chinese Academy of Sciences in Beijing. The ZrHe age measurements occurred in the laboratory of Göttingen, while the U-Pb age measurements were carried out in the ionprobe laboratory of LCPU in Beijing.

III. New scientific results (theses)

1.) Through my investigations the structure of the feeding magma storage system of the Csomád was inferred. Amphibole barometry indicates 200-300 MPa pressure for crystallization, i.e. upper crust conditions. With an average crustal density this pressure range corresponds to 8-12 depth. The eruptions were fed by a magma storage, located in that depth. This storage could be characterized as a plutonic-like crystal mush zone. It was shown by the zoned pyroxene crystals that in the lower crust or at the crust/mantle boundary there is a separate mafic magma storage.

2.) The complex petrogenetic significance of the amphiboles were highlighted by my research. Based on their textural and chemical investigation the pre-eruptive processes and its conditions were described and an estimation was given for the temporal distribution of these processes. During my research it was pointed out the importance of the amphibole crystal growth stratigraphy. Identifying the growth stratigraphy and conditions precisely is essential to interpret the results of thermobarometry calculations.

3.) Detailed analyses of the mafic crystal clots revealed the magmatic origin of the Mg-rich olivine and clinopyroxene crystals, thus they can be used to characterize the mafic magmas supply the in the plumbing system of Csomád. The olivine crystals of the group1 mafic crystal clots represents primitive basaltic magmas. Their occurrence in the dacite suggests direct supply of the basaltic magmas into the upper crustal magma storage from their mantle-source. The clinopyroxene and olivine crystals of the group2 mafic crystal clots have different origin. They suggest that some of the mafic magmas evolved through open system magmatic processes (i.e. mixing of magmas). The composition of Cr-spinel inclusions in olivine crystals suggest that basaltic magmas in the Csomád magma plumbing system originates from subduction related mantle source.

4.) Based on the high-resolution analyses of the amphibole crystals, the basaltic magmas could have had an essential role in the triggering of the eruptions of the Csomád volcano. The amphiboles imply that more than 200 °C reheating affected the crystal mush prior to the eruption, which probably was the result of the basaltic intrusions. As the result of the reheating the felsic crystal mush was partially remelted, reactivated, thus the proportion of the liquid phase inside this magmatic body increased, and the magma was formed which was capable of eruption. The analyses of the amphibole reaction rims suggest that after the renewal of the crystal mush the volcano could have reactivated in weeks or months.

5.) Through the detailed investigation of the phenocrysts of the Csomád dacite, various crystal populations were be able to ditinguish. In this method, I used mainly the amphibole crystals as a tool for correlation. This mapping of the crystal populations gave the possibility to characterize precisely the different components of the magma storage system. Two main components, a felsic and a mafic one can be identified in the dacite. The felsic, Si-rich component is represented by a near-solidus, plutonic-like mineral assemblage: hornblende, biotite, quartz, K-feldspar, plagioclase, titanite, apatite, zircon and allanite. These mineral phases could derive from a dioritic-granodioritic crystal mush or proto-pluton. The mafic component is represented by the olivine, Cr-spinel and pyroxene crystals, which imply for the role of basaltic magma. Besides, an additional crystal population can be divided - the pargasites and plagioclase microphenocrysts - which was formed during the mixing of the felsic and mafic components. Although the homogeneous chemical composition of the Csomád dacitic magmas obscures the bimodal character of the magmatic system, the analysis of the phenocrysts implies that a great number of them are present in the rocks as antecrysts (i.e., cognate, but crystallized not in the host dacitic magma), and the dacites are in fact the mixture of crystals and melts of different origin.

6.) My detailed petrogenetic analyses threw new light upon the formation of the Csomád dacite. The eruptions of Csomád were fed by dacitic magmas of relatively homogeneous chemical and modal compositions, which imply that they were formed through similar processes in the magmatic system. In the formation of the dacitic magmas an important role was played by a long-lived dioritic-granodioritic proto-pluton or rather crystal mush. High-temperature mafic magma replenishments were able to reactivate this mechanically locked magma body, which resulted in the formation of the dacitic magma that was capable for the eruptions. The investigation of, for example, the Fish Canyon Tuff, the Chao coulée, the Mt. St. Helens dacite or the Unzen dacite indicate similar crystal mush remobilization processes (Bachmann és mtsi., 2002; de Silva és mtsi., 1994; Claiborne és mtsi., 2010; Nakamura, 1995), which suggests a general petrogenetic model in the case of the dacitic magmas feeding these volcanoes. Therefore, the analysis of the Csomád dacite not only helps to get knowledge about its magma storage system, but also gives the opportunity to unravel the magmatic processes of the dacitic volcanoes in general (e.g., to get an insight into the processes of the crystal mush reactivation).

7.) Based on the results of the zircon geochronology the volcanic activity is much younger than it was shown by the former age data. The presented (U-Th)/He age data indicate that the volcanic activity in the central lava dome complex occurred in the past ~150 kyr in two eruptive phases. In the first eruptive phase (~150-100 ky ago) effusive volcanic activity took place during which lava domes were extruded, then this was followed by a quiescence period that could have been even 40 kyr long. In the second eruptive phase (~50-30 ky ago) explosive eruptions also occurred beside the lava dome extrusions. The age results also draw the attention that the effusive and explosive eruptions cannot be separated entirely, as the former volcanological model suggested it. The zircon U-Pb crystallization ages imply a period of 80-160 ky ago for the main phase of the formation of the magmatic system, moreover it is possible that the magmatic activity has already began before this time, ca. 300-400 ky ago, which can be suggested by the older U-Pb age data. Crystallization of zircons in the inactive volcanic phase indicates that the magmatic system was active even when there was no volcanic activity on the surface.

IV. Conclusions

The petrogenesis of the magmas that fed the Csomád volcano and the pre-eruptive processes are similar and comparable to those of other dacitic (and andesitic) composite volcanoes in the world. Thus, the results of the investigation of the Csomád dacite are not only confined to this volcano, but also aim to answer in general the questions about the nature of the activity of andesitic and dacitic volcanoes, the processes operating in their magma storage systems together with their circumstances. The Csomád volcano can be considered as a natural laboratory of the crystallization of volcanic amphiboles where there are excellent opportunities for the high-resolution analysis of this mineral which has special importance from petrogenetic point of view.

My detailed investigations indicate that in the formation of the Csomád dacitic magmas, a long-lived felsic crystal mush played an important role that was unable to erupt in itself, however, fresh mafic magma intrusions were able to reactivate this magmatic body. This implies that the magma storage system beneath the Csomád volcano can reawaken even in that case when the magmatic bodies, which feed eruptions, have already come into a near-solidus state.

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