PETROGENESIS OF THE MIOCENE SILICIC PYROCLASTIC ROCKS OF BÜKKALJA: INFERENCES FOR THE MAGMA RESERVOIR PROCESSES

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I. Introduction, aims of the study

Silicic (SiO$_2$>65wt%) magmas evolve in shallow level magma reservoirs following the segregation of their parental melts from the source regions. Eruption of the felsic residual magmas, the erupted volume of the magma and the mechanism of the eruption are primarily controlled by the processes occurred in this magmatic system. Thus, studies of these rocks could contribute to our knowledge on the reason of large volume – sometimes supersized - explosive eruption of silicic magmas and also to understand the growth and evolution of silicic plutons, which add significant mass to the continental crust. Recently, there has been a change of paradigm concerning the processes in the shallow silicic magma reservoirs (Hildreth & Wilson, 2007; Bachmann & Bergantz, 2008 and references therein).

Silicic volcanism played a major role in the initial stages of the evolution of the Pannonian Basin. This kind of volcanc activity occurred during a changing geodynamic environment (Harangi and Lenkey, 2007), i.e. during the pre-extensional and syn-extensional phases of the Pannonian Basin. The southern foreland of Bükkalja (Bükkalja) provides an excellent area to study these silicic pyroclastic rocks. In spite of their fairly old ages (13-21 Ma; Márton és Pécskay, 1998), they are particularly fresh and preserved their original compositions including also the less stable glass phases.

Among the so called Lower, Middle and Upper Tuff Horizons three representative ignimbrite occurrences were selected (Szomolya Ignimbrite, Bogács Ignimbrite and Harsány Ignimbrite belonging to the lithostratigraphic units of the Gyulakeszi Rhyolite Tuff Formation, Tar Dacite Tuff Formation and Harsány Rhyolite Tuff Formation, respectively) to carry out a detailed petrogenetic study in order to reveal the processes occurred in the shallow magma reservoirs. This study involved an integrated textural and in-situ major and trace element geochemical investigation of the juvenile glasses (i.e., glassy groundmass of the pumices and lithic clasts, glass shards and silicate melt inclusions) and the mineral phases of the ignimbrites combined with quantitative model calculations.

The Szomolya ignimbrite is located at the southern part of Bükkalja and represents a well-preserved member of the Early Miocene Lower Tuff Horizon. One of the peculiarities of this pyroclastic rock is the relative abundance of cogenetic lithic clasts, which could be effectively used to have an insight into the deep magma reservoir processes. Furthermore, the mineral phases of the lithic clasts contain abundant silicate melt inclusions. Their studies provides a new perspective to reveal the genesis of the silicic magmas.
The 17 Ma old Bogács Ignimbrite (Middle Tuff Horizon) consists of a dacitic to rhyolitic pyroclastic sequence with a lower welded and an upper mixed scoria-pumice facies. This formation can be recognized throughout the Bükkalja volcanic field (Czuppon, 2003). It shows an upward gradual change of volcanologic, petrographic and geochemical features. The importance of magma mixing in its genesis was recognized by many researchers (eg., Póka et al., 1998; Czuppon et al., 2001; Czuppon, 2003). This study refined the petrogenetic model of Czuppon (2003) using new in-situ major and trace element analyses of different glasses, silicate melt inclusions and the mineral phases.

The 13.5 Ma old Harsány Ignimbrite is the youngest volcanic rock in the Bükkalja volcanic field and belongs to the Upper Tuff Horizon. The peculiarity of this pyroclastic formation is the occurrence of distinct rhyolitic pumices described previously by Lukács (2002).

Petrogenetic studies of these rocks could provide valuable data and model for the evolution of the silicic volcanic rocks in the Pannonian Basin. However, these results of these case studies could contribute also to our knowledge on the silicic volcanic systems, worldwide. Results of this study emphasize the open-system processes in the silicic magma reservoirs, particularly the importance of ascent and intrusions of mafic magmas.

II. Methods

In this study, petrogenesis of the silicic rocks was revealed by combined application of classic petrographic observations and in-situ major and trace element analytical data of different juvenile glasses and mineral phases. Investigations of silicate melt inclusions trapped in various minerals as well as interpretation of bulk rock compositional data were also an important tool to describe the processes in the magma reservoirs. Based on these data quantitative model calculations helped to reveal the closed and open system petrogenetic processes in more detail.

The bulk rock analyses were performed by different analytical methods such as X-ray fluorescent spectrometry (XRF), ICP-atomic emission spectrometry (ICP-AES), ICP масс spectrometry (ICP-MS) and instrumental neutron activation analysis (INAA). The XRF analyses were done at the Department für Litosphärenforschung, Universität Wien, Austria using a Philips PW2400 X-ray fluorescence spectrometer on fused glass discs (for major elements) and pressed powder pellets (for trace elements). In addition, XRF data obtained by
Sz. Harangi during the Royal Society Fellowship at the Royal Holloway College (RHUL), Egham, U.K. were also used in this study.

Some of the trace elements of pumices and lithic clasts were determined by INAA at the Nuclear Institute of the Technical University Budapest and by ICP-AES at the Royal Holloway College (RHUL), Egham, U.K. Further bulk rocks analyses were carried out in the AcmeLabs Ltd. (http://acmelab.com/), Vancouver, Canada by ICP-MS.

The major element composition of the glasses (glass shards, pumices and fiamme) and the main mineral phases was determined using a CAMECA SX100 electron microprobe at the Department für Litosphärenforschung, Universität Wien, Austria. In situ trace element analysis of glasses, silicate melt inclusions and a couple of mineral phases was performed by LA-ICP-MS using a 193 nm ArF excimer laser ablation system (MicroLas GeoLas 200Q) in combination with a quadrupole ICP-MS (Micromass Platform ICP) at Utrecht University.

III. Results (theses)

1. Based on an integrated textural and geochemical investigations of various mineral phases and glasses petrogenesis of three representative silicic ignimbrite occurrences from the so called Lower, Middle and Upper Tuff Horizons of the Bükkalja volcanic field, were reconstructed. Application of in situ geochemical investigations of glasses including the silicate melt inclusions trapped in mineral phases combined with quantitative model calculations was a novel research on silicic volcanic system. Several hundreds of mineral and glass compositional data were produced. This data set can contribute to the general geochemical characterisation of the volcanic formations of this area.

2. Studies of cognate lithic clasts in silicic ignimbrites could be crucial in order to reveal the petrogenetic processes in the shallow magma reservoir. A detailed magma reservoir model was produced based on the combined petrographic and geochemical investigation of the host ignimbrite and the lithic clast of the Szomolya ignimbrite, Lower Tuff Horizon, southern Bükkalja. In this model open-system processes played an important role including in situ crystallization, repeated magma replenishments and crystal mush remobilization and mixing of various crystal phases.

3. Mantle-derived mafic magmas often with fairly primitive composition (mg-number>0.6) were shown to played a major role in the evolution of the silicic magma reservoir of the Szomolya ignimbrite. Thus, it was the first firm indication that the Early Miocene silicic magmas of the Bükkalja region were generated by mixing of mantle derived and crustal
magmas and not by pure crustal anatexis as was proposed by many researchers. As a working hypothesis, it is suggested that the Miocene silicic volcanism of Bükkalja could belong to the intracontinental bimodal basalt-rhyolite style volcanic activities.

4. In the Bogács ignimbrite, which belongs to the Middle Tuff Horizon, several groups of juvenile glasses were determined. They represent distinct melts variously interacted with each other in the magma reservoir. Using in situ major and trace element data a quantitative petrogenetic model was given for their genetic relationships. The previous petrogenetic model proposed by Czuppon (2003) were refined and partly modified setting the complex processes in a magma reservoir model where open system processes occur within an extended crystal mush zone. Results of the silicate melt inclusions indicate that the mineral phases particularly the orthopyroxenes in the less differentiated scoria clasts are entirely xenocrysts, i.e. they were incorporated by the ascending dacitic melt from the mush zone.

5. In the Harsány ignimbrite (Upper Tuff Horizon) two distinct rhyolitic magmas were recognized based on the bulk rock composition of the pumices. Results of quantitative model calculations indicate that fractional crystallization could not result in the distinct compositions, thus syn-eruptive mingling of rhyolitic melts coming from spatially separated melt lenses was suggested.

6. Based on the in-situ (LA-ICP-MS) trace element data of a couple of mineral phases (orthopyroxene, Na-rich plagioclase and zircon) and the accompanying glass phases, mineral-melt distribution coefficients were determined. These values could be more precise than the previous data (Mahood and Hildreth, 1983; Bacon and Druitt, 1988) calculated from the composition of separated mineral and groundmass phases. Thus, they could be more effectively used in the petrogenetic studied of silicic magmatic systems.

7. An important outcome of this study was that bulk rock composition of igneous rocks does not necessarily indicate a magma, which played a role in the magma evolution. The “andesitic” major element composition of lithic clasts of the Szomolya ignimbrite and the juvenile clasts of the Bogács ignimbrite reflects complex mixing of crystals and melt fractions with different origins rather than the existence of an andesitic magma. They can be interpreted as consisting of mineral phases partly derived from mafic magmas and dacitic-rhyolitic residual melts. In this regard, origin of the pyroclastic rocks of the Tar Dacite Tuff Formation should be also reinterpreted. They could not represent eruption of dacitic magma as proposed by many researchers, but belong to a silicic magma system with a bimodal mafic-silicic character.
8. Silicate melt inclusions trapped in different mineral phases of ignimbrites and lithic clasts could provide important information for the magma evolution. However, as this study revealed, post-entrapment modification of their composition should be considered in the genetic interpretation of the obtained geochemical data. Interpretation of the origin of the host mineral, i.e. phenocrystic, antecrystic or xenocrystic is crucial. Results of quantitative model calculations imply up to 30% post-entrapment crystallization in the plagioclase hosted melt inclusions.

9. Results of quantitative petrogenetic model calculations for each silicic ignimbrite suggest that the trace element content of silicic magmas is primarily controlled by the crystallization of accessory minerals such as allanite and zircon even in very low – a few tens or hundreds percent – amounts.

10. The petrogenetic models proposed in this research are consistent with the new views for the silicic magma reservoirs put forward just recently by many authors (Hildreth, 2004; Bachmann és Bergantz, 2004; 2008; Hildreth és Wilson, 2007) rather than the traditional magma chamber models. Results of our studies could reveal some important processes taking place in the silicic magma reservoirs. It is shown that evolution of silicic magmas is quite complex involving repeated magma recharge, magma mixing and hybridization, mixing of crystal mushes, in situ crystallization and most importantly ascent and intrusion of mantle-derived mafic magmas.

**IV. Conclusions**

Detailed petrogenetic study of three silicic ignimbrites with different age and compositional features could reveal the complex processes occurred in the shallow magma reservoir. This implies that fairly different processes could take place even in a single volcanic field. Recently, there is a change of paradigm in the understanding of silicic magma systems. Interpretation of our combined petrographic and geochemical data is more consistent with the new views on the silicic magma reservoirs and could help to reveal the processes occurred in them in more detail. The wide variation of the magma reservoir processes revealed in this study and the particularly fresh preservation of the silicic pyroclastic rocks implies that the Bükkalja volcanic field could act as a natural laboratory in such investigations.

There are a couple of important questions coming out from this research that should be resolved during further studies. One of these is the possible interaction of silicic magmas
from the Lower, Middle and Upper Tuff Horizons in the Bükkalja volcanic field, i.e. could a new magma batch remobilize the older crystal mush and crystal sponge zones? A further important question is the interpretation of chemical composition of igneous rock, particularly whether andesitic composition does indeed reflect the existence of andesitic magmas in the magma evolution? Resolving of such questions should involve integrated petrographic and in situ geochemical investigations of mineral and glassy fractions of the igneous rocks.

V. References


VI. Publications related to the Ph.D. dissertation

Publications in peer-reviewed journals:

In press publications in peer-reviewed journals:

Extended abstracts:


**Selected abstracts:**


**Popular science articles:**