2-D and 3-D magnetotelluric modeling to support the petrological result for the nature of the magma storage system beneath the Ciomadul volcano (SE Carpathians)

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SUMMARY

The Ciomadul volcano is the youngest in the Carpathian-Pannonian region (eastern-central Europe) and there are indications that magma could still reside at the depth. The Ciomadul volcanic complex contains a central amalgamated set of lava domes and a few peripheral domes with two explosion craters in the central zone. The magmatic activity could have been connected to the seismically powerful region of the nearby Vrancea zone. Long period magnetotelluric (MT) soundings were carried out to aim of define to electric resistivity distribution of the volcanic system and find correlation with the petrologic model to confirm the hot magma chamber beneath the region. With dimensionality analysis and decomposition parameters we characterized the geometry of measuring area. Traditional MT interpretation - 2-D inversion and modeling - was carried out taking into account the decomposition results. The 2-D inversion along the profiles defined a low resistivity zone between 5 and 20 km depth which in continuation to the north-eastern with a deeper and wide extensive conductive anomaly. The indication can be connected to the melt storage or magma volumes which were not emptied during the last eruption. This depth range is consistent with our petrological investigation suggesting a dacitic magma reservoir at 6-14 km depth, whereas another, basaltic magma storage zone could be at the lower crustal depth (30-40 km). The 3-D modeling and inversion was also calculated supporting this feature.

Keywords: magnetotelluric, petrology, volcano, magma storage, Ciomadul

INTRODUCTION

Ciomadul volcanic system is located in the southernmost end of Harghita Mountains and part of the 700 km-long Inner Carpathian Volcanic Arc where the last eruption occurred at 30 ka (Szakács et al., 1993; Harangi et al., 2010; Seghedi and Downes, 2011). Although the long quiescence period seems to imply that this volcano is already inactive, there are several indications that a hot magmatic body could still reside beneath the volcano.

The present knowledge the volcanism of the Ciomadul is mainly based on the studies of Szakács and Seghedi (1989, 1995). The age of the explosive volcanic events still has not been clarified but youngest eruption of Ciomadul was dated at 42–35 14C ka BP (Moriya et al., 1996) and by radiocarbon method at 43,250±1000 cal yr BP (Harangi et al., 2010).

In this study, we performed magnetotelluric (MT) investigation with aim to prove the petrologic suggestion about open-system processes at a deep magma chamber and the suggested repeated intrusion of primitive mantle-derived basaltic magma into this magma chamber (Figure 1). The seismic tomography is proved the clear connection to the seismically powerful region to the Vrancea zone (Popa et al, 2011). A Low-velocity lithosphere has been detected beneath the volcanic system related to a thermal anomaly (800 C°, 20 km depth) and concluded that the more probable explanation of this anomaly is generated by migrating fluids, magma ascent and magma chamber processes.

GEOLOGICAL BACKGROUND

The Ciomadul volcano is located at the southern termination of the Călimani–Gurghiu–Harghita (CGH) andesitic-dacitic volcanic chain, at the southeastern edge of the Carpathian-Pannonian region (Szakács et al., 1993). The geodynamic setting of the CGH volcanism and particularly the volcanic activity of southern Harghita and Ciomadul is still highly debated. The active geodynamic situation is clearly indicated by the continuous seismic hazard attributed to the descent of a near vertical slab beneath the Vrancea zone about 50 km southeast from Ciomadul.

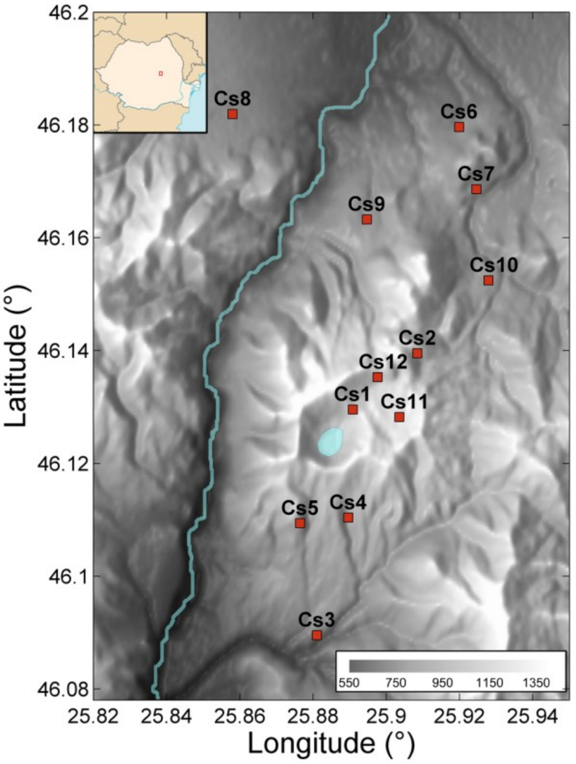

Figure 1. SRTM map of Ciomadul volcanic area with the MT stations (red symbols). The elevation is in meter.

The volcanism along the CGH is characterized by a gradually younging volcanism from 11.3 Ma. There was a sharp compositional change of the erupted magmas within the Harghita Mountains around 3 Ma and since that time more potassic and incompatible element-enriched volcanic products have been formed (Seghedi and Downes, 2011; Szakács et al. 1993). Termination of the volcanic activity at the southern Harghita was followed by eruption of even more potassic magmas after a couple of 100's ka repose time. Shoshonitic and banakitic magmas with strongly mixed mineralogical character formed isolated lava dome or cryptodome bodies at about 1.5 Ma. Preliminary zircon (U-Th)/He dating indicates that the volcanic activity in Ciomadul could have started around 200 ka (Karátson et al., 2013) after very sparse volcanism for about a 1-Myr-long period. Initially a lava-dome complex developed, whereas in the latest phase of volcanism vulcanian to sup-plinian explosive volcanism was more frequent. As a result, two explosion craters were formed, the Mohos and later the St. Anna craters. The former one is covered presently by a swamp, whereas the youngest crater is filled by a lake. Charcoal fragments in pumiceous pyroclastic flow deposits were used for radiocarbon dating (Moriya et al., 1996; Harangi et al., 2010) setting the last known eruption at 31,000±260 cal BP (Harangi et al., 2010).

PETROLOGY OF THE CIOMADUL VOLCANO

The lava dome rocks and the pumices of the Ciomadul volcano have uniformly dacitic composition (62-66 wt% SiO2) and contain the same mineral assemblages (Szakács and Seghedi, 1986; Kiss et al, 2011). The crystal-rich lava dome dacites (30-40% phenocrysts s.l.) contain a large number of mineral phases (15) as phenocrysts (s.l.): plagioclase, amphibole, biotite, K-feldspar, quartz, titanite, apatite, zircon and allanite. Olivine, clinopyroxene and tiny Cr-spinel xenocrysts s.l. occur also in the dacites and represent constituents from mafic magmas intruded into the crystal mush body.
Most of the studied rocks contain felsic and mafic inclusions. These inclusions represent a granodioritic crystal mush which had been heated up and was partially remelted by upwelling hot mafic magmas. Thermobarometric calculations were performed to estimate the pre-eruptive temperature and pressure of the studied dacitic magma. The calculation yielded a pre-eruptive temperature and pressure were 840±11 °C and 2.88±0.47 kbar. Antecrystal amphibole - plagioclase pairs and plagioclase - K-feldspar pairs were used to estimate the T-p of the crystal mush. This resulted equilibrium temperature of 735±26 °C at a pressure of 2.68±0.47 kbar. Thus, according to the pre-eruptive pressure estimate the magma chamber could have been at 10-11 km depth.
Clinopyroxenes often show oscillatory zoning suggesting that they were formed by open-system processes at a deep magma chamber. Zoning patterns suggest repeated intrusion of primitive mantle-derived basaltic magma into this magma chamber.

MAGNETOTELLURIC RESULTS

The aim to define the electrical resistivity distribution of the volcanic system we carried out magnetotelluric soundings around the Ciomadul volcanic system. 12 sites were collected with average spacing 1-4 km using LEMI-417 acquisition system (Figure 1). The average recording time was approximately 4 days at a station and measured electric (Ex, Ey) and magnetic (Hx, Hy and Hz) fields at the surface of the earth. Electromagnetic time variations were observed between 0.25-15.000 sec period range. The data were processed using robust single-site and in some cases remote reference processing code to eliminate artificial noises and estimate MT transfer functions (Egbert and Booker 1986, Egbert and Livelybrooks, 1996).

We performed a 2-D modeling by inverting MT impedances using non-linear conjugate gradient algorithm of Rodi and Mackie (2001) with identifying three different elongation profiles (a) N-S, b) NNE-SSW) c) NNW-SSE. Separation of the two polarization modes (TE and TM) and the bimodal (TE and TM with Hz conjugate gradient) inversion was also carried out. By 2-D inversion a well conductive structure is observed between 5-20 km depth. Lateral distribution of the conductive anomaly (< 10 Ωm) is less than 5-6 km long in both direction (Figure 2).

This anomaly is located near the main volcanic crater and related to the dacitic magma reservoir marked as DMR. The conductive feature is associated with the dacitic magma reservoir or the magma chamber with intrusion of primitive mantle-derived basaltic magma which may be has continuation with depth (30-40 km, BMS) to the direction of Mohos bog (Figure 2). Supposedly, if the magma reservoir is exist, then the storage of providing the magma intrusion should be continue with the depth to the northeastern direction.

For supporting the 2-D results we performed the 3-D inversion by using WSIN3DMT inversion code (Siripurnvaraporn and Egbert, 2000; Siripurnvaraporn et al, 2005a). The 3-D inversion represents in many aspects similar results as the 2-D inversion, mainly the indication of dacitic magma reservoir in 5-20 km depth range (Figure 3). The significant difference is observed at deeper part of the results where there was not any indication of the basaltic magma storage. Supposedly the 3-D inversion, due to the lack of the vertical magnetic field integration provide different resistivity model against the 2-D inversion.

As it was shown by induction arrows the conductive anomaly is shifting with depth to S-E to N-E direction. Although the 3-D inversion does not manifest the basaltic magma storage there is sufficient evidence of existence of it by 2-D inversion, induction arrows and phase tensor ellipses (Figure 3).

CONCLUSION

The 2-D and 3-D inversions of magnetolluric data provided imaging about well conducting anomalies beneath the Ciomadul volcanic complex with two different depth range. The indications of crustal depth related to the open-system processes dacitic magma reservoir and the suspected magma storage at deeper part. This structures is recovered in all tested models, in 2-D as well as in 3-D inversions. The estimated depth of shallow magma reservoir is in good agreement with the seismic tomography results by Popa et al (2011).

A number of supposed features of the Ciomadul volcano and its environments are strongly suggested that the magma plumbing system of this volcano is not definitely frozen.

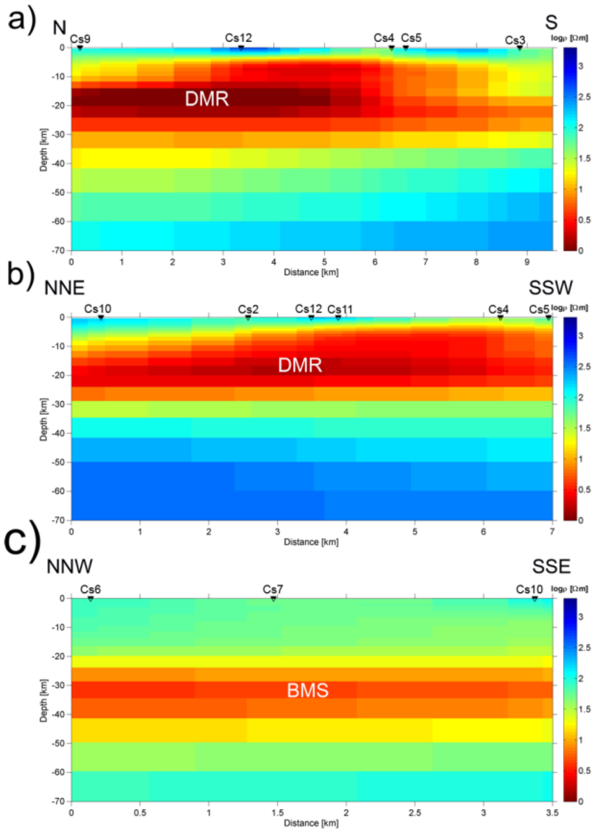

Figure 2. 2-D inversion results of profiles: a) profile 9-12-4-5-3; b) profile 10-2-12-11-4-5; c) 2-D profile 6-7-10. (Bimodal inversion with Hz conjugate). DMR - Dacitic Magma Reservoir. BMS – Basaltic Magma Storage. Resistivity values are in logarithmic scale.

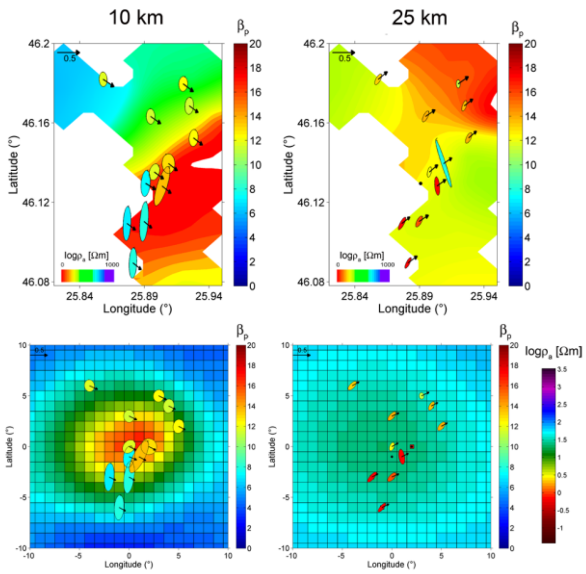

Figure 3. Comparison 2-D and 3-D inversion results (horizontal maps), with the induction arrows (Wiese, 1962; Parkinson convection) and the phase tensor ellipses (Caldwell et al., 2004). The fill of ellipses represent by the βp skew angle in degree. Resistivity values are in logarithmic scale.

ACKNOWLEDGEMENTS

This research on the Ciomadul volcano belongs partly to the scientific project supported by the OTKA (Hungarian National Research Fund) No. K68587. This project was supported by the János Bolyai Scholarship of the Hungarian Academy of Sciences and was supported by the TAMOP-4.2.2.C–11/1/KONV-2012-0015 (Earth-system) project and TÁMOP-4.2.4.A/ 2-11/1-2012-0001 `National Excellence Program's sponsored by the EU and European Social Foundation. We thank Institute of Geodynamics, Romanian Academy for logistic support.

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