LOW ^{18}-OXYGEN SIGNATURE OF NEOGENE CALC-ALKALINE SUBVOLVCANIC INTRUSIONS OF THE RODNA-BÂRGĂU MOUNTAINS (ROMANIA): EVIDENCE FOR THEIR INTERACTION WITH HYDROTHERMALLY ALTERED CRUST AND HEATED METEORIC WATER

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Abstract: Low $\delta^{18}O$ values (3.8 to 6.7‰ SMOW) are reported for the amphibole, pyroxene, and garnet in the magmatic rocks and cognate xenoliths of Rodna-Bârgău Neogene calc-alkaline subvolcanic intrusions, which are interpreted in terms of assimilation of altered country rocks and interaction between intrusion bodies and heated meteoric water. Several individual intrusive complexes are described from the point of view of oxygen and strontium isotope data (0.705 to 0.709).

Key words: Rodna-Bârgău, subvolcanic intrusions, low $\delta\ ^{18}O$, water-rock interaction

Geological setting and petrography of the magmatites

The magmatic rocks generated in the internal part of the Carpathian arc belong to an active continental margin type, in connection with a subduction zone located at the southwestern border of the Eurasian plate. The host-rocks of the subvolcanic intrusions are the metamorphic rocks of the internal Dacides (Rodna Mountains) and the sedimentary deposits of the Transcarpathian flysch (Bârgău Mountains).

Using geographical, tectonical, mineralogical and geochemical criteria two parallel alignments have been separated, one in the southwest (Sturzii, Pleşii-Mal, Heniu, Oala, Iliuța) and another in the northeast (Măguri, Cornii). Petrographically, the southwestern alignment plot in medium to low-K series, while the northeast alignment fit in high-K series. Stocks and laccoliths, associated with sills and dykes represent the main intrusive structures. The intrusions show a large variation in volume and a surface exposure between 1 km^2 (Pleşii-Mal) to 20 km^2 (Cornii, Heniu). The age of the various intrusions is between 11 – 9 Ma (Sturzii-10.6±0.7, Runc-10.4±0.8, Cornii-9.8±0.8, Mg. Arsente-8.8±0.5), corresponding to Pannonian, similar with other volcanic activity in the East Carpathians (Pécskay et al., 1995). Basaltic andesites, microdiorites, quartz biotite hornblende andesites, quartz-garnet andesites, dacites, rhyodacites, and rhyolites are the main petrographic types. Transitional textures between subvolcanic and plutonic facies, and between hypabisic and volcanic-like facies occur. There is a relative high degree of crystallization and most of the rocks are porphyritic. The main minerals are plagioclase, amphibole, biotite, quartz, and subordinated potassic feldspar. As accessory minerals apatite, magnetite, zircon, and garnet can be found. Magmatic cognate xenoliths are relatively frequent in the intermediary to basic rocks and are interpreted as result of mixing processes. The sizes vary from 2-3 cm up to 20-25 cm. Amphiboles ± feldspars (hornblendite-like) represent the mineralogical composition of most cognate xenoliths. Pyroxene ± amphibole ± feldspars (pyroxenite-like) are also present.

Sampling and analytical techniques

Almost all-important petrographic types have been considered for the study. Sr isotope analyses were made using standard ion exchange separation techniques at the Department of Earth Science of the “La Sapienza” University of Rome. Mineral separates of amphibole, pyroxene have been analyzed for O isotope ratio at the CNR - Centro di Studio per il Quaternario e l’Evolutione Ambientale, Rome, using a laser fluorination system attached to a Finnigan MAT ‘DELTA plus’ mass spectrometer. Some samples have been replicated or newly performed at Royal Holloway University of London using a laser fluorination system. The average reproducibility of isotopic analyses is ± 0.2‰ or better. The analytical data are reported in the familiar δ - notation referenced to SMOW as the mean of two or more replicate analyses.

Results

The amphibole and pyroxene display $\delta^{18}O$ values between 3.7 and 6.7‰ (SMOW). The highest $\delta^{18}O$ values were found in Cornii andesite (6.6‰) and Colibița andesite (6.7‰). Pyroxene hornblendite xenolith within Cornii andesite displays equilibrium $\delta^{18}O$ values for pyroxene (5.7‰) and amphibole (5.6 ‰), very similar to a mantle source. The low isotopic composition observed for most of the rocks and xenoliths reflect interaction with a contaminant with lower $\delta^{18}O$.

The $\delta^{18}O$ value for garnet (alm 58%; adr 0.5 %; sps 4 %; prp 12 %, without zonation) from the Pleşii garnet-quartz andesite (4.3 ‰) lies within the range of the δ-values exhibits by the amphiboles from the medium-K series. The garnet appears to be in isotopic equilibrium with the coexisting amphibole (4.6 ‰). Much higher $\delta^{18}O$ value (7.3‰) was obtained for the metamorphic garnet (alm 60%; grs 11 %; sps 8 %; prp 21 %) from the staurolite garnet mica schist within Rebra series. This suggests that the garnets of the Pleşii andesite could be of a primary magmatic origin, crystallized from low-$\delta^{18}O$ magmas. However, high temperature chemical homogenization and isotopic equilibration could be an alternative explanation.

The total range of $^{87}Sr/^{86}Sr$ ratios is from 0.70588 (Iliuța basaltic andesite) to 0.70929 (Heniu andesite).

Discussion and conclusions

Low $\delta^{18}O$ values (3.8 to 6.7 ‰ SMOW) reported for the amphibole, pyroxene, and garnet in the magmatic rocks and cognate xenoliths of the intrusions, are interpreted in terms of assimilation of hydrothermally altered country rocks and sub-solidus interaction between intrusion bodies and heated meteoric water. This interpretation is consistent with the fairly uniform oxygen isotope composition observed in all lithologies (from basaltic andesites to dacites) and with the poor development or total absence of the hydrothermal alteration products in most of the intrusive bodies. Important assimilation processes took place in intermediary magma chambers, located in the upper/middle crust, where repeated fed by mafic magmas also occurred, as proven by the presence of the cognate xenoliths. Sub-solidus interaction with the meteoric water was a continuous process during the cooling history of the rocks. Control on the scale of hydrothermal phenomena is given by the tectonic structure (fault and fractures system), by the lithology of the country rocks (more or less permeable), and by the emplacement depth of the intrusions.

The medium-K suite defines a slightly negative correlation (fig. 1). The decreasing of the $\delta^{18}O$ values as $^{87}Sr/^{86}Sr$ ratios and SiO_2 increase could be interpreted as a progressively contamination of a mantle derived magma with a contaminant depleted in $\delta^{18}O$ and enriched in $^{87}Sr/^{86}Sr$ (i. e. hydrothermally altered crustal rocks). **Iliuța basaltic andesite** is the less contaminated rock. Taking into account its volcanic-like texture and the small volume of the intrusion, we can assume that the magma has been solidified rapidly near the surface, without important interaction with meteoric water to affect the initial $\delta^{18}O$ oxygen. On the contrary, the more acid intrusions display higher degree of crystallization, which imply a longer period of stagnation in the upper crust, and consequently a longer time of interaction with the meteoric system. Lower $\delta^{18}O$ values displayed by the **Sturzii and Pleşii dacites**, as compare to other rocks of the series, could result from their location near the Someş fault, which could facilitate intensive circulation of the meteoric water.

In spite of its more basic composition relative to Pleşii quartz andesite and Sturzii dacite, **Heniu amphibole andesite** exhibits higher $^{87}Sr/^{86}Sr$ ratios and higher $\delta^{18}O$ value. An AEC process (Assimilation and Equilibrium Crystallysation) (Huppert and Sparks, 1985) could be a possible explanation for the increasing $^{87}Sr/^{86}Sr$. Hotter and voluminous mafic magmas are able to assimilate more crustal material than cooler less voluminous acid ones. The preservation of an intermediate composition during assimilation and crystallization imply new inputs of mafic magma, which are supported by the presence of cognate xenoliths (Heniu, by far is a larger intrusive structure). Slightly higher $\delta^{18}O$ values could also be due to repeated mixing processes with mafic magmas.

Cornii and Colibița andesites are characterized by the highest $^{87}Sr/^{86}Sr$ ratio (0.709) and $\delta^{18}O$ (6.7 ‰), which imply extensive crustal assimilation. The higher $\delta^{18}O$ values are not consistent with large interaction with meteoric water or assimilation of a highly altered crust. Cornii and Colibița intrusive complexes intrude Paleogene clay and marl formation, which involves restricted circulation of the meteoric water. The analyzed samples from Cornii andesite belong from a drilling (500m) in the center of the body. This indicates that large interaction with meteoric water occurred mostly at the edges of the intrusive bodies.

Măguri andesite intrusive complex clearly shows characteristics of a lower temperature hydrothermal system with a shorter lifetime. Oxygen isotope disequilibrium between coexisting pyroxenes and amphiboles, both in host-rocks and cognate amphiboles have been observed, as well as additional mineralogical and petrographical alteration effects (some alteration of primary mafic minerals, miarolitic cavities and veins filled with quartz, and calcite). Taking into account that Măguri intrusion is the youngest, at the termination of the intrusive magmatic activity, these features are predictable.

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Fig. 1: $\delta^{18}O$ (mineral separate) vs. $^{87}Sr/^{86}Sr$ (whole-rock) diagram for Rodna - Bârgău magmatic rocks. Bulk rock fields of Pannonian Basin lower crust (LC) (Kempton et al., 1997) and for East Carpathians (EC) including Călimani – Gurghiu – Harghita segment (Mason et al, 1996) and Ukrainian Carpathians (Seghedi et al., 2001) are also shown for comparison.