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The Quantitative Link between Fold Geometry, Mineral Fabric and Mechanical Anisotropy: as Exemplified by the Deformation of Amphibolites Across a Regional Metamorphic Gradient

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This work shows the lateral variations in fold geometry affecting an amphibolite unit of constant mineralogical composition showing increasing metamorphic grade from east to west. A systematic decrease in the mechanical anisotropy of the folded fabric is observed with increase in metamorphic grade. These variations are represented by changing fold shapes interpreted as: 1) medium amplification associated with low post buckle flattening in the lowest grade zone, 2) high amplification coupled with medium post buckle flattening in the intermediate grade zone and, 3) passive amplification dominated by intense post buckle flattening in the highest grade zone. Quantitative microstructural study shows contrasting deformational mechanisms associated with folding. This is manifested by: 1) brittle dominated deformation of amphibole forming stress supporting network with a high competence contrast to plagioclase in lowest grade zone, 2) ductile dominated heterogeneous deformation of an interconnected weak layer structure with low competence contrast in the intermediate zone, 3) homogeneous deformation of a stress supporting framework with low competence contrast in the highest grade zone. The difference in the folding style between the garnet and staurolite zones is associated with the lateral variations in microstructure of the amphibolites inherited from a pre-folding metamorphic zonation and with different deformation micromechanisms in hinge zones. However, the change in fold style between the garnet and staurolite zones, and the sillimanite zone is controlled by the recrystallization associated with an important syn-folding heat input from an adjacent granite intrusion.

Petrology of Lamprophyres Occuring in the Northern Part of the Ditrău (Ditró) Alkaline Massif (Jolotca Creek Basin), Romania

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Introduction

The Ditro Alkaline Massif (DAM) is one of the most diverse and compound geological formations of the Eastern Carpathians. In the past decades numerous scientific essays were published on the complex geological interpretation of the massif, while the origin of lamprophyre dykes intersecting the different rock-types (granitoids, syenitoids, hornblendites) of DAM and

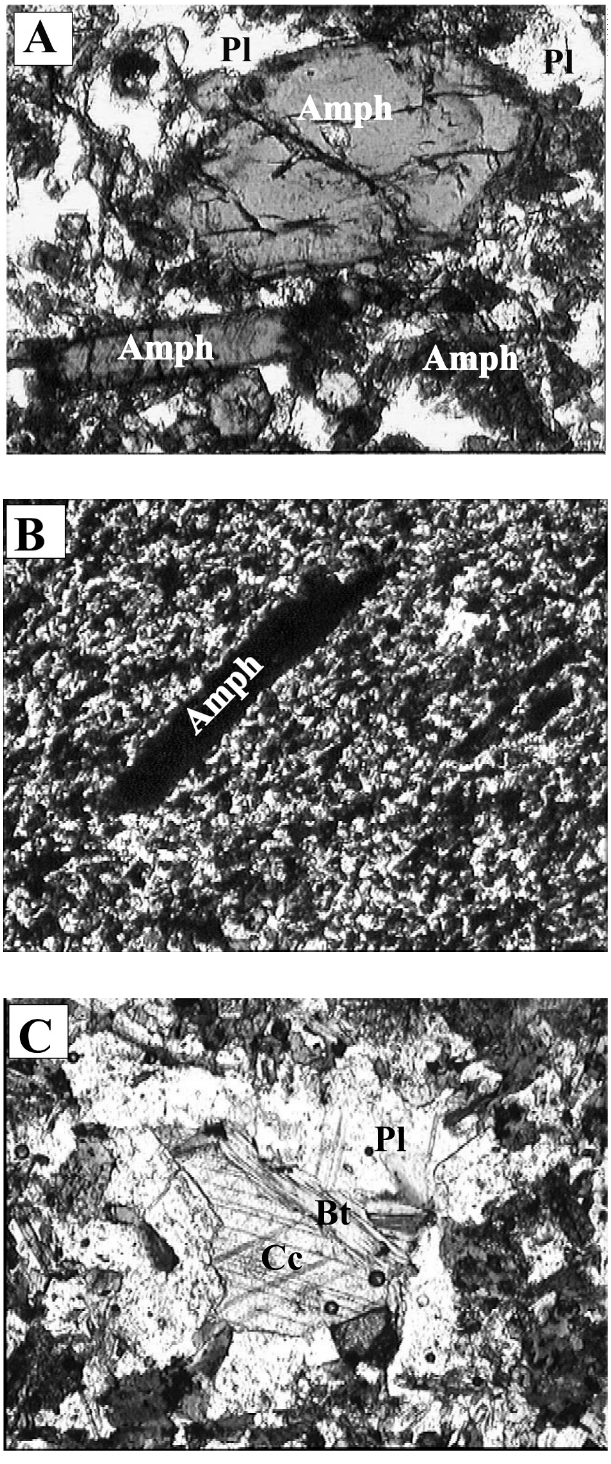

Fig. 1. Photomicrographs showing characteristics textures of lamprophyre dykes of the northern part of Jolotca Creek
(A) Euhedral amphibole phenocrysts in a groundmass of amphiboles and plagioclase feldspars (1N, ×50);
(B) Amphibole phenocryst in a microcrystalline, subhedral groundmass (1N, ×50);
(C) Felsic globular structure characterized by calcite, plagioclase feldspar and biotite (1N, ×50).

the genesis of lamprophyre-magma (separation of co-magmatic and co-genetic sequences) was slightly discussed. So far, only petrographical analyses were performed on the lamprophyre bodies (Herbich, 1871; Berwerth, 1905; Mauritz, 1912; Mauritz, Vendl, Harwood, 1925; Vendl, 1926; Streckeisen, 1954; Streckeisen, Hunziker, 1974; Anastasiu, Constantinescu, 1982; Jakab, 1998), hence, the petrological and petrotectonical interpretation of these rocks would be highly contribute to the understanding of DAM's genetics. This paper presents the results of petrographical and preliminary major element geochemical analyses performed on the lamprophyre rocks from the northern part of DAM.

Geological setting

DAM is situated in the S-SW part of the Giurgeu Alps belonging to the Eastern Carpathians (Romania). Diameter of its surface is 19 km in NW-SE and 14 km in SW-NE directions, respectively; its area is 225 km^2, including the bordering zones as well. This body intruded into the central crystalline unit of the Eastern Carpathians which is petrologically very complicated allochtonous body divided into tectonic units of E-NE dip, and it has a complex form (Pál-Molnár, 1994). The DAM is considered to represent an intrusion body with an internal zonal structure, which was emplaced into pre-Alpine metamorhpic basement complexes of the Bucovinian Nappe Complex. These metamorphics were involved in several nappe structures that are cut by the DAM and were welded by its thermal contact aureole. The center of the DAM was formed by nepheline syenite, which is surrounded by syenite and monzonite. The northwestern and northeastern parts are composed of hornblendite, diorite (called Tarnica Complex, Pál-Molnár, 2000), monzonite and alkali granite. All these rocks are cut by late-stage lamprophyre dykes.

Sampling and analitical methods

The studied rocks (55 samples) were collected from natural outcrops at the northern part of Jolotca Creek. The optical analyses were performed by NIKON Microphot-FXA polarizing microscope. The major element composition of the samples representing the main lamprophyre types were determined with ICP-MS at the University of Graz.

Petrography

The 20–40 cm wide lamprophyre dykes are bounded sharply from the wall rock. The fine-grained rocks are greenish grey to dark grey colour and have a hypocrystalline, porphyritic and panidiomorphic texture with phenocrysts of amphibole, biotite, clinopyroxene and garnet. The microcrystalline groundmass is composed of amphibole, plagioclase feldspar ±biotite, ±carbonate, ±quartz, ±glass (Fig. 1a, b). Accessories are titanite, apatite and opaque minerals. Felsic globular structures are very typical in all lamprophyre types. The mineral composition of these structures are both carbonatic and feldspathic (Fig. 1c). Lamprophyres are characterized by the following secondary minerals: amphibole (after pyroxenes), chlorite, carbonate, epidote, sericite, limonite and opaque components. Carbonate and epidote veins penetrate the rocks.

wt%	AL (1)	AL (2)	AL (3)	AL (4)	AL average	CAL (1)	CAL (2)	CAL (3)	CAL (4)	CAL average
SiO_2	43.90	46.70	44.70	45.60	41.90	53.50	55.50	55.10	54.20	51.50
Al_2O_3	15.60	15.10	15.70	14.90	13.70	21,00	19.80	19.30	20.50	14.00
TiO_2	4.00	4.00	3.90	4.00	3.00	1.20	1.30	1.20	1.10	1.30
FeO_t	13.20	12,00	12.80	11.70	10.90	5.20	4.90	5.00	5.10	7.40
MgO	6.60	5.20	6.10	5.70	7.20	2.70	2.30	2.40	2.50	6.90
MnO	0.25	0.24	0.26	0.24	0.21	0.16	0.13	0.13	0.15	0.15
CaO	4.70	5.00	4.80	5.10	10.60	2.60	2.60	2.80	2.90	6.60
Na_2O	3.10	3.40	3.20	3.60	3.20	4.30	4.30	4.20	4.10	2.70
K_2O	2.90	1.90	2.60	2.20	2.30	5.60	5.70	5.70	5.50	3.80
P_2O_5	0.78	0.98	0.84	0.93	0.85	0.22	0.22	0.26	0.28	0.71
Total	95.03	94.52	94.9	93.97	93.86	96.48	96.75	96.09	96.33	95.06

FeOt – as total iron; AL – alkaline lamprophyre; CAL – calc-alkaline lamprophyre; AL and CAL average (Rock, 1987)

Tab. 1. Representative chemical analyses of lamprophyres from the northern part of Jolotca Creek (DAM, Romania)

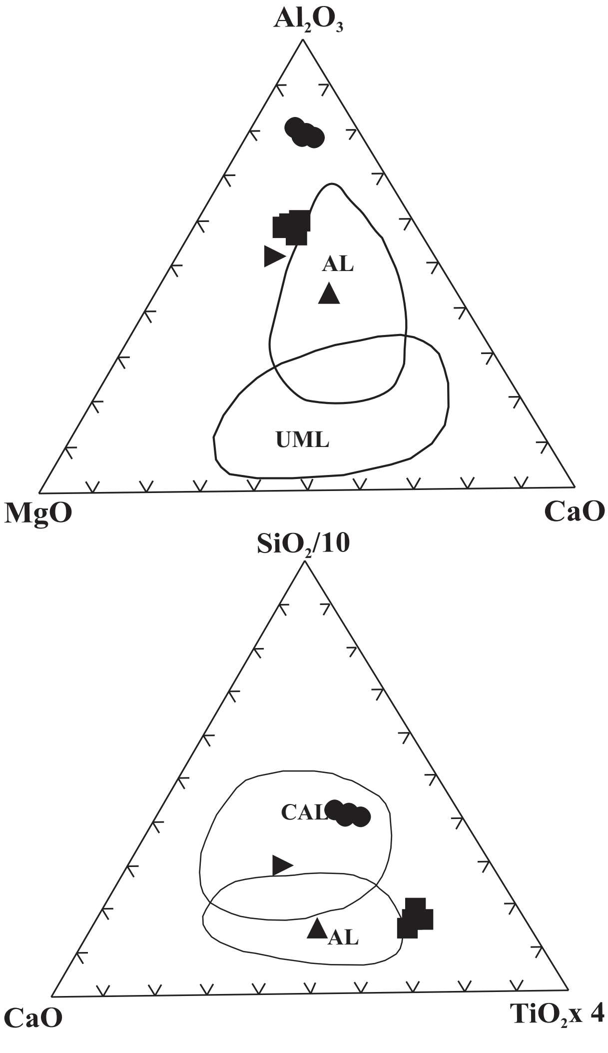

Fig. 2. Simple plots discriminating the whole-rock compositional fields of lamprophyres (Rock, 1987). ■ AL (camptonites) from the northern part of Jolotca Creek; ● CAL (spessartites) from the northern part of Jolotca Creek; ▲ AL average (Rock, 1987); ► CAL average (Rock, 1987); UML – ultramafic lamprophyres.

Preliminary geochemistry

Based on their major element composition the investigated samples (Table 1) can be classified in two groups. The first group (Fig. 2a) has Na_2O content similar to that of average alkaline lamprophyres (camptonites) (Rock, 1987). The high Al_2O_3 and K_2O content of the second group indicates a calc-alkaline (spessartitic) affinity (Fig. 2b), whereas their sodic nature is characteristic of alkaline lamprophyres and the concentration of Al_2O_3 is much higher than the average CAL (Rock, 1987). Both groups have lower CaO contens as the average alkaline and calc-alcaline lamprophyres.

Conclusion

The 20–40 cm wide lamprophyre dykes and dyke swarms intersect all the rock types of the DAM. The studied rocks have porphyritic and panidiomorphic texture with phenocrysts of amphibole, biotite, clinopyroxene, garnet and felsic globular structures. They are alkaline (camptonite) and calc-alkaline lamprophyres (spessartite), accordingly these rocks are the last stage of the magmatic evolution of the DAM.

Acknowledgements

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Petrography and Geochemistry of Granitoids from South Part of Strzelin Crystalline Massif (SW Poland)

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The Strzelin Crystalline Massif represents an isolated fragment of the Variscan basement exposed in the southern part of Fore Sudetic Block (SW Poland). The igneous rocks represented by granodiorites, quartz diorites and tonalites, biotite granites (347 ± 12 Ma) and two mica granites (of 330 ± 6) form small bodies, mostly stocks and flat dykes within metamorphic rocks (Oberc-Dziedzic, 1991, Oberc-Dziedzic et al., 1996). Crystalline rocks usually occur as small exposures therefore many important information about history of the Massif must be obtained from borehole material. This paper focuses on rocks from five boreholes in southern part of the Massif.

Several types of granitoids were distinguished according to drill documentation. Detailed observation led to simplified division into three types of granitoids: (1) granodiorites (dominating type) and subordinate (2) tonalites and (3) two mica granites.

Granodiorites are medium- to coarse-grained and locally exhibit parallel alignment of minerals. They consist of quartz, plagioclase, K-feldspar, biotite, amphibole and accessory apatite, titanite and zircon. Plagioclases are commonly normally zoned (45% An in the core to 25% An in the rim) with slight oscillations. Inner parts of the cores are often strongly altered. Small inclusions of biotite occur in the mantles. Several grains exhibit different zonation style with reversly zoned cores (30% An in the inner core and 51% An in outer core) and constant anorthite content in the mantle (27%–30% An). Mafic minerals (biotite and amphibole) occur as aggregates or as individual grains. Biotite is characterized by slight decrease of Al^{IV}, Ti and $Mg/(Mg+Fe^{tot})$ from the cores towards the rims. Amphibole grains consist of Fe-hornblende and Mg-hornblende cores and thin actinolite rims.

Tonalites are fine- to medium-grained, consist of plagioclase, quartz, biotite, amphibole, K-feldspar and apatite, titanite and zircon as accessories. Large grains of plagioclases are characterized by complex zonation. The poor in anorthite (29–33%) cores are surrounded by mantles richer in anorthite (43%). Anorthite content decreases again towards the rim to 28%. Small plagioclases are normally zoned from 39% An to 33% An. Biotites form large aggregates up to 4 mm. Al^{IV} in biotites increases from the cores to the rims by 0.2 in average. Slight increase in Ti content is also noted in the same direction. Amphiboles consist of Fe-hornblende cores, Mg-hornblende mantles and strongly enriched in Mg-hornblende rims.

The granites are fine-grained and consist of quartz, K-feldspar, plagioclase, muscovite and biotite.

Investigated granitoids are mostly calcic, metaluminous with positive correlation between aluminium saturation index (molar $Al_2O_3/(CaO+K_2O+Na_2O)$) and SiO_2 (% wt) content. They show 'normal' variation trends of decreasing MgO, Fe_2O_3, CaO, MnO, TiO_2 and P_2O_5 with increasing SiO_2. K_2O increasing together with SiO_2, whereas Na_2O and Al_2O_3 show a relatively large scatter with no evident trends. Granitoids have relatively high abundances of Yb, low abundances of Sr and low values of Sr/Y, Sr/Nd, Zr/Y and $(Tb/Yb)_N$. Negative correlation is noticeable between SiO_2 and V, whereas SiO_2, Sr, Ba and Y content are not mutually dependent. There is also positive correlation between SiO_2 and Rb.

Chondrite-normalized rare earth element (REE) patterns are characterised by moderate concave-upward shapes with relatively low negative Eu anomaly. The magnitude of the negative Eu anomaly is not dependent on the SiO_2 content.

Conclusions

Only scarce contacts between granodiorites and tonalites were found but structural characteristics of both rocks together with previously described relationships (Oberc-Dziedzic personal communication) indicate that tonalite forms veins crosscutting granodiorite. Two-mica granite crosscuts granodiorite and is supposedly the youngest rock type as it was described from field relations and dating in other parts of Strzelin Crystalline Massif (Oberc-Dziedzic et al., 1996, Oberc–Dziedzic, 1999).

Normal zonation in type I plagioclases from granodiorite and crystallization of biotite and amphibole after plagioclase (structural evidence) indicates their crystallization in steadily cooled magma body progressively enriched in water (e.g. Naney, 1983). Occurrence of second scarce type of plagioclase grain