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**AMPHIBOLITES AND METABASITES
FROM THE IZERA BLOCK, WEST SUDETES**

INTRODUCTION

The Karkonosze-Izera massif situated in the West Sudetes is typically associated with the Saxothuringian domain (e.g. Mazur, 2002 and references therein) and has been differently subdivided by the authors (see the review in: Mierzejewski and Oberd-Dziedzic 1990, Mazur and Aleksandrowski 2001). The majority of the massif is built by the Izera-Kowary unit considered as the lowermost of four lithotectonic units (Mazur, 1998) enveloping the Karkonosze granite (329 ±17 Ma, Duthou et al. 1991). The northern part of the Izera-Kowary unit situated to the north of the Karkonosze granite, known as the Izera block, is basically composed of the lower Palaeozoic granite-gneisses and granites (ca. 500 Ma; Borkowska et al. 1980, Oliver et al. 1993, Korytowski et al. 1993, Kröner et al. 2001) as well as of metapelites (mica schists). These are segregated into four, W-E trending narrow belts regarded as remnants of a Neoproterozoic envelope of the former ones (Aleksandrowski et al. 2000). Metabasites and amphibolites abundantly outcrop within the Izera block. Metabasites, indisputably of igneous origin, form dykes and veins usually steeply (60-90°) plunging to the north, mostly concordant with the foliation and display different degrees of deformation (Nowak 2000, 2001), while amphibolites devoid of any primary textures and structures appear as discontinuous layers, intercalations and lenses within metapelitic rocks. Both metabasites and amphibolites were only but petrographically studied (e.g. Kozłowska 1971, Kozłowski 1974, Szałamacha and Szałamacha 1974, Smulikowski 1972, Żaba 1985) and only single, chemical analyses of bulk rocks were published (e.g. Żaba, *op. cit.*, Klimas-August 1990, Kotowski 1971). Recently, Ilnicki (1998, 2000, 2001, 2002 this volume), Ilnicki and Rozenek (1996), Nowak (1997, 2000, 2001) and Seston et al. (2000) presented results of geochemical and petrological research devoted to these rocks.

PETROGRAPHY

Metabasites could be divided into three groups (Ilnicki, 2000): 1) medium- to coarse-grained metagabbros (veins up to 20-30 m in thickness), 2) fine-grained

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metadolerites (0.2-0.3 m to 1.5 m thick; types 1 and 2 both concordant with foliation of the host Ižera granite-gneisses), 3) fine and medium-grained low-metamorphosed basites (up to 3 m thick), discordant with foliation of host rocks.

As a matter of fact, metagabbros and metadolerites are very similar in their textures and structures, mineral composition and metamorphic grade differing substantially in the size of crystals only. Both groups underwent deformation that partly or totally obliterated primary magmatic structures producing mylonitic and blastomylonitic textures. On the contrary, the third group of metabasites is markedly distinguished by the lack of deformation and the relation to the country rocks as well as its modal composition and metamorphic grade.

All types of metabasites are composed of amphibole (brown, colourless, pale-green to blue-green varieties), plagioclase, chlorite, biotite, apatite and quartz in varying proportions. Relics of magmatic clinopyroxene (augite, diopside) as well as epidote, calcite and Fe-oxides are also found. Primary pyroxene has been to different degrees replaced by brown, kaersutitic amphibole which in turn has been overgrown or replaced by colourless actinolite and green Mg-hornblende, both of metamorphic origin. In metagabbros and metadolerites prisms or fibres of blue-green Fe-tschermakite or edenite rim such aggregates. Arrangement of subhedral plagioclase crystals gives the metabasites subophitic and ophitic texture thus indicating their magmatic origin. The mineral is strongly sericitized and saussuritized. The latter process is particularly well advanced in the cores of crystals that yield labradorite composition, whereas the rims (albite and oligoclase) are free of any secondary changes. It is assumed that these outer parts of plagioclase crystals are product of recrystallisation in metamorphic conditions. Presence of biotite, chlorite and sphene is most often ascribed to retrogressive changes of, respectively, amphibole and ilmenite.

Low-metamorphosed basites constitute vertical veins discordant with the foliation of the Ižera gneisses. Apart from the lack of substantial deformation, they are basically characterized by the dominant role of plagioclase over amphibole, better preservation of primary clinopyroxene (augite) than in metagabbros and metadolerites, presence of K-feldspar and fairly abundant chlorite. Metamorphic amphibole replacing brown kaersutite or augite has not reached tschermakite composition, yielding only actinolite–to–Mg-hornblende composition. Plagioclase composition is similar as in two other groups of metabasites, with the exception for the rims that yield albite composition only.

Amphibolites are composed of green and blue-green amphibole, plagioclase, quartz, ilmenite and minor chlorite, biotite, garnet. Sporadically epidote, apatite, sphene and pyrite appear. In one sample corundum partly replaced by kyanite was found (Ilnicki and Rozenek, 1996). The rocks display fairly distinct foliation and mineral lineation which resulted from deformation and recrystallisation during metamorphism thus leading to erasure of primary, presumably magmatic structures and textures. Subhedral to euhedral amphibole crystals along with its rounded, yet subordinate in number, xenoblasts contribute to the granoblastic and nematoblastic structure of amphibolites. Due to numerous intergrowths of quartz, ilmenite, plagioclase and epidote in amphibole crystals, poikiloblastic structure of

the rocks is frequently observed. Also blasts oblique to the foliation with their inclusion trails parallel to it are also present. Amphiboles have the composition of tschermakite, Fe-tschermakite or Fe-pargasite (X_{Mg} 0.40-0.50) in the core and Mg-hornblende (X_{Mg} 0.50-0.70) at the rims. Plagioclase blasts are smaller than amphiboles and together with quartz, ilmenite, apatite and other minerals they make up the groundmass of the rock. Most often plagioclases are not twinned and yield oligoclase/andesine composition in the core and andesine/labradorite at the rims. Sporadically, blasts of the mineral are partly replaced by sericite and epidote. Rare garnet crystals not exceeding 1.2 mm in diameter are surrounded by small pressure shadows filled with quartz and amphibole. Inclusions of quartz, ilmenite, epidote and sphene form linear or undulose trails parallel to the foliation of the rock. Likewise plagioclase and amphibole, garnet blasts developed zonation of chemical composition reaching $Alm_{55}Sps_{15}Pyr_5Grs_{25}$ in the core and $Alm_{64}Sps_5Pyr_5Grs_{26}$ at the rims. Chlorite and sphene are of secondary origin replacing amphibole/post-amphibole biotite and ilmenite, respectively.

GEOCHEMISTRY

The majority of samples plots on the fields of alkaline and subalkaline basalts on the Zr/TiO₂ vs Nb/Y diagram of Winchester and Floyd (1977), therefore amphibolites, metagabbros and metadolerites are classified as mildly alkaline, transitive to tholeiitic rocks (Ilnicki 2000, Nowak 1997, Seston et al. 2000, Winchester et al. 1995). Only the samples of low-metamorphosed basites (andesites *sensu* Nowak 2000) have the composition typical for andesites and ryodacites/dacites. Major elements data and concentration of most compatible and incompatible trace elements suggest that metagabbros, metadolerites and amphibolites were co-magmatic and the process of fractional crystallisation of probably olivine, pyroxene and plagioclase shaped their parental magma composition. Smooth lines of REE diagrams, linear trends on binary plots of pairs of incompatible elements prove the absence of substantial mobility of trace elements in metamorphic conditions. High LREE-to-chondrite ratios point to enriched, asthenospheric source of magma. Whereas low abundances of HREE in some samples are indicative of presence of residual garnet that could have been removed from the source due to the increasing degree of partial melting. Multi-element diagrams (spider diagrams) for metagabbros, metadolerites and amphibolites provide further evidence for derivation of the parental magma from enriched, OIB-like asthenospheric source and subsequent, crustal contamination-free emplacement of the rocks in within-plate environment. Moreover, position of these rocks on discrimination diagrams of Holm (1985), Cann and Pearce (1973), Pearce and Gale (1977) Pearce and Norry (1979), Meschede (1986) and Mullen (1983) is typical for the alkaline and tholeiitic rocks generated in an environment typical for initial (abortive) rift at the continental margin. Despite the lack of determinations of isotopic age of the Izera metabasites, it is supposed that the formation of these rocks was brought about by early Palaeozoic Gondwana break-

up that is widely reported for the Karkonosze-Izera block and West Sudetes alike (e.g. Patočka and Smulikowski 1998, 2000).

Low-metamorphosed basalts are to some extent different geochemically than the rest of the Izera metabasites. Although the REE and multi-element diagrams are typical for rocks of within-plate affinity formed from enriched, asthenospheric source, they exhibit distinct features typical for contamination with crustal material. Also their position on Harker diagrams is conspicuous by sticking out of trends created by the other metabasites. Therefore there is possibility that low-metamorphosed basalts originated in somewhat different geotectonic situation and are not co-magmatic with the rest of the Izera metabasites.

METAMORPHISM

Metamorphism and concurrent deformation of the protolith of amphibolites and metabasites led to numerous changes in their modal and mineral composition. Primary metamorphic assemblage (augite/diopside + labradorite ± olivine + ilmenite) has been completely or almost completely replaced by minerals of metamorphic origin. Textural and mineral composition data enabled recognition of distinct mineral assemblages corresponding to the appropriate stages of changing conditions of metamorphism, which in turn allowed calculation of their temperatures and pressures (for details of geothermobarometric calculations see Ilnicki 2000).

First stage of metamorphism M_1 under greenschist facies conditions ($T = 460^\circ\text{C}$) is documented mainly in metagabbros and metadolerites by actinolite + albite assemblage. Second stage M_2 ($T: 540\text{-}570^\circ\text{C}$, $P: 6.7\text{-}8.3$ kbar; epidote-amphibolite facies conditions) is recorded by the assemblage (Fe-)tschermakite + oligoclase/andesine ± garnet $\text{Alm}_{55}\text{Sps}_{15}\text{Pyr}_5\text{Grs}_{25}$. In amphibolites it is preserved in cores of blasts, while in metagabbros and metadolerites as rims of amphibole aggregates and plagioclase crystals. Third stage M_3 ($T: 600\text{-}615^\circ\text{C}$, $P = 5$ kbar) is ascertained in due to the assemblage Mg-hornblende + andesine ± garnet $\text{Alm}_{64}\text{Sps}_5\text{Pyr}_5\text{Grs}_{26}$ preserved in amphibolites at the rims of blasts and in a few samples of metadolerites as well. Fourth stage M_4 was a retrogressive one resulting in biotitisation of amphibole and chloritisation of both biotite and amphibole, crystallisation of sphene at the expense of ilmenite and sericitisation and saussuritisation of plagioclase.

Low-metamorphosed basites (“meta-andesites”) were distinguished not only according to their geochemical features but also by much weaker conditions of their metamorphism. The only metamorphic assemblage found in these rocks (actinolite/Mg-hornblende + albite + chlorite) is indicative of merely greenschist facies conditions what was confirmed by calculations of T and P values, 445°C and 2 kbar, respectively. Moreover, it may be assumed that these conditions, apparently corresponding to the retrogressive M_4 stage recorded by the majority of amphibolites and metabasites, combined with the absence of deformation of these rocks suggest that they are relatively young and appeared during late phases of metamorphic evolution of the Izera block.

At final stages of metamorphic evolution (M_3 - M_4) amphibolites and metabasites were probably thermally affected by the Karkonosze granite (Ilnicki 2001). In the extreme case of this thermal influence (contact zone) the HT/LP cummingtonite + anorthite assemblage appeared (Ilnicki 2002, this volume).

CONCLUSIONS

Amphibolites and metabasites of the Izera block display several features that prove their OIB-like, enriched asthenosphere affinity and formation in within-plate environment of a continental rift. Chemical evolution of their parental magma and concentration of trace elements are inconclusive for attaining the more mature stage of the rift thus providing evidence for its abortive (initial) character (?failed rift). Despite the lack of radiometric data the appearance and emplacement of the protolith of amphibolites, metagabbros and metadolerites could have been coeval with the Gondwana break-up, so widespread in the Variscan structures of Central Europe. Subsequent polyphase metamorphic evolution of the Izera block resulted in the clockwise P-T path. The first progressive stages (M_1 - M_2) of MP/MT metamorphism could be associated with crustal thickening and compression (D_1) within the Karkonosze-Izera block suggested by Mazur and Kryza (1996; see also Mazur 2002, this volume), whereas the LP/HT stage (M_3) with the extensional phase D_2 of gravitational collapse. Rather steep shape of the P-T path caused by pressure decrease of 2-3 kbar and slight increase of temperature of about 50°C between M_2 and M_3 may be due to relatively rapid exhumation of the whole structure. The following retrogressive stage (M_4) was the final episode recorded by metabasites and amphibolites. Locally, however, the emplacement of the Karkonosze granite influenced the rocks in question and along the northern contact zone thermal metamorphism partly or totally overprinted their assemblages of previous regional metamorphism stages.

Geochemical and petrological distinctiveness of low-metamorphosed basites ("meta-andesites") points to their different genesis as compared to the rest of amphibolites, metagabbros and metadolerites. Tentatively, it may be concluded that low-metamorphosed basites were the product of late-orogenic or even post-orogenic magmatism within the Karkonosze-Izera block, the phenomenon that is also evidenced in the other parts of the Bohemian massif (Neubauer et al. 1999, Marheine et al. 1999).

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