Petrochemical and geotectonic characteristics of amphibolites from the Zagorje-Mid-Transdanubian shear zone (Mt. Kalnik, Croatia)

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Mt. Kalnik is located at the southwestern tip of the Zagorje-Mid-Transdanubian shear Zone and is largely composed of ophiolite mélange (i. e. the Kalnik Unit) which discontinuously extends to the SW into the Medvednica Mts. Conodont paleontology in sedimentary cover overlying MORB-type pillow lavas from the mélange suggests Illyrian-Fassanian to Bathonian-Early Callovian age of top-most layers of relict oceanic crust (GORIČAN et al., 2005). The Kalnik Unit originated from a trench accretionary prism setting during the Middle Jurassic to Hauterivian as indicated by palynomorph assemblages documented in the mélange matrix (BABIĆ et al. 2002). Remnants of an intraoceanic arc is recognised in the greenschist facies metabasites of the Medvednica Mts. obducted onto Adria platform in the Early Cretaceous (LUGOVIĆ et al., in review) implying the existence of an island arc during Middle Jurassic to Hauterivian time. Amphibolites were sampled from the scarce outcrops representing a few meters thick slices composed of amphibolites and overlaying serpentinised mantle peridotites, and from amphibolite-bearing debris of the nearby streams. These slices were tectonically emplaced within Upper Cretaceous-Paleogene sedimentary succession.

Amphibolites, previously assumed as blocks of ophiolite mélange (PAMIĆ, 1997) are fine- to medium-grained, well foliated with nemathoblastic texture. Primary assemblage comprises light green amphibole, plagioclase, accessory titanite and apatite ± garnet ± clinopyroxene ± zoisite-clinozoisite. Retrograde paragenesis consists of epidote, zoisite-clinozoisite, titanite, chlorite and actinolite. Reaction rim around remnant garnet cores and patches comprises albite ($An_{0.1\text{-}0.3}$), actinolite, chlorite and quartz. The mineral paragenesis deciphers an amphibolite to lower granulite facies prograde metamorphic event followed by a greenschist facies retrograde metamorphism. The amphibolites overlain by serpentinites are sheared and show penetrative deformation, all others are undeformed. Lenses and veins filled by calcite and prehnite are common in the deformed amphibolites. All characteristics allow us to interpret these amphibolites as sub-ophiolite metamorphic sole.

Clinopyroxene is homogeneous ferroan diopside with $Mg/(Mg+Fe^{2+})$ ratio around 73.5. A*mphibole* representing peak-metamorphism displays wide compositional range stretching from Ti-rich (0.037-0.195 i.p.f.u.) through magnesio-hornblende and tschermakite to pargasite. *Plagioclase* ranges in composition from $An_{29.8}$ to $An_{48.6}$. The *garnet* is almandine rich ($Pyp_{10.8\text{-}19.7}Alm_{52.1\text{-}56.7}Sps_{2.9\text{-}8.4}Grs_{16.5\text{-}25.0}$) and shows prograde compositional variation across the grains. *Epidotes* have the range of $100{*}Fe^{3+}/(Fe^{3+}+Al^{VI})$ ratios between 14.3 and 23.8, and show the highest values in the secondary assemblages indicating high oxygen fugacity during the retrogression. High grade *titanites* have abundant Ti (up to 0.957 i.p.f.u.) apart from the retrograde compositions (around 0.777 Ti i.p.f.u.).

Peak equilibrium temperatures of the Mt. Kalnik amphibolites were estimated for rim to rim compositions of coexisting minerals using different geothermometers. The geothermometers based on coexisting amphibole-plagioclase pairs in silica-saturated systems calibrated by SPEAR (1980) and DALE et al. (2000) and on garnet-clinopyroxene Fe-Mg exchange equilibrium introduced by KROGH (1988) have given the most consistent results. Pressure estimation was performed by the geobarometers calibrated by SCHMIDT (1992) and DALE et al. (2000). The results are summarised in the Table 1. All results correspond to peak values except for the garnet-clinopyroxene temperatures which are significantly lower than would be the maximum temperature due to consumed garnet periphery.

Table 1. Summarised results of thermobarometric estimations for the Mt. Kalnik amphibolites

Sample	Protolith	SCHMIDT P GPa	SPEAR T °C	DALE et al. P GPa; T °C	KROGH T °C
KB	IAT	1.05 ± 0.06	-	-	-
KD	BARB	0.59 ± 0.04	580 ± 100	-	-
KF	BARB	0.70 ± 0.08	600 ± 100	0.88 ± 0.02; 620 ± 50	680 ± 10

Amphibolites from the Mt. Kalnik originated from igneous mafic protoliths. REE patterns of the amphibolites and their plots in discrimination diagrams decipher geochemical affinity of the back-arc ridge basalts (BARB) and tholeiitic island arc mafic magmas (IAT), respectively. Spidergrams of the arc related magmas reveal geochemical signatures similar to MORB but show slight flavour of subducted slab fluids recorded by negative Ta-Nb and other HFSE anomalies. Some IAT samples show strong positive Eu anomaly suggesting that cumulate rocks were also involved in the metamorphism.

In the absence of clear field relations between the amphibolites and other rocks from the Kalnik Unit we use the geochemical data as plausible substitute. Overall signatures of the protoliths indicate two geochemical types of metamorphic sole which were formed in a suprasubduction setting. We suppose that subduction was initiated by detachment of oceanic lithosphere at the slow rate back-arc spreading ridge. The hot oceanic crust was heated by the overridden mantle sequence peridotites to form the high grade amphibolites of tholeiitic BARB affinity. Closely latter, the peridotites were obducted over an active or a while ago dormant intraoceanic magmatic arc yielding metamorphic sole amphibolites with IAT geochemical signatures. The greenschist facies metamorphic overprint of the metamorphic sole took place during the exhumation of composite peridotite-metamorphic sole slices before their emplacement into continental margin Upper Cretaceous-Palaeogene sedimentary succession. Proposed geodynamic model implies the existence of a separated marginal basin during the Early Cretaceous located more to the north from the Central Dinaridic oceanic strand. On account of overall characteristics of the metamorphic sole the correlation between these two oceanic domains seems not viable since the protoliths of metamorphic sole from the Central Dinaridic Ophiolite Belt show exclusively MORB affinity and were metamorphosed around 172 Ma ago (OLKER et al., 2001).

References

BABIĆ, Lj., HOCHULI, A.P. & ZUPANIČ, J. (2002): The Jurassic ophiolitic mélange in the NE Dinarides: Dating, internal structure and geotectonic implications.- Eclogae geol. Helv., 95, 263-275.

DALE, J.; HOLLAND, T. & POWELL, R. (2000): Hornblende-garnet-plagioclase thermobarometry: a natural assemblage calibration of thermodynamics of hornblende.- Contrib. Mineral. Petrol., 140, 353-362.

GORIČAN, Š., HALAMIĆ, J., GRGASOVIĆ, T. & KOLAR-JURKOVŠEK, T. (2005): Stratigraphic evolution of Triassic arc-backarc system in northwestern Croatia.- Bull. Soc. géol. Fr., 176, 3-22.

KROGH, E. J. (1988): The garnet-clinopyroxene Fe-Mg geothermometer - a reinterpretation of existing experimental data.- Contrib. Mineral. Petrol., 99, 44-48.

LUGOVIĆ, B., ŠEGVIĆ, B. & ALTHERR, R. (in review): Petrology and tectonic significance of greenschists from the Medvednica Mts. (Sava unit, NW Croatia).- Ofioliti.

OLKER, B., ALTHERR, R. & LUGOVIC, B. (2001): Metamorphic evolution of mafic granulites from the metamorphic sole of Central Dinaric Ophiolites (Bosnia-Herzegovina). EUG XI Meeting, 8-12 April 2001, Strasbourg, France, Abstracts, 321-322.

PAMIĆ, J. (1997): The northwesternmost outcrops of the Dinaridic ophiolites: a case study of Mt. Kalnik.- Acta Geol. Hungar., 40, 37-56.

SCHMIDT, W. M. (1992): Amphibolite composition in tonalite as a function of pressure: an experimental calibration of the Al-in-hornblende barometer.- Contrib. Mineral. Petrol., 110, 304-310.

SPEAR, F. S. (1980): NaSi-CaSi exchange equilibrum between plagioclase and amphibole.- Contrib. Mineral. Petrol., 72, 33-41.