NEW DATA ON THE LOW-TEMPERATURE METAMORPHISM OF MT. MEDVEDNICA AND THE SLAVONIAN MTS. (CROATIA)

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Abstract: Preliminary results of complex mineral paragenetic, illite and chlorite "crystallinity", K-white mica geobarometric and microstructural studies proved that the Late Jurassic–Early Cretaceous ophiolitic mélange and the Late Cretaceous–Paleocene sequence of Mt. Medvednica are diagenetically altered, the Paleo–Mesozoic complex of Mt. Medvednica is anchimetamorphosed, whereas the Paleozoic Radlovac Formation is affected by very low- to low-grade regional metamorphism (high anchizone and epizone).

Key words: illite "crystallinity", chlorite "crystallinity", K-white mica geobarometry, diagenesis, low-temperature metamorphism, Croatia

Introduction

The bilateral collaboration between the Laboratory for Geochemical Research, Hungarian Academy of Sciences and the Croatian Academy of Sciences and Arts has started in 2001. The aim of this project is to reveal the possible relations between the low-temperature metamorphic Paleo-Mesozoic sequences of North Hungary and North Croatia. This contribution presents the first, preliminary results of this on-going research project. For this case, pioneering field work coupled with collection of representative samples was carried out in North Croatia in spring 2001. Complex mineral paragenetic, illite and chlorite "crystallinity", white mica geobarometric and microstructural studies were performed in order to determine the diagenetic and metamorphic conditions of the Late Jurassic–Early Cretaceous ophiolitic mélange, the Late Cretaceous–Paleocene sequence and the Paleo–Mesozoic complex of Mt. Medvednica and the Silurian to (?) Early Carboniferous Radlovac Formation in the Slavonian Mts.

Geological setting and previous data on metamorphism

Mt. Medvednica

The Zagorje–Mid-Transdanubian Zone (ZMTZ) situated in the triple junction of the Dinaridic, Alpine and Pannonian units has complex structural features. Its northern and northwestern boundary is the Periadriatic-Balaton Lineament, the Zagreb-Zemplén Lineament is considerd to be its southeastern boundary, while in the south it is bordered by the north-northeastern margin of Adriatic-Dinaridic carbonate platform (i.e. the External Dinarides) - (Pamić & Tomljenović, 1998). Mt. Medvednica is one of the few outcrops within ZMTZ composed of four pre-Neogene tectono-stratigraphic units. Representative samples from the following units were studied: (1) Middle Jurassic–Early Cretaceous ophiolitic mélange; (2) the Paleo–Mesozoic complex i.e. Eoalpine (122-110 Ma) very low- to low-grade metamorphic complex; and (3) Late Cretaceous–Paleocene overlying sequence. The Middle Jurassic–Early Cretaceous ophiolitic mélange is characterized mainly by sheared shaly-silty matrix, containing fragments of ophiolites, graywackes, radiolarites, shales and limestones. The age of radiolarite fragments is considered to be Late Ladinian–Late Carnian (Halamić & Goričan 1995) and Jurassic (Halamić et al. 2000) based on radiolarite biostratigraphy. Diabase and gabbro samples gave Early to Middle Jurassic (189-185 Ma) and Early to Late Cretaceous (110-66 Ma) K/Ar whole rock apparent ages (Pamić 1997a, b). The very low- to low-grade metamorphic complex is built up by greenschists, metagraywackes, slates, phyllites, marbles, recrystallized dolomites, metaconglomerates and quartzites. Biostratigraphic data based on conodonts and graptolites indicate Silurian to Late Triassic age of the protolith (e.g. Đurđanović, 1973; Sremac & Mihajlović-Pavlović, 1983). Muscovite concentrates separated both from metamorphic rocks gave Eoalpine (122-110 Ma) K-Ar ages (Belak et al., 1995). The Late Cretaceous–Paleocene alluvial-fan to turbiditic overlying sequence starts with red, poorly sorted, alluvial to delta-fan conglomerates and *Inoceramus*-bearing sandstones and shales (Crnjaković, 1979). Upwards this sequence grades into grey-green to red, Late Campanian and Maastrichtian hemipelagic biomicrites (Scaglia-type). The biomicrites are overlain by calcareous turbidites and carbonate megabreccias grading into calcareous and siliciclastic turbidites of Paleocene age.

Slavonian Mts. (Radlovac Formation)

The Slavonian Mts. represent the largest outcropping crystalline complex in South Tisia consisting of different Variscan sequences. The Silurian to (?) Early Carboniferous

Radlovac Formation is one of the units having questionable origin and relation to the other, mostly medium- to high-grade Variscan units of the Slavonian Mts. The Radlovac Formation is composed of predominantly slates, phyllites and schistose metasandstones with subordinate quartzites intruded by diabase and gabbro sills (Pamić & Jamičić 1986). The formation was affected by low-temperature metamorphism indicated by the presence of pyrophyllite and paragonite, while b values of "white mica" point to low to intermediate pressure “facies” of the greenschist facies (Pamić and Lanphere 1991).

Petrography and XRD results

Mt. Medvednica

(1) Middle Jurassic–Early Cretaceous ophiolitic mélange

The *shales* of the matrix of the ophiolitic mélange complex contain dominantly quartz, illite-muscovite, chlorite, plagioclase and subordinately rutile. The shales are foliated, moreover the presumably bedding (sub)parallel foliation a second, closely spaced, oblique foliation is also developed. The *marls* with subordinate dolomite content contain quartz, illite-muscovite, chlorite, plagioclase and/or rutile and large (0.2-1 cm thick) calcite intraclasts and echinoderm fragments as well. The marls are also foliated, beside the supposedly bedding parallel foliation a widely spaced, oblique foliation can also be seen. S*andstones* are dominantly built up by quartz grains as crystal and quartzite as lithic fragments, although detrital illite-muscovite, biotite and plagioclase can also be recognized in the samples. The cement of this rock type consists of mainly carbonate and hematite, the grains are angular and poorly sorted. *Metagabbro* fragments contain strongly chloritized clinopyroxene relicts rimmed by actinolite needles, sericitized plagioclase pseudomorphs, albite and quartz, as well as 3-4 mm thick prehnite and calcite veins. Pseudomorphs, presumably, after clinopyroxene containing dominantly chlorite are very abundant in the *metabasalts*. Chlorite, calcite, quartz and subordinate albite veins are recognized in the samples.

(2) Paleo–Mesozoic metamorphic complex

In contrast to the matrix shales, *slates* from this unit contain paragonite and show complex microstructural features. Two penetrative foliations can be observed in the slates. The first one is bedding-parallel syn-metamorphic foliation (S_1), later crenulated along axial plane cleavage (S_2). Randomly orientated, lens-shaped chlorite-muscovite aggregates are sometimes dragged into the foliaton planes. In *cipolino,* besides the mainly carbonate contained parts, phyllosilicate-rich intercalations are recognized consisting of illite-muscovite, chlorite, quartz, plagioclase and subordinate rutile. Similarly to the slates crenulation cleavage (S2) developed in the phyllosilicate-rich layers. *Greenschist* with macroscopically observable banding contains darker bands rich in actinolite-tremolite, chlorite and ilmenite (partially altered to leucoxene), and the light grey bands consisting of albite, epidote, zoisite and/or clinozoisite and quartz. Fine-grained *metasandstones* have crystal- and lithic fragment content very similar to sandstones from the mélange. The cement of the sandstones is hematitic, the grains are angular and poorly sorted.

(3) Late Cretaceous–Paleocene overlying sequence

Marly *shales* with subordinate dolomite content consist of quartz, illite-muscovite, chlorite, plagioclase and subordinate hematite. In marly shales two distinct foliations developed. The first one (S_0) is considered to be the original sedimentary bedding of the rock; layers enriched in forams, mollusc and echinoderm fragments alternate with layers having low fossil content. The second foliation is widely spaced and oblique to the sedimentary bedding.

Slavonian Mts. (Radlovac Formation)

In *slates* only one observable foliation developed in contrast to the slates from Mt. Medvednica. Moreover the 20-40 μm thick chlorite-illite-muscovite lenses, slates from the Slavonian Mts. consist of large, 2-5 mm thick, macroscopically observable chlorite-calcite, chlorite-quartz, chlorite-opaque lenses and small, 20-50 μm thick lenses of quartz and muscovite. The phyllosilicate-rich lenses are randomly orientated, while the large ones are usually dragged into the foliation. Coarse-grained *metasandstones* have variable feldspar content with quartz, illite-muscovite, chlorite, paragonite, sometimes chloritized biotite and high amount of quartzite lithic fragments. Tourmaline and zircon are accessory minerals. The cement of the metasandstones consists of mainly calcite and hematite, the grains are angular and poorly sorted. In some cases a weak foliation can be seen. *Silty sandstones,* with similar crystal and lithic fragment content to the metasandstones are foliated and contain abundant, randomly orientated muscovite-chlorite lenses similarly to the slates. *Marls* from the Radlovac Formation are foliated; this foliation is extensively folded and supposed to be (sub)parallel to the original sedimentary bedding. *Metabasalt* samples contain altered clinopyroxenes with a colourless core, weak, light-brown-brown pleochroic inner rim and colourless outer rim. Actinolite-tremolite edges the relict pyroxene crystals. Some of the clinopyroxene crystals are totally chloritized, pseudomorphs after plagioclase contain sericite, epidote, zoisite and/or clinozoisite, albite and quartz. Ilmenite partially altered to leucoxene and apatite are accessories. *Metagabbro*s contain sericitized and saussuritized plagioclase laths and altered clinopyroxene. Clinopyroxenes are chloritized and in some samples actinolite-tremolite needles rim them. In these samples altered biotite and very fine-grained epidote can also be recognized. Clinopyroxenes in some metagabbros have colourlesss core, light brown-yellowish green pleochroic inner rim and colourless outer rim. In these samples sericitized, saussuritized plagioclase laths and symplectite of quartz and plagioclase can be found.

Illite, chlorite "crystallinity" and K-white mica b cell dimension

The XRD-based illite "crystallinity" is a useful empirical parameter for determining diagenetic and incipient metamorphic grades of metasedimentary rocks containing no facies or zone indicating mineral assemblages. The term illite "crystallinity" (IC), recently abbreviated KI (Kübler index), was introduced by Kübler (1967 a.,b.; 1968). IC expresses the full width at half-maximum (FWHM) of the first basal reflection of dioctahedral illite-muscovite at 10 Å measured in º Δ2θ. Kübler index of illite "crystallinity" defines the limits of the diagenesis, anchizone and epizone. Although numerous methods have been developed measuring the first basal reflection of illite-muscovite peak profile, the method of Kübler became the most widely adopted. Kübler index, as an indicator of the metamorphic grade, ought to be used cautiously because of the many factors affecting the peak profile. Obviously the intensity of the physical and chemical weathering of the source area of the sedimentary rocks, the lithology of their original source rock types, the temperature and pressure conditions during and after the diagenesis, the lithology of the sedimentary sequence, the abundance of the detrital muscovite and its degradation state and the paragonite and the swelling component content of the illite-muscovite affect the peak profile intensively.

Illite "crystallinity" measurements were carried out on samples from the ophiolithic mélange complex, the Cretaceous–Paleocene overlying sequence and the Paleo–Mesozoic complex of Mt. Medvednica and from the Radlovac Formation of the Slavonian Mts. All of the illite "crystallinity" values obtained on samples from the mélange and from the Cretaceous–Paleocene overlying sequence of Mt. Medvednica indicate that the units are not metamorphosed, the samples are diagenetically altered (IC >0.42 ºΔ2θ). Samples from the Paleo–Mesozoic complex of Mt. Medvednica are metamorphosed, the IC values fall into the high anchizone (IC = 0.25-0.30 ºΔ2θ). Data from the Slavonian Mts. indicate that the metamorphism of the Radlovac Formation has reached the high-temperature part of the anchizone (IC = 0.25-0.30 °Δ2θ) and, in some cases also the epizone (IC < 0.25 °Δ2θ).

Chlorite "crystallinity" (ChC001 and ChC002) values were also obtained on samples from Mt. Medvednica and the Slavonian Mts. The ChC data show positive correlation to the IC data.

K-white mica *b* cell dimension was measured on samples with different lithotypes from the Radlovac Formation in order to characterize the pressure range of the very low- to low-grade metamorphic rocks. Because of the variable *b* data (8.992-9.044 Å) the determination of pressure conditions of the studied area is questionable.

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