ing to fields B and C were progressively closing from 0.1 up to 50 MPa of confining pressure. The electron back-scattered diffraction (EBSD) method showed that poles (110) of omphacite cleavage planes fit well with field B. Comparison of results from all three applied methods showed that 1) oriented microporosity characterised by field A maximum corresponds mainly to grain boundaries parallel to foliation plane, 2) field B maximum most probably corresponds to omphacite cleavage planes and 3) field C maximum corresponds very likely to intersection between two sets of cleavage planes or/and grain boundaries in the strongly linear microstructure of the sample JK1b. In the sample SNW3, the partial subtractions of P-wave velocities measured at individual pressure levels shows neither clear concentration of directions of high P-wave velocity difference values nor systematic progressive closure of microporosity in any direction. However the bulk subtraction of measured P-wave velocities between 400 MPa and 0.1 MPa shows three maxima of directions of important values of P-wave velocity differences. These maxima correspond well to orientation of clinopyroxene cleavage planes.

Results show that grain boundaries are the most important contributors to the bulk microporosity in studied rocks. The mean of ΔV_P has been calculated in order to assign the relative amount of open space and the anisotropy of P-wave velocity differences. It shows that microporosity in the sample JK1b is relatively large and strongly preferentially oriented, whereas it is significantly lower and less preferred oriented in the sample SNW3. It implies that grain size of rock forming minerals controls amount of microporosity. Also, orientation of microporosity depends mostly on preferred orientation of grain boundaries and somewhat less on orientation of cleavage planes. This study showed that experimental pulse transmission technique is useful tool for visualization of oriented microporosity in 3D and provide important basis for further study of permeability anisotropy through studied rocks.

References

PROS Z. and BABUŠKA V., 1968. An apparatus for investigating the elastic anisotropy on spherical rock samples. *Studia Geophysica and Geodetica*, 12: 192-198.

PROS Z., LOKAJÍČEK T. and KLÍMA K., 1998. Laboratory study of elastic anisotropy on rock samples. *Pure and Applied Geophysics*, 151: 619-629.

LEXA O., 2003. Numerical Approach in Structural and Microstructural Analyses. Ph.D. Thesis, Charles University Prague, Czech Republic.

Limestone Microstructures and Strain Patterns as Metamorphic Indicators of Low-Temperature Deformation in the Eastern Part of the Bükk Mountains (NE Hungary)

Ferenc MÁDAI

University of Miskolc, Dept. of Mineralogy and Petrology, H-3515 Miskolc-Egyetemváros, Hungary

The (North) Bükk Parautochton is a major tectonic unit of the Bükk Mountains, consisting its central, eastern and northern parts. It is composed of a rock sequence from Middle Carboniferous to Upper Triassic, predominantly of metacarbonates intercalated with metapelites, metapsammites and metavolcanics. The most exposed rock types are platform and basin facies limestones.

The whole sequence was affected by the Alpine dynamothermal metamorphism (e.g. Lelkes-Felvári et al. 1996). This metamorphism in the eastern part of the Bükk Mts. reached the greenschist and pumpellyite-actinolite facies, represented first of all with higher anchizonal metasediments (Árkai 2001). The metamorphic grade was determined by mineral assemblages from Paleozoic and Mesozoic metasediments and Middle Triassic metavolcanics, as well as by analytical methods such as illite crystallinity (IC) data from metapelites and metavolcanics, vitrinite reflectance from metapelites. Based on minerals, occurring in the Upper Triassic metabasalts, the maximal fluid pressure is estimated for 300 MPa, while the temperature could reach 350 °C.

The Mesozoic limestones of the Parautochton are generally neomorphosed and have medium to strong shape preferred orientation (SPO). The macro- and microscopic features show multiphase deformation. The first, recognizable deformation phase ("early phase" in Németh and Mádai 2003) is characterized by ductile forms and textures, showing cleavage ("main cleavage" in Csontos 1999) and multi-order folding on the macro-scale, SPO and other ductile strain patterns on the micro-scale. Later deformation phases resulted predominantly in brittle deformation in the limestones, however the less competent metapelites and metavolcanics could form ductile strain patterns also in later phases.

Having been an entirely ductile deformation phase, it is believed that the early deformation phase took place during the peak of the Alpine dynamothermal metamorphism (Csontos 1999, Németh and Mádai 2004). The aim of this study is to correlate the available data on metamorphism with the stress-temperature conditions of the most ductile (early) deformation phase, by means of limestone microstructure and strain pattern analyses and interpretation of foreign analogies (Groshong et al. 1984, Ferrill 1991). The investigated strain patterns comprise the type and intensity of crystal preferred orientation (CPO), development of "core and mantle" structures, as well as the width and deformation of mechanical e-twins in large calcite crystals.

The strongest deformation was detected in mylonitized limestones. These rocks occur in shear zones, their texture is characterized by "c-axis fibre type" CPO, that indicates dynamic recrystallization. Relicts of coarse, strongly-twinned crystals ("cores") flow in these rocks in the broad "mantle" of the dynamically recrystallized matrix.

Out of shear zones, the appearance of "core and mantle" structures is a general feature, too. Here the core corresponds to the strongly-twinned large crystals, while the mantle is a rim of recrystallized calcite grains with d ~ 20–30 µm size. The thickness of the mantle and the deformation style of mechanical twins depend on the intensity of shear strain. During small strain, only twins form in the large crystals, mantle does not develop. Conversely, in strongly-strained limestones a broad mantle develops around the coarse grains, which include curved and recrystallized twins. The microcrystalline matrix of these rocks shows an a-axis fibre type CPO or it lacks CPO that points to the appearance of grain boundary sliding (GBS) as the dominant deformation mechanism. Applying these strain patterns, the shear strain developed during the early deformation phase can be estimated between $\gamma = 0{,}3–5$. The latter value characterises the shear zones. The average twin-width in the coarse calcite grains exceeds 5 µm which indicates that twinning took place above 200 °C.

The results obtained from strain patterns of the coarse-grained calcite aggregates and mechanical twins in the Eastern Bükk correlates well with metamorphic grade indicators, measured directly in limestones such as Conodont Color Alteration Index (CAI) (Sudar and Kovács in press) and measured in other rock types, using mineral assemblages, IC and vitrinite reflectance data (Lelkes-Felvári et al.1996). The epizonal metamorphism correlates with strain patterns such as dynamic recrystallization, strongly developed core and mantle structures, curved and recrystallized calcite twins with at least 5 microns width. The anchizonal metamorphism correlates with dynamic recrystallization and GBS, with less-developed core and mantle structures, curved or straight twins with 3–6 microns width.

References

ÁRKAI P., 2001. Alpine regional metamorphism in the main tectonic units of Hungary: a review. *Acta Geol. Hung.*, 44: 329-344.

CSONTOS L., 1999. Structural outline of the Bükk Mts. (N Hungary). *Földtani Közlöny*, 129: 611-653. (in Hungarian with English abstr.)

FERRILL D.A., 1991. Calcite twin widths and intensities as metamorphic indicators in natural low-temperature deformation of limestone. *J. Struct. Geol.*, 13: 667-675.

GROSHONG R.H., PFIFFNER O.A. and PRINGLE L.R., 1984. Strain partitioning in the Helvetic thrust belt of Eastern Switzerland from the leading edge to the internal zone. *J. Struct. Geol.*, 6: 5-18.

LELKES-FELVÁRI Gy., ÁRKAI P., SASSI F.P. and BALOGH K., 1996. Main features of the regional metamorphic events in Hungary: a review. *Geologica Carpathica*, 44: 257-270.

NÉMETH N. and MÁDAI F., 2003. Early phase ductile deformation elements in the limestones of Eastern part of the Bükk Mts. part I. *Földtani Közlöny*, 133: 563-583. (in Hungarian with English abstr.)

NÉMETH N. and MÁDAI F., 2004. Early phase ductile deformation elements in the limestones of Eastern part of the Bükk Mts. part II. – patterns of microstructure. *Földtani Közlöny*, 134: 1-28. (in Hungarian with English abstr.)

SUDAR M. and KOVÁCS S., 2005. Metamorphosed and ductilely deformed conodonts from Triassic limestones situated beneath ophiolite complexes: Kopaonik Mt., Serbia and Bükk Mts., NE Hungary – a preliminary comparison. *Geologica Carpathica* in press.

The Miocene Transpressional Tectonics along the Pieniny Klippen Belt (Zázrivá, Western Carpathians)

František MARKO, Rastislav VOJTKO, Dušan PLAŠIENKA and Ľubomír SLIVA

Department of Geology and Paleontology, Comenius University, Mlynska dolina G, 842 15 Bratislava, Slovak Republic

Meso-Neoalpine tectonic evolution of the Western Carpathians was controlled by long lasting (Upper Cretaceous – recent) squeezing between the North European Platform and promoted the Apulia-Adria microcontinent pushed by the Africa lithospheric plate to the north. It led to the strong dominance of the north-verging tectonic structures within the Outer Western Carpathians (Flysch Belt), where asymmetric accretionary orogenic wedge was created due to the consumption of a quasi-oceanic Peninic (Vahic) crustal slab. Nevertheless, south-verging, high-angle thrusts have been already described in the eastern part of the Pieniny Klippen Belt (Nemčok and Rudinec 1990, Plašienka et al. 1998). The south vergent reverse faulting in studied area has been first suggested by Matějka (1931) in the Medzirozsutce saddle and later accepted in tectonic interpretation of the area (Haško and Polák 1978). During the last years, we have had an opportunity to study systematically the zone of tectonic junction of the Central and Outer Western Carpathians in the eastern part of the Malá Fatra Mts. and the Kysucké vrchy Mts. From structural analysis supported by detail geological mapping has resulted that the geological structure in tight contact with the Pieniny Klippen Belt zone is really strongly affected by