



Temperature, pressure and age constraints on the very low-grade metamorphism of the Jurassic Telekesoldal Nappe (Inner Western Carpathians) in NE Hungary – a summary

S. KÖVÉR^{1*}, L. FODOR², K. JUDIK³, T. NÉMETH³, P. ÁRKAI³, K. BALOGH⁴ AND S. KOVÁCS¹

¹*Geological, Geophysical and Space Science Research Group of the Hungarian Academy of Sciences, 1/C Pázmány str, H-1117, Budapest, Hungary.*

²*Hungarian Geological Institute, 14 Stefánia str, H-1143, Budapest, Hungary.*

³*Institute for Geochemical Research, Hungarian Academy of Sciences, 45 Budaörsi str, H-1112 Budapest, Hungary.*

⁴*Institute of Nuclear Research, Hungarian Academy of Science, 18/c Bem sqr, H-4026, Debrecen, Hungary.*

**e-mail: kovorsz@yahoo.com*

Abstract: Jurassic metasedimentary rocks of the Telekesoldal Nappe (Inner Western Carpathians) were sampled for metamorphic studies. The Telekesoldal Nappe represents a mélange-like accretionary complex consisting of black shales, sandstone turbidites and olisthostromes, deposited by gravity mass flows in a backarc (forearc?) basin. It was affected by ductile deformation and metamorphic alteration connected to the Middle Jurassic-Early Cretaceous subduction and obduction processes of the Neotethys Ocean. In the case of the 120-140 Ma very low-grade metamorphism – which is younger than the subduction-related blueschist facies metamorphism (Faryad and Henjes-Kunst, 1997) – the peak temperature was ca. 300-350 °C, while the minimum pressure was ca. 2-2.5 kbar.

Keywords: Inner Western Carpathians, accretionary metamorphism, very low-grade metamorphism, Kübler-index, chlorite “crystallinity”, K-white mica *b* “geobarometry”, K/Ar geochronology.

The interest in the thermal history of sedimentary rocks has grown rapidly over the last 40 years due to the oil industry, where predicting oil generation is one of the most important questions. This interest has resulted in the development of several methods, which can approach the transition between diagenesis and low-grade metamorphism. Such methods are the Kübler index (illite “crystallinity”), Árkai index (chlorite “crystallinity”), vitrinite reflectance, conodont colour alteration index (CAI), and the determination of clay mineral assemblages. These methods –inte-

grated with pressure and age data– provide the possibility of determining temperature and pressure conditions in the very low-grade metamorphic realm, where most of the methods used in the higher grades, i.e. geothermobarometers and trace element patterns, are useless because of the lack of diagnostic minerals. However, low-temperature metamorphism is usually present in accretionary wedges, where high-pressure metamorphic blocks and slices –ranging from several decimetres to several kilometres in size– are tectonically emplaced in an unmetamorphosed or only

slightly metamorphosed, usually clastic sedimentary matrix. Metamorphic features of the various constituents of these mélanges may elucidate the physical conditions (pressure-temperature paths) of subduction, collision and subsequent uplift (decompression-cooling) of the upper oceanic crust and related rocks of the accretionary prism. These P-T paths were reconstructed both for the blueschist facies and the very low-grade metamorphic rocks of the accretionary wedge of the Meliata Unit (Inner Western Carpathians) in Slovakia (Faryad, 1995; Faryad and Henjes-Kunst, 1997; Árkai *et al.*, 2003). However, our knowledge of the metamorphic conditions of other tectonic units found in Hungary is incomplete. The aim of this paper is to summarize all the unpublished data and present new data on the temperature, pressure and age constraints on this Telekesoldal Nappe, which shows a great similarity in its sedimentary features and its Bajocian-Bathonian age to the type localities of the Meliata Unit.

Geological setting

The Aggtelek-Rudabánya Hills are located in north-eastern Hungary. They are parts of the Inner Western Carpathians, and contain a nappe stack of Late Permian-Middle Jurassic sediments. The previous researchers pointed out that there are metamorphic and non-metamorphic structural units among the nappes (Grill *et al.*, 1984; Árkai and Kovács, 1986; Less *et al.*, 1988; Less, 2000; Szentpétery and Less, 2006). During the last twenty years several new problems have emerged in the structural settings and stratigraphy of this area. Among them, the definition and accordingly the number of the structural units, the superposition of the nappes, the age and style of deformations, metamorphism and nappe stacking have not yet been clarified. In the last years a new project has been initiated to obtain new structural and metamorphic data to better understand the structural position, the deformation history and the metamorphic conditions of the nappes of the Aggtelek-Rudabánya Hills (Fodor and Koroknai, 2000, 2003; Kövér *et al.*, 2005, 2006, 2007). As a part of this project, new data on the very low-grade metamorphism of the Jurassic Telekesoldal Nappe will be summarized in this paper.

The metasedimentary rocks of the Telekesoldal Nappe represent a mélange-like accretionary complex consisting of black shales, sandstone turbidites and olisthostromes. A relatively deep marine basin in the proximity of a submarine slope is likely to be the depositional environment of this unit. The carbonates

of the olisthostromes are predominantly Middle to Late Triassic eupelagic to hemipelagic limestones showing features of the grey “Hallstatt facies” (radiolarian and “filament” wackestones), but crinoidal limestones and, rarely, platform carbonates of unknown age also occur. Rhyolite volcanoclasts and related quartz and feldspar grains, derived from a supposed coeval island-arc volcanism, are also common among the clasts. The characteristic features of the Telekesoldal Nappe, i.e. upwards coarsening succession formed via gravity mass flow processes, clasts of calc-alkalic volcanic associations derived from a supposed coeval suprasubduction magmatic arc, and deformed strata suggest deposition, probably took place in a forearc or backarc basin in connection with the Middle-Upper (?) Jurassic subduction of the Neotethys Ocean.

Methods

Thirty four rock samples from the Jurassic Telekesoldal Nappe were selected for metamorphic studies. From seventeen new samples, collected from borehole material as well as from surface outcrops, fifteen produced useable illite Kübler index (KI) data, while sixteen produced chlorite “crystallinity” (ChC) data. Eleven illite Kübler Index data and K-white mica *b* cell dimension –in order to characterize the pressure conditions– were measured more than twenty years ago by the same laboratory and team (Árkai, 1985; Árkai and Kovács, 1986) with the same method, which ensured the comparability of the earlier and recent data.

X-ray powder diffractometric (XRPD) patterns were obtained using a Philips PW-1730 diffractometer (with a computerized APD system) with the following instrumental and measuring conditions: CuK α radiation, 45 kV/35 mA, proportional counter, graphite monochromator, divergence and detector slit of 1°, and collection of data in 0.01 and 0.02° 2-steps, using time intervals of 1 and 5 s, respectively. Diffraction patterns were performed from non-orientated and highly orientated powder mounts of whole rock and <2 μ m spherical equivalent diameter (SED) size fraction samples in order to determine bulk-rock mineral assemblages, *b* cell dimension of K-white mica, and illite Kübler and chlorite “crystallinity” indices. The statistical parameters of the *b* cell dimension data was measured on whole rock. Calibration procedure of phyllosilicate “crystallinity” index measurements was carried out against that of the Kübler’s laboratory using 0.25 and 0.42 $\Delta^{\circ}2\Theta$ as anchizone boundary values (for details see Árkai *et al.*, 1996).

TELEKESOLDAL NAPPE KI, ChC (002) values

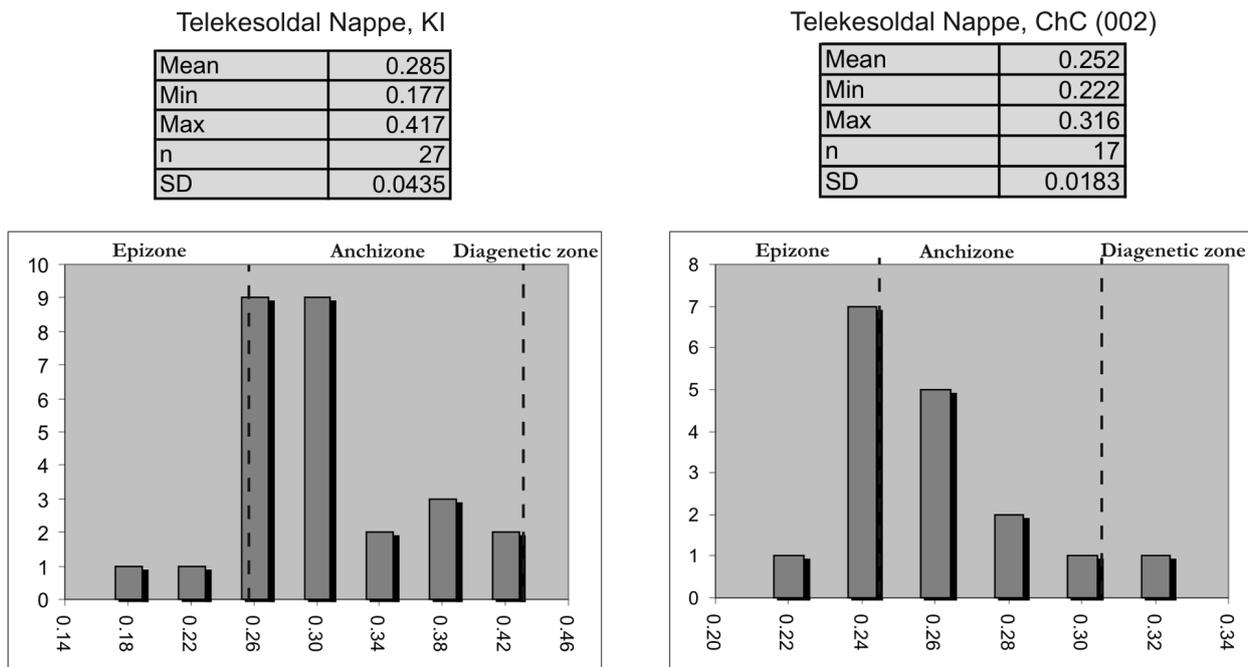


Figure 1. Illite Kübler (KI) and chlorite “crystallinity” ChC (002) Árkai index data of the Telekesoldal Nappe show high-temperature anchizonal metamorphism.

Results

Illite KI, chlorite “crystallinity”, K-white mica *b* parameter, vitrinite reflectance and K/Ar age were determined using samples from the Jurassic Telekesoldal Nappe. Most of the KI values fall within the high-temperature part of the anchizone (KI = 0.25–0.30 $\Delta^{\circ}2\Theta$), giving an average of $0.30 \pm 0.03 \Delta^{\circ}2\Theta$. While some of them reach the anchizone-epizone boundary (0.25 $\Delta^{\circ}2\Theta$), only a few KI values are in the low-temperature part of the anchizone (0.30–0.42 $\Delta^{\circ}2\Theta$) (Fig. 1).

Similarly to the relationships found by Árkai (1991) and Árkai *et al.* (1995) the ChC (001) and ChC (002) values show a positive correlation with the KI data. Most of the ChC (002) data fall within the anchizone (ChC (002) = 0.24–0.26 $\Delta^{\circ}2\Theta$) with an average of $0.25 \pm 0.01 \Delta^{\circ}2\Theta$. Almost the same number of samples reaches the anchizone-epizone boundary (0.24 $\Delta^{\circ}2\Theta$) (Fig. 1).

Vitrinite reflectance (VR) measurements were carried out by Árkai (1985). The maximum VR (R_{\max}) values are 4.8–5.6% R_{\max} . From the several approaches that

developed to convert VR data to peak paleotemperatures, the Barker’s equation (Barker, 1988) was chosen, because the random vitrinite reflectance (% R_r) is used as the only input parameter of this regression equation [$T(^{\circ}\text{C}) = 104 (\ln R_r) + 148$]. It follows that it neglects the effect of heating time. However, it is very useful to help appreciate the peak temperature of metamorphism if there is a lack of detailed information on the time parameters of the metamorphic process. Using the equation on the average $R_r = 4.86\%$ of the Telekesoldal Nappe the estimated peak temperature of metamorphism is ca. 310 $^{\circ}\text{C}$.

The average K-white mica *b* cell dimension data measured on paragonite-free whole rock samples (Árkai, 1985) fall within the transition zone of low- and medium-pressure zones, giving an average of $8.99 \pm 0.03 \text{ \AA}$ (Fig. 2).

Conclusions

On the basis of our compilation, the illite Kübler and chlorite “crystallinity” indices (Fig. 1), measured over the last twenty five years, correspond to the high temperature part of the anchizone up to the

TELEKESOLDAL NAPPE *b* cell dimension data

Mean	8.996
Min	8.987
Max	9.018
n	19
SD	0.005

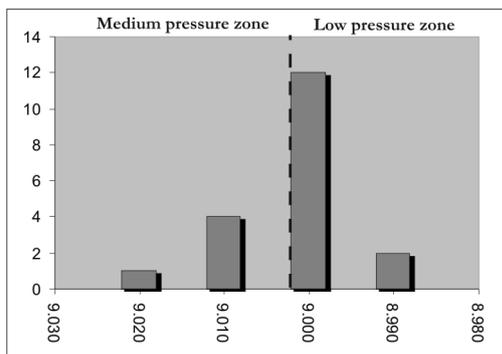


Figure 2. K-white mica *b* data of the Telekesoldal Nappe (Árkai, 1985) indicate low to medium pressure metamorphism (pressure estimates give possible minimum P values).

lower part of epizone and suggest a metamorphic temperature of ca. 300–350 °C (Fig. 3) (Árkai and Kovács, 1986; Árkai, 1985, new measurements). Vitrinite reflectance data of $R_r = 4.86$; $R_{max} = 5.13$; $R_{min} = 4.53$ were measured on the unit (Árkai 1985). Using Barker's equation (Barker, 1988), the estimated peak temperature of metamorphism is ca. 310 °C, which shows a close agreement with temperatures suggested by illite Kübler and chlorite "crystallinity" indices. K-white mica *b* "geobarometry" suggests possible minimum pressure of ca. 2–2.5 kbar (Árkai, 1985) (Figs. 2 and 3). These data were compared with the temperature and pressure constraints on the 4 type localities of the very low-grade metamorphic event, which affected the similarly Jurassic accretionary mélangé of the Meliata Unit (Inner Western Carpathians). The temperature conditions of this Early Cretaceous very low-grade metamorphic event were similarly ca. 270–350 °C at Meliata and Telekesoldal (300–350 °C), and slightly higher (ca. 340–350 °C) at Hačava and Držkovce. Comparing the pressure data –on the basis of the K-white mica *b* parameters–, Držkovce, Hačava and Telekesoldal might represent a lower pressure segment (min. 2–2.5 kbar), while Meliata may be considered as a relatively higher pressure one (ca. 3.5–5.4 kbar; Árkai *et al.*, 2003) (Fig. 3).

The prograde anchizonal metamorphism of the Meliata accretionary wedge sediments and the retro-

gression of blueschist facies metapelites occurred between ca. 150 and 120 Ma, with a thermal peak in the anchizonal sequences at around 140–145 Ma (Árkai *et al.*, 2003). This very low-grade metamorphism was younger than the 160–155 Ma old, subduction-related blueschist facies metamorphism (Faryad and Henjes-Kunst, 1997). The age of the investigated very low-grade metamorphic event in the Telekesoldal Nappe is under examination using the K/Ar method. On the basis of the preliminary data, the metamorphic event took place in the Early Cretaceous, between 120–140 Ma (136.6 ± 5.2 Ma, 127.9 ± 5.0 , 125.8 ± 4.8 Ma), showing a close correlation with the 120–150 Ma metamorphism of the other accretion-related sequences of the Inner Western Carpathians.

Acknowledgements

The research was supported by the Hungarian Scientific Research Found OTKA No. 48824, 60965, 61872. L. Fodor benefited the Bolyai János scholarship of the Hungarian Academy of Sciences.

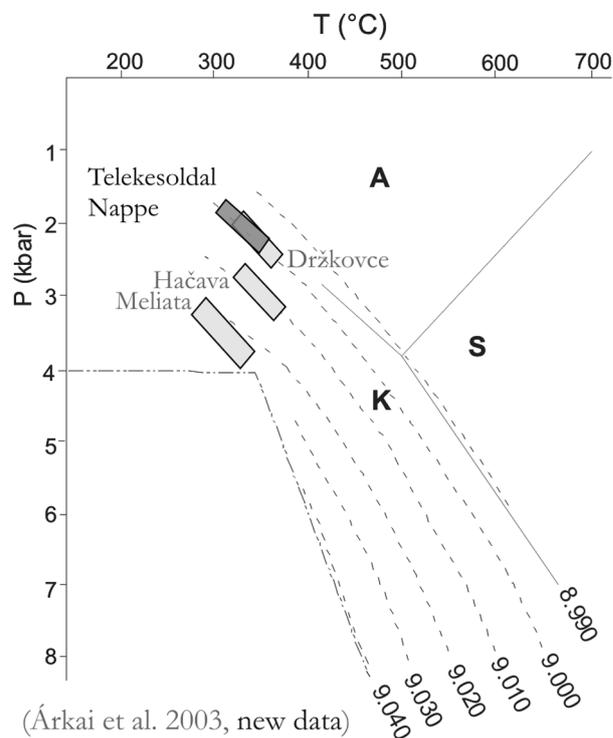


Figure 3. Comparison of the very low-grade metamorphism of the Telekesoldal Nappe (NE Hungary) and the type localities of the Meliata Unit (Inner Western Carpathians). P-T diagram of the compared units based on the illite Kübler index and K-white mica *b* data from the present study and from Árkai *et al.* (2003).

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