History of the Podhale flysch basin revealed by K-Ar and AFT dating and XRD study of clay minerals

J. Środoń | Institute of Geological Sciences | Polish Academy of Sciences

The shale and sandstone rocks outcropping today in Podhale fill a Tertiary sedimentary basin developed on a basement composed of Hercynian crystalline rocks and their Mesozoic carbonate cover, which itself is outcropping in the Tatra (Fig. 1). The Podhale basin is a remnant of a much larger Tertiary basin, which once covered the entire Inner Carpathians, but was latter broken into parts and preserved in tectonic depressions, but removed by erosion from the elevated blocks, including the Tatra block (Fig. 2).

The Podhale basin continues towards the west into the Orava basin. Their northern border with the Pieniny is tectonic and the contact with the Tatra is erosional (Fig. 1). In the east the basin continues into the Spišská Magura area and it is separated from the Levoča basin by a major Ružbachy fault, which is a continuation of the Tatra fault

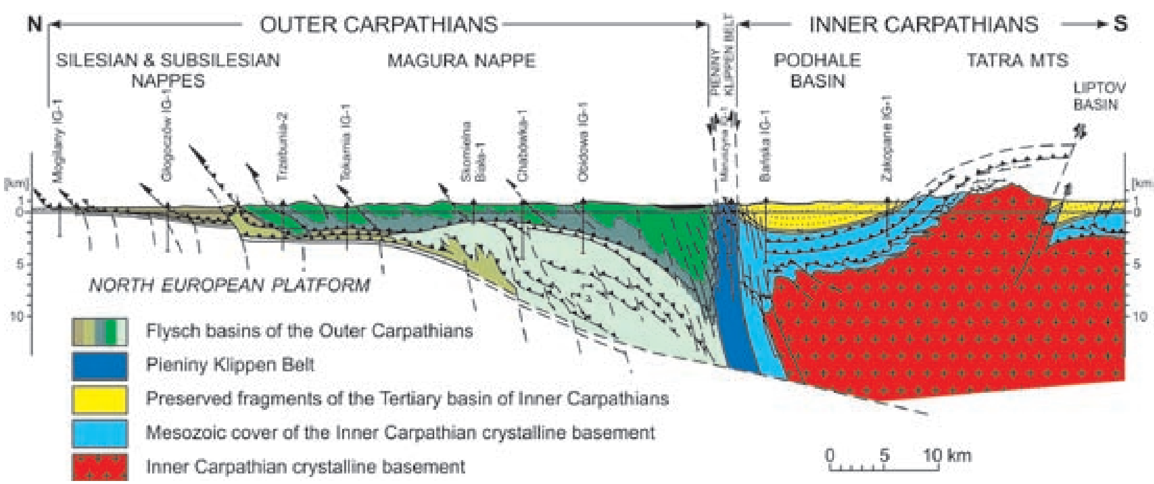

Fig. 1. Cross-section of the Carpathians along the Kraków-Zakopane transect (after K. Birkenmajer), illustrating the geotectonic position of the Podhale basin

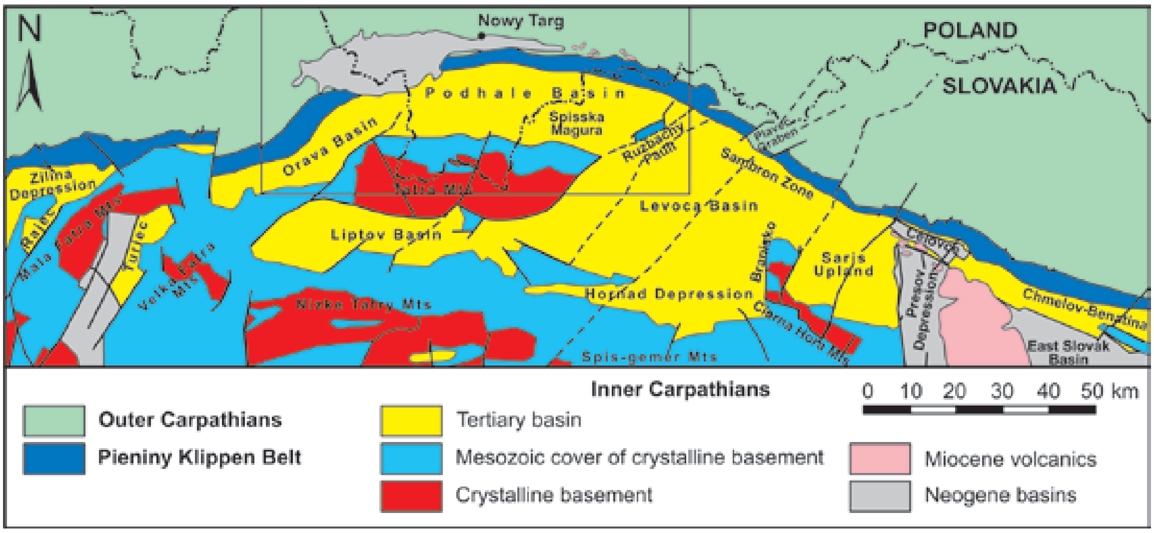

Fig. 2. Part of the geological map of the Western Carpathians (compiled by A. Łaptaś) with the study area marked by the rectangle

(Fig. 2). The preserved column of the Tertiary basin fill reaches 3 km in the axial western part of the basin and decreases to less than 1 km in the east, close to the Ružbachy fault. Locally, next to the fault, the Mesozoic basement is outcropping at the surface (Fig. 2). The flysch strata are lying almost flat over most of the basin, steeper only close to its northern and southern border. The tectonic deformations are minimal, compared to the underlying Mesozoic basement and to the contemporary Tertiary flysch basins of the Outer Carpathians, situated further to the north (Fig. 1). The present-day elevation of the basin surface increases gradually from ca. 600 m asl in the west to a maximum of 1100m close to the Ružbachy fault. Topography also becomes slightly more rugged towards the east and the local differences in elevation increase from 200 to 600 m.

Such tranquil geology and topography offers no apparent clues to the surprising history of this basin, which was revealed recently by combined X-ray diffraction (XRD) study of clay mineralogy, radiometric K-Ar dating (Środoń et al., 2006) and apatite fission track (AFT) dating (Anczkiewicz et al., 2005).

Each of these techniques provides a specific type of information on the basin history. The clay mineralogy of sediments deposited in a basin evolves during burial in response to increasing temperatures. XRD allows this evolution to be quantified and the maximum paleotemperatures to be identified, in particular by measuring the ratio of smectite to illite layers (%S) in mixed-layer illite-smectite minerals separated from shales. K-Ar dating of illite-smectite separated from bentonites, i.e. from altered volcanic ash layers free of detrital contamination, provides the age of the smectite illitization process (the age of locking potassium in the illite crystalline structure), which approximates the age of the maximum paleotemperatures (Środoń et al., 2002). AFT dating is based on counting defects (tracks) in the crystalline structure of detrital apatite produced by fission of uranium nuclei, both spontaneous and induced in a nuclear reactor. Such tracks undergo thermal annealing (resetting) at 100-120°C, thus AFT technique provides two types of information: 1) whether the rocks were buried in the basin to >100-120°C (detrital vs. reset AFT ages), and if yes 2) when they passed the 100-120°C isotherm on the way back to the surface, i.e. during uplift and erosion.

XRD studies of shales were performed over the entire surface of the basin and in five boreholes. K-Ar dating was completed for three grain-size fractions of five bentonite samples collected at the surface. AFT dating was made for apatites separated from sandstone samples, which were collected both at the surface and from the Bukowina Tatrzańska borehole. The results of these measurements are presented in synthetic form in Figure 3.

The measured %S values indicate that the rocks outcropping today at the surface experienced in their burial history very different maximum paleotemperatures: from <100°C in the west to >160°C in the east. This temperature gradient across the basin

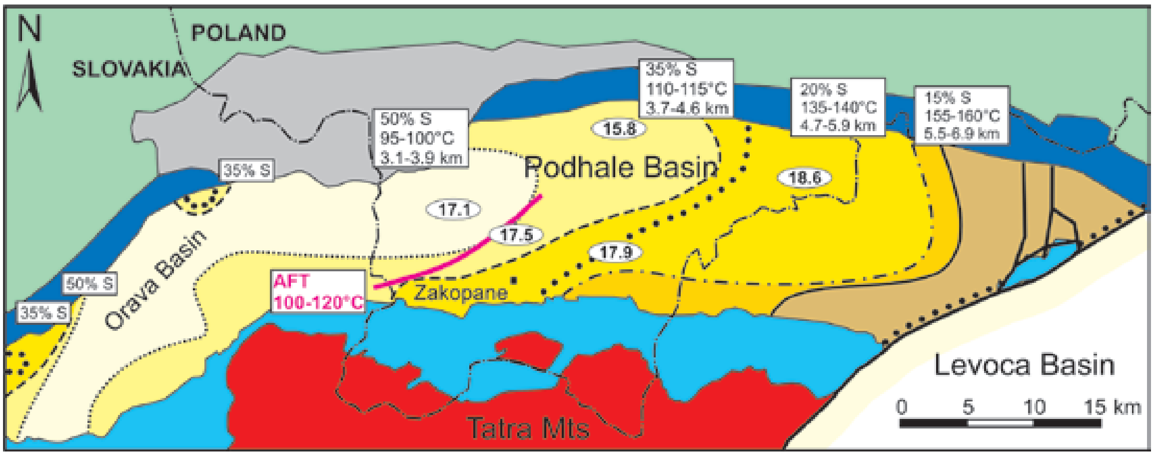

Fig. 3. Thermal history indicators for the Podhale-Orava basin. The maximum burial temperatures and the thickness of eroded cover were calculated for %S isolines, established from the XRD data, which were collected for the surface samples. Dotted lines mark the limit of kaolinite, which disappears due to diagenesis in the eastern part of the basin and reappears in the Levoča basin. The pink line separates AFT dates totally reset (east) from incompletely reset (west). K-Ar dates from bentonites in the ellipses.

surface is confirmed by the disappearance of kaolinite in the east and by the AFT dates, which are totally reset in the east and only partially reset in the west. Grain density measurements for the Chochołów and the Bukowina borehole samples confirmed that these profiles were buried to very different depths and that they can be superimposed into one continuous diagenetic profile (Fig. 4). The paleothermal gradient measured from %S data is the boreholes ranges from 20 to 25°C/km, which is identical to the measured present-day gradient. Based on these values, the thickness of rocks removed by erosion from the surface of the basin can be evaluated as ranging from <3 km in the west to >7 km in the east. The basin uplift started after the maximum paleotemperatures evaluated by K-Ar measurements were reached (16-19 Ma), as confirmed by younger reset AFT dates (6-12 Ma). Using the K-Ar values, the uplift rates can be estimated as ranging from 200m/Ma in the west to 360m/Ma in the east. A similar value of 420 m/Ma was obtained independently from the AFT dates measured in the Bukowina profile. The nature of contact of %S isolines with the basement outcropping in the Tatra indicates that the Tatra block surface was strongly inclined towards the east during the flysch sedimentation.

Using these data the Podhale basin history can be reconstructed as follows:

- The basin developed due to uneven subsidence of the tectonic block comprising the present day Podhale and Tatra area: the rate of subsidence and sedimentation was highest in the east;

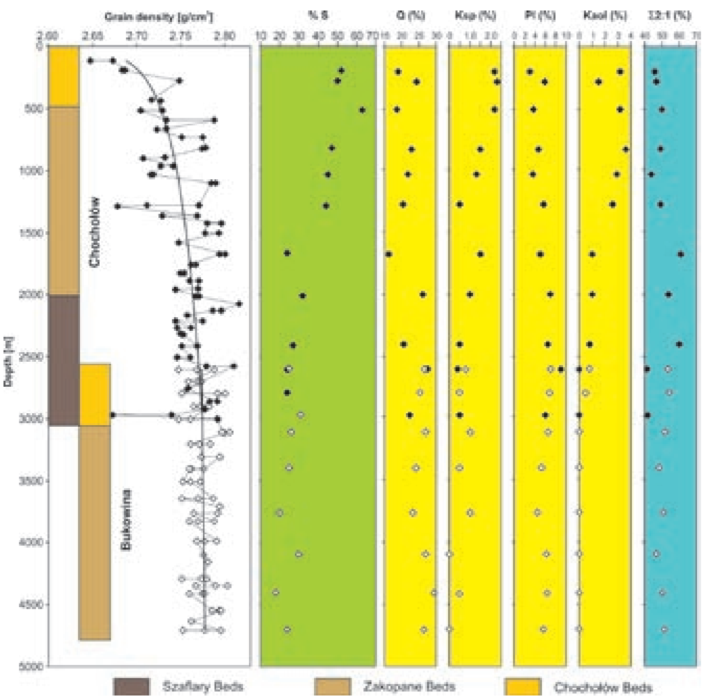

Fig. 4. Superposition of the Chochołów and Bukowina wells into one continuous diagenetic profile of the Podhale Basin based on the grain density data. The weight % of the sum of the dioctahedral 2:1 phyllosilicates (Σ2:1) and the most prominent diagenetic trends are presented %S – percent smectite in illite-smectite, Q – quartz, Ksp – K-feldspar, Pl – plagioclase, Kaol – kaolinite.

• The subsidence and sedimentation continued much longer than previously evaluated from the preserved sedimentary record: a thick layer of Lower Miocene sediments was deposited until 16-19 Ma. Only the Tatra block started to rise earlier;

• The Podhale basin uplift was also very uneven: much faster in the east than in the west. The consequences are: a) much higher grade of diagenesis of the surface rocks, and b) more elevated and rugged topography in the eastern part of the basin.

References

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Institute of Geological Sciences
ul. Twarda 51/55, 00-818 Warszawa
phone: 48 (022) 697 87 00
fax: 48 (022) 620 62 23
e-mail: ingpan@twarda.pan.pl
www.ing.pan.pl