

Paweł POPRAWA<sup>1</sup>, Michał M. ŻYWIECKI<sup>2,3</sup>, Izabella GROTEK<sup>1</sup>

## BURIAL AND THERMAL HISTORY OF THE HOLY CROSS MTS. AREA – PRELIMINARY RESULTS OF MATURITY MODELLING

**Abstract:** Thermal and burial history of the Holy Cross Mountains area was reconstructed by means of maturity modelling. The thermal maturity for about 50 samples was determined on the basis of the vitrinite reflectance measurements, supplemented with literature data. Thermal maturity of the Variscan and Permian-Jurassic successions was achieved during the Late Jurassic or the Late Cretaceous burial, characterized by heat flow equal to the recent one. The cumulative thickness of the Permian-Mesozoic sedimentary cover above the Palaeozoic core of the Holy Cross Mountains did not exceed 2,000-3,000 m. The regionally high geothermal gradient during the Variscan stage of burial, previously suggested, was not confirmed. There are indications for the Carboniferous-Permian time advective heat transfer by hot fluid migration, particularly along Holy Cross fault zone.

**Keywords:** burial history, thermal history, Palaeozoic, Mesozoic, Holy Cross Mountains

### INTRODUCTION

The Holy Cross Mountains (HCM), located in the southern part of central Poland (Fig. 1), is a part of the Trans-European Suture Zone with the Palaeozoic sediments emerged and available to study in outcrops. The HCM region suffered the Variscan compressional deformation, followed by the Late Carboniferous to Early Permian uplift and erosion, removing partly the Variscan and Caledonian succession. During the Permian-Mesozoic the area was the southern part of the Polish basin. The Late Cretaceous and/or Early Cainozoic inversion and erosion removed most of the Permian-Mesozoic sediments from the HCM area. This causes substantial difficulties in reconstructing the burial history of this region. According to Kutek, Głazek (1972), at the end of Cretaceous the pre-Permian successions of the HCM was buried beneath some 3,000-5,000 m thick sedimentary cover of the Permian-Mesozoic. This was however questioned *e.g.* by Marynowski (1999).

Thermal history of the HCM was studied by Belka (1990) who concluded that maturity of the Palaeozoic rocks was attained during the Variscan burial, when heat flow was significantly higher than the recent one. According to Marynowski (1999) the Variscan heating was intensive particularly in the western and north-western part of the HCM. Most of the authors agreed on a significant role of the Holy Cross fault zone in the Variscan heat transfer of the region (Belka 1990; Marynowski 1999; Poprawa, Żywiecki 2005).

For the Late Cretaceous stage of burial of the HCM Belka (1990) suggested presence of heat flow significantly lower than the recent one. However, this was not confirmed by data of Marynowski *et al.* (2002). Instead, the latter authors advocated for the Late Permian-Early Triassic positive thermal event in the northern part of the HCM.

<sup>1</sup>Polish Geological Institute, Department of Regional and Petroleum Geology, ul. Rakowiecka 4, 00-975 Warszawa, Poland; e-mails: pawel.poprawa@pgi.gov.pl; izabella.grotek@pgi.gov.pl

<sup>2</sup>Faculty of Geology, Warsaw University, al. Żwirki i Wigury 93, 02-089 Warszawa, Poland; e-mail: m.m.zywiecki@uw.edu.pl

<sup>3</sup>OG Petroleum Consulting, ul. Artura Grottgera 5A/6, 00-785 Warszawa, Poland

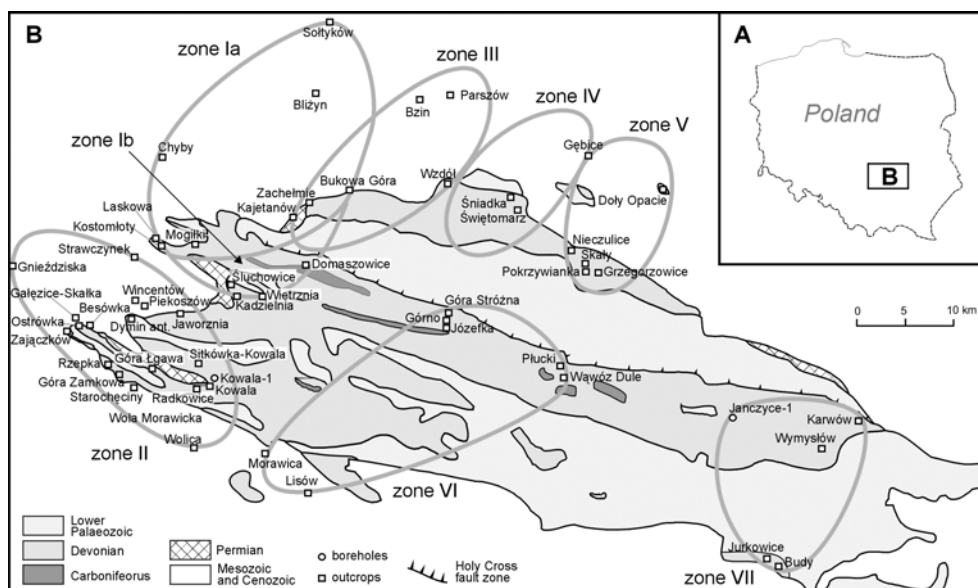


Fig. 1. (A) Location of the studied area. (B) Simplified geological map of the Holy Cross Mountains with location of samples for which thermal maturity was measured (vitrinite reflectance –  $VR_0$ ), as well as division of the studied area and  $VR_0$  data into individual synthetic sections, for which burial and thermal history was reconstructed.

The aims of the present contribution are to reconstruct heat palaeo-flow regimes at the main stages of the HCM area evolution, to identify heat palaeo-transfer mechanisms, and to quantify the Permian-Mesozoic burial of the region. For this reason thermal maturity of 50 samples was determined, and supplemented with the data of Marynowski (1997, 1999) and Marynowski *et al.* (2002), as well as the thermal and burial histories was modelled for 8 synthetic sections (Fig. 1) and 2 well sections (Kowala-1 and Janczyce IG-1).

#### THE APPLIED METHODS

For the area of Holy Cross Mountains the synthetic sections were reconstructed (Fig. 1), composed of the Upper Palaeozoic and Mesozoic sedimentary fill of the relevant basins. For each individual synthetic section 1-D modelling of thermal and burial history was conducted, performed with use of the Sweeney and Burnham (1990) algorithm. Correction for decompaction was calculated according to the model of Baldwin and Butler (1985). Thermal conductivity and heat capacity of rock matrix for the typical lithologies were adopted from literature. History of surface temperature was included in the modelling. Maturity models were calibrated with  $VR_0$  data. Reflectance of vitrinite was measured on polished slices in reflected light in oil immersion with use of Axioscop microscope (Zeiss).

#### BURIAL AND THERMAL HISTORY – PRELIMINARY RESULTS

Tectonic deformations of the HCM region and presence of several phases of significant erosion, causes uncertainties in reconstruction of the synthetic sections. Particularly, controversial are the estimations of the pre-erosional stratigraphic thickness of the Carboniferous, Upper Jurassic and Upper Cretaceous successions. Another possible source of errors in modelling, conducted for synthetic sections, is that across an individual zone a

thermal palaeo-regime could differ, therefore  $VR_0$  data in a single section might not be co-genetic.

Irrespective of the above uncertainties the main results of modelling are coherent across the studied area. Maximum burial of the HCM region was achieved during the Late Jurassic or the Late Cretaceous, when thermal maturity of the Palaeozoic sediments was ultimately formed. This is confirmed by absence of unconformity of the reconstructed maturity profiles between the Devonian, Carboniferous and the Permian-Mesozoic successions in each individual section (Fig. 2C). In general, the Palaeozoic rocks could not attain their present-day maturation during the Variscan stage of the HCM evolution, as postulated by Belka (1990) and Marynowski (1999), even assuming that heat flow at that time was substantially higher (*op. cit.*), because the Variscan burial was not deep enough. For example the Carboniferous burial of the top of Devonian succession did not exceed 1,000 m, comparing with some 2,000-3,000 m in the Late Jurassic and/or Late Cretaceous (Fig. 2B). A general conclusion is that heat flow in the HCM region was roughly constant in time and, both during the Late Palaeozoic and Mesozoic time, was equal to the recent one (Fig. 2A).

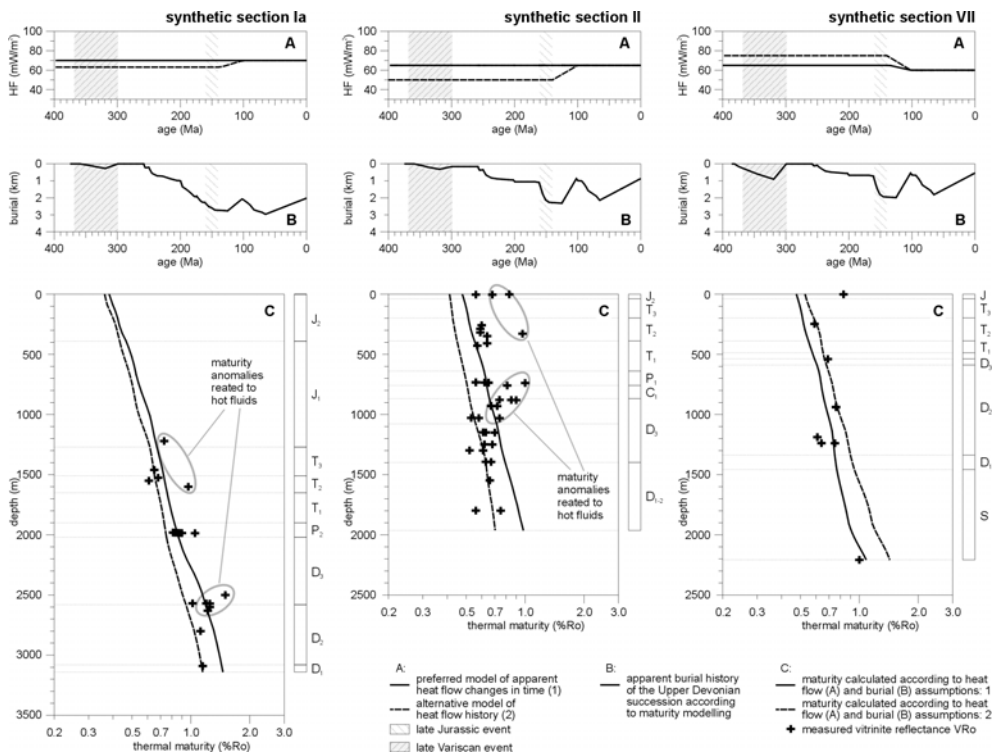


Fig. 2. Reconstructed apparent heat flow histories (A), burial histories (B), and calibration of the relevant thermal maturity models (C) for exemplary synthetic sections from the Holy Cross Mts.

In the most of the analysed sections we observe positive maturity anomalies with respect to general trend of thermal maturity increase with depth (Fig. 2C). The anomalies are interpreted in terms of advective heat transfer. Presence of the anomalies both in the Mesozoic and Upper Palaeozoic successions could reflect two separate general phases of hot fluid migration, the Late Jurassic and the Carboniferous-Permian ones. In the latter case the anomalous maturity at the limited fragments of the sections could be exceptionally

achieved during the Variscan time. Impact of hot fluids on thermal maturity is confirmed in a micro scale by observation of significant maturity gradients (e.g. from 1.25 % to 1.9 %  $R_o$ ) across individual thin sections towards micro-veins filled with diagenetic minerals, the latter characterized by relatively high homogenization temperatures of fluid inclusions.

## CONCLUSIONS

Present-day thermal maturity of the Devonian and Carboniferous successions of the Holy Cross Mountains developed mainly during the Late Jurassic or, less probably, the Late Cretaceous maximum burial. At that time heat flow generally was similar to the recent one (Fig. 2A). Modelling results indicate that the concept of high heat flow in the region during the Variscan burial, which was suggested by Belka (1990) and Marynowski (1999), is not necessary to explain the present-day maturation of the Palaeozoic rocks.

There are positive thermal maturity anomalies observed in some of the sections, which could be attributed to advective heat transfer (Fig. 2C). Hot fluids could be active mainly during the Carboniferous-Permian time. Distribution of thermal maturity is suggestive for important role of Holy Cross fault zone and its western prolongation as a carrier way for fluid migration during the Late Palaeozoic time (Belka 1990; Marynowski 1999; Poprawa, Żywiecki 2005). Thermal maturity depth profiles in the Mesozoic successions to the south-west of the HCM allow to reconstruct also the Late Jurassic phase of hot fluid migration, presumably related to enhanced permeability of faults and fractures driven by extension.

According to obtained results, burial of the Palaeozoic core of the HCM in the Alpine cycle was lower than previously suggested by Kutek, Głazek (1972) and did not exceed 2,000-3,000 m (Fig. 2B). The discrepancy with the previous study, apart of controversies regarding stratigraphic thickness of the Carboniferous, Upper Jurassic and Upper Cretaceous successions, results from incorporation of the Early Cretaceous phase of the erosion into the models. This excludes cumulative burial of the substratum by the pre-Early Cretaceous and the Late Cretaceous successions together.

Stimulating discussions with Leszek Marynowski, Zbigniew Szczepanik, Andrzej Kozłowski, Andrzej Matyja, Sylwester Salwa and Jerzy Nawrocki are acknowledged. This study was financially supported by MŚ/NFOŚiGW, project No 2.15.0000.00.0.

## REFERENCES

- BALDWIN B., BUTLER C. O. 1985: Compaction curves. *AAPG Bull.*, 69, 622-626.
- BELKA Z. 1990: Thermal maturation and burial history from conodont colour alteration data, Holy Cross Mountains, Poland. *Courier Forsch.-Inst. Senckenberg*, 118, 241-251.
- KUTEK J., GŁAZEK J. 1972: The Holy Cross area, Central Poland, in the Alpine cycle. *Acta Geol. Pol.*, 22 (4), 604-653.
- MARYNOWSKI L. 1997: Stopień dojrzałości materii organicznej ze skał węglanowych dewonu Gór Świętokrzyskich. *Prz. Geol.*, 45 (9), 899-903 [in Polish].
- MARYNOWSKI L. 1999: Thermal maturity of organic matter in Devonian rocks of the Holy Cross Mts (Central Poland). *Prz. Geol.*, 47 (12), 1125-1129 [in Polish with English summary].
- MARYNOWSKI L., SALAMON M., NARKIEWICZ M. 2002: Thermal maturity and depositional environments of organic matter in the post-Variscan succession of the Holy Cross Mountains. *Geol. Quart.*, 46 (1), 25-36.
- POPRAWA P., ŻYWIECKI M. 2005: Variscan heat transfer along the western prolongation of the Holy Cross Fault Zone by migration of hot fluids related to igneous intrusions (northern Małopolska Block, southern Poland). *Pol. Tow. Mineral. Prace Spec.*, 25, 180-183.
- SWEENEY J.J., BURNHAM A.K. 1990: Evaluation of a simple model of vitrinite reflectance based on chemical kinetics. *AAPG Bull.*, 74, 1559-1570.