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IMPACT OF THE PERMIAN MAGMATIC ACTIVITY ON THE THERMAL MATURATION OF THE CARBONIFEROUS SEDIMENTS IN THE OUTER VARISCAN OROGEN (SW POLAND)

Abstract: 1-D maturity modelling was applied to reconstruct thermal and burial history of the external Variscan orogen in the SW Poland. The Carboniferous heat flow was laterally changeable, but relatively high, particularly in the northern and eastern part of the studied area, compatible with the model of a "hot" Variscan orogeny. Palaeoburial, reconstructed from modelling, was very high. This might be an artefact, caused by impact of the lower Permian volcanic covers and related hot fluids on the thermal maturation of Carboniferous sediments.

Keywords: Variscan orogen, Carboniferous, Permian, vitrinite reflectance, fluid inclusions, maturity modelling, volcanics, SW Poland

INTRODUCTION

In the SW Poland, north of the Lower Odra fault zone, deep boreholes recognized the siliciclastic Carboniferous sediments of significant thickness, present beneath the Mesozoic and Permian sedimentary cover of the Polish Basin (PB). The Carboniferous succession in this zone suffered Variscan deformation, and is regarded as the external part of the Variscan orogenic zone. During the early Permian the area was partially covered by up to few hundred meters thick pile of volcanic rocks, at least in its western part (*e.g.* Pokorski 1997). Since the Late Permian through Mesozoic the region become a SW part of the PB. Two separate uplift events in the early Cretaceous and the late-most Cretaceous to early Paleogene, led to partial erosion of the Mesozoic sedimentary cover and development of the individual unit of the PB in the studied area, referred to as Fore-Sudetic monocline.

Previous studies of thermal history of the SW Poland resulted with two models. The first one suggested a high geothermal gradient during the Carboniferous, and a subsequent systematic cooling throughout the Permian to Cenozoic (Majorowicz *et al.* 1984; Speczik, Kozłowski 1987; Poprawa *et al.* 2002). The second model of Karnkowski (1999) pointed to the presence of significant thermal event in the southern part of the studied area during the Permian to Jurassic time. The recent study aims to quantify burial and thermal conditions, leading to development of thermal maturity of the Carboniferous succession, as well as to constrain time of the main heating event and mechanisms of heat transfer in the analysed area. Particular emphasis is placed on possible impact of the Permian volcanic activity on development of thermal maturity.

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APPLIED METHODS

Thermal maturity of the Carboniferous, Permian and Mesozoic successions was studied for more than 40 deep borehole sections from the outer part of the Variscan orogen (Fore-Sudetic monocline in terms of "Laramian" tectonic units). For each borehole at least several samples were analysed. Reflectance of vitrinite and vitrinite-like substance was measured on polished slices in reflected light in oil immersion with Axioscop microscope.

Fluid inclusion studies were performed with use of LINKAM TP92 stage with heating-cooling HFS 91 equipment. Measurements calibrated by SynFlinc synthetic fluid inclusions had accuracy of ±0.2°C. Recognition of primary inclusions and fluid salinity, gas types, and fluid chemistry was based on criteria of Roedder (1984), Kerkhof (1990) and Kozłowski (1984). At the present stage 13 samples from two boreholes (Siciny IG-1 and Marcinki IG-1; Fig. 1) were analysed.

Modelling of thermal maturity and thermal history was performed for 15 well sections (Fig. 1) with use of Sweeney and Burnham (1990) algorithm. Burial history was corrected for decompaction according to model of Falvey and Middleton (1981). Thermal conductivity and heat capacity for each type of lithology were adopted from published values, based on averaged results of laboratory measurements for their equivalents. Constant temperature logs were used to constrain recent heat flow. History of surface temperature was included in the modelling.

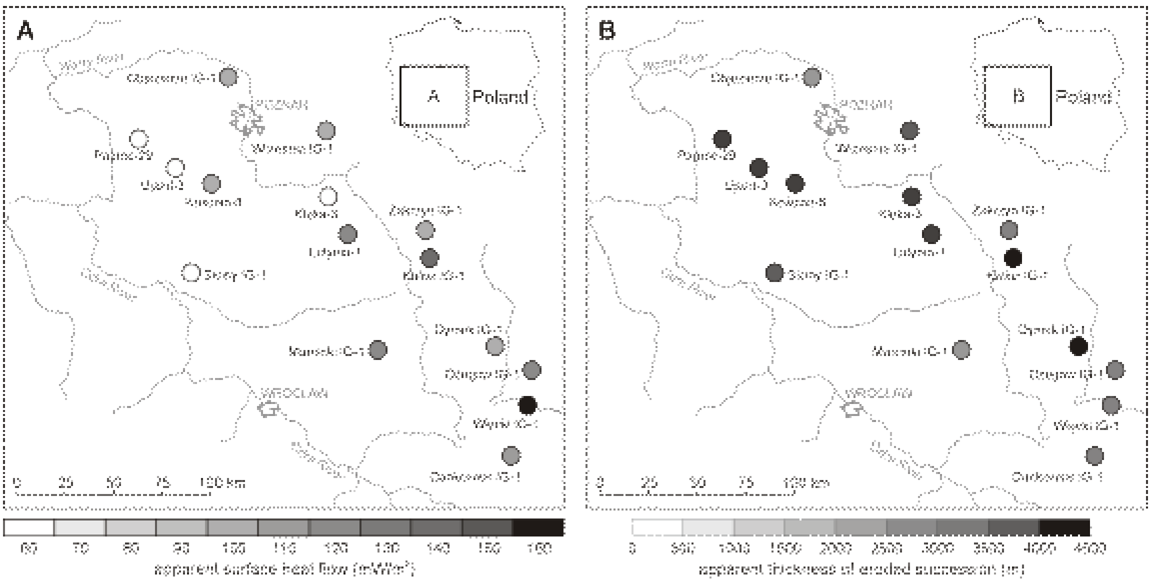

Fig. 1. Lateral distribution of the results of maturity modelling for the Outer Variscan orogen: (A) apparent heat flow at the stage of the maximum Variscan burial, and (B) apparent thickness of sediments and/or volcanic rocks eroded during the Late Carboniferous and/or Early Permian.

FLUID INCLUSION ANALYSIS

Fluid inclusion analysis, conducted for vein filling minerals in the Carboniferous succession, allowed to distinguish two separate types of calcite and one type of anhydrite, each with own temperature and chemical characteristics (Fig. 2). The first type of calcite shows low homogenisation temperatures (+65 to +78°C; Fig. 2). Presence of brines of $CaCl_2$ (88% of total dissolved salts) – NaCl (12% of tds) chemical system, with enrichment of Ca^{2+} ions, and composition of gas dominated by CH_4 and CO_2, indicate that the solutions were genetically related to the mixed magmatic-formation water fluids.

The second type of calcite is characterised by high homogenisation temperatures (+324 to +374°C), Ca^{2+} ions variable but still high ($CaCl_2$ of 68-91% of total dissolved salts) and subordinate contribution of NaCl, $MgCl_2$ and KCl, with CO_2 as gas dissolved in solution (Fig. 2). Such characteristic strongly suggests the direct impact of magma on the fluids. The anhydrite, younger in diagenetic sequence, originated from fluids connected with the Zechstein evaporates of the higher up section.

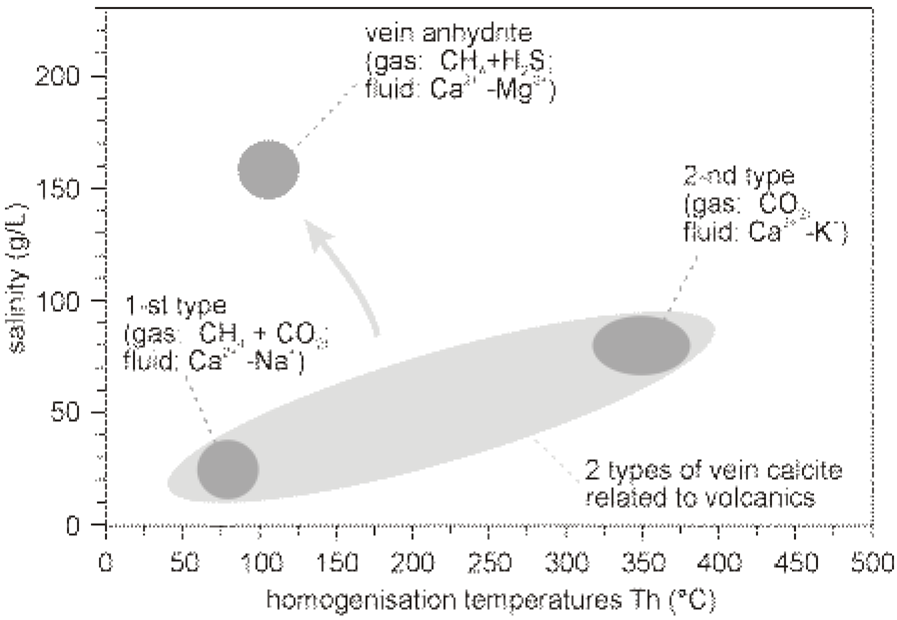

Fig. 2. The main results of the fluid inclusion microthermometry, *i.e.* homogenisation temperatures, salinity and the main ion composition, obtained for minerals filling veins in the Carboniferous succession.

MODELLING OF THERMAL AND BURIAL HISTORY

Results of the modelling indicates, that Carboniferous sediments in the SW Poland attained their thermal maturity prior to the late Permian. This is clearly shown by significant difference in maturity development between the top of the Variscan succession and the lower part of the Permian-Mesozoic one (Fig. 3). The same conclusion is obvious from the presence of unconformity between the maturity profiles of the upper Permian-Mesozoic and the Carboniferous successions in the individual well sections (Fig. 4C). Only along the NE margin of the Fore-Sudetic monocline it is difficult to exclude entirely possible impact of the Mesozoic burial and thermal regime on the maturity of Carboniferous succession. On the other hand, the maturity was achieved after the Late Carboniferous tectonic deformation. This is evidenced by observation, that the maturity profiles are not dependent on tectonic dipping or presence of thrust sheets.

Thermal regime, reconstructed for the Late Carboniferous to Early Permian is characterised by relatively high, however laterally changeable, heat flow, commonly ranging between 100 and 150 mW/m² (Figs. 1A, 4A), compatible with the results of Majorowicz *et al.* (1984) and Speczik, Kozłowski (1987). This indicates, that the model of "hot" Variscan orogeny could be extrapolated for the outer zone of the orogen. The only sections with the well documented lower heat flow (60-80 mW/m²) at that period of time are located in the SW part of the studied area (Paproć-29, Siciny IG-1; Fig. 1A).

Very characteristic feature of the outer Variscan orogenic zone in SW Poland is a high thickness of the eroded section, reconstructed from the maturity modelling (Figs. 1B, 4B). In the here analysed cases it ranges between 2500 and 4000 m (Fig. 1B). The above values are incompatible with models of burial in the Carboniferous sedimentary basin. The higher ones are also difficult to explain by the late Carboniferous tectonic burial.

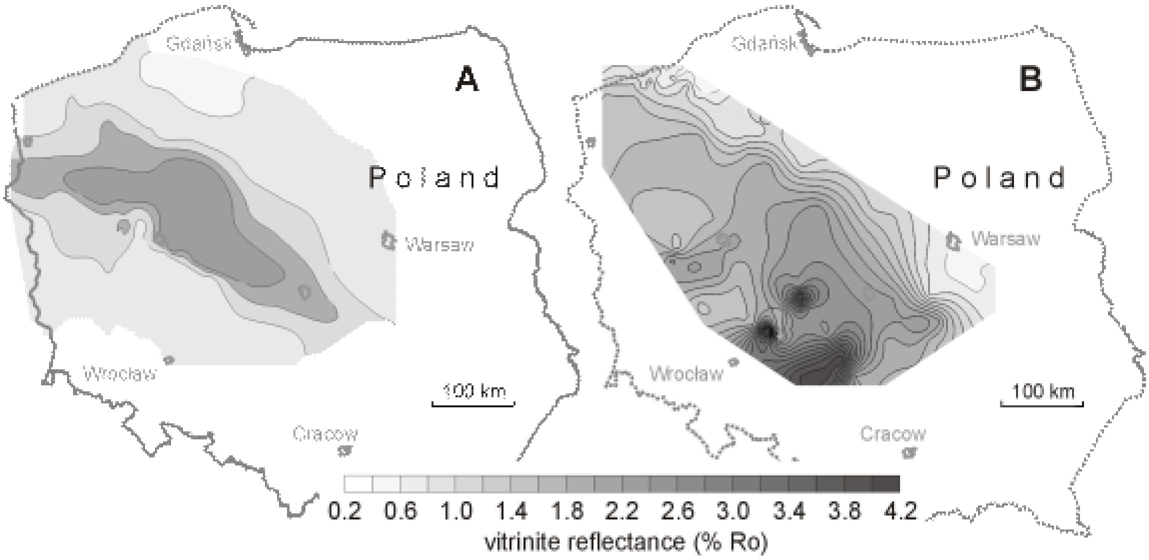

Fig. 3. Simplified maps of thermal maturity at: (A) the level of Main Dolomite, Zechstein, Upper Permian (after: Grotek 1998; Kotarba 2000), and (B) the top of the Carboniferous or the Devonian. The maps are based on data from a few hundred wells (A) and more than fifty wells (B).

Characteristic feature of the SE part of the analysed area is a presence of relatively broad, oval shape zones of significant positive anomalies of thermal maturity of the Carboniferous sediments (Fig. 3B). SE part of the studied area is characterized also by a very high apparent palaeoheat flow (Fig. 1A). Reconstructed thickness of the eroded section is lower, and more realistic, than further to the west (Fig. 1B). According to here preferred interpretation, thermal regime of this zone at the stage of the late Carboniferous tectonic burial was governed by emplacement of the large plutonic bodies in the lower part of crust, being northward equivalents of the granite massifs known from the Sudetes and their foreland (Poprawa *et al.* 2002). Such plutonic bodies are capable to elevate heat flow within sedimentary cover above (Fig. 5A). Effect of thermal doming combined with post-collisional isostatic reaction are responsible for uplift and erosion, leading to elevation of the fossil maturity profile (Fig. 5B).

In the western part of the studied area heating during the late Carboniferous tectonic burial was less prominent. This is indicated by lack of significant lateral maturity changes and its lower values, as well as by calculated palaeoheat flow being lower than in the eastern zone (Fig. 1A). Characteristic feature of the western zone is a presence of the lower Permian volcanic traps, few hundreds meters thick at most, which disappears towards the east (*e.g.* Pokorski 1997). In the western zone thickness of the eroded section calculated from the maturity profiles reach suspiciously high values (Fig. 1B).

On the base of the above considerations we propose a model linking the presence of volcanic traps with the maturation of the Carboniferous substratum. According to that model, occurrence of relatively thick cover of volcanics caused shift of the geotherm towards higher temperatures with little of changes of the geothermal gradient. Fossil profile of thermal maturity, which developed at the stage of Late Carboniferous tectonic burial, was replaced by a new one (Fig. 5C). Impact of volcanism on thermal regime is documented by fluid inclusion analysis, *i.e.* high homogenisation temperatures and specific chemistry of fluids and gases (Fig. 2). Influence of migration of hot fluids on maturation of the Carboniferous sediments is also capable to explain presence of significant local anomalies of apparent palaeo-heat flow or palaeoburial (Fig. 1), and appearance of sub-vertical maturity profiles.

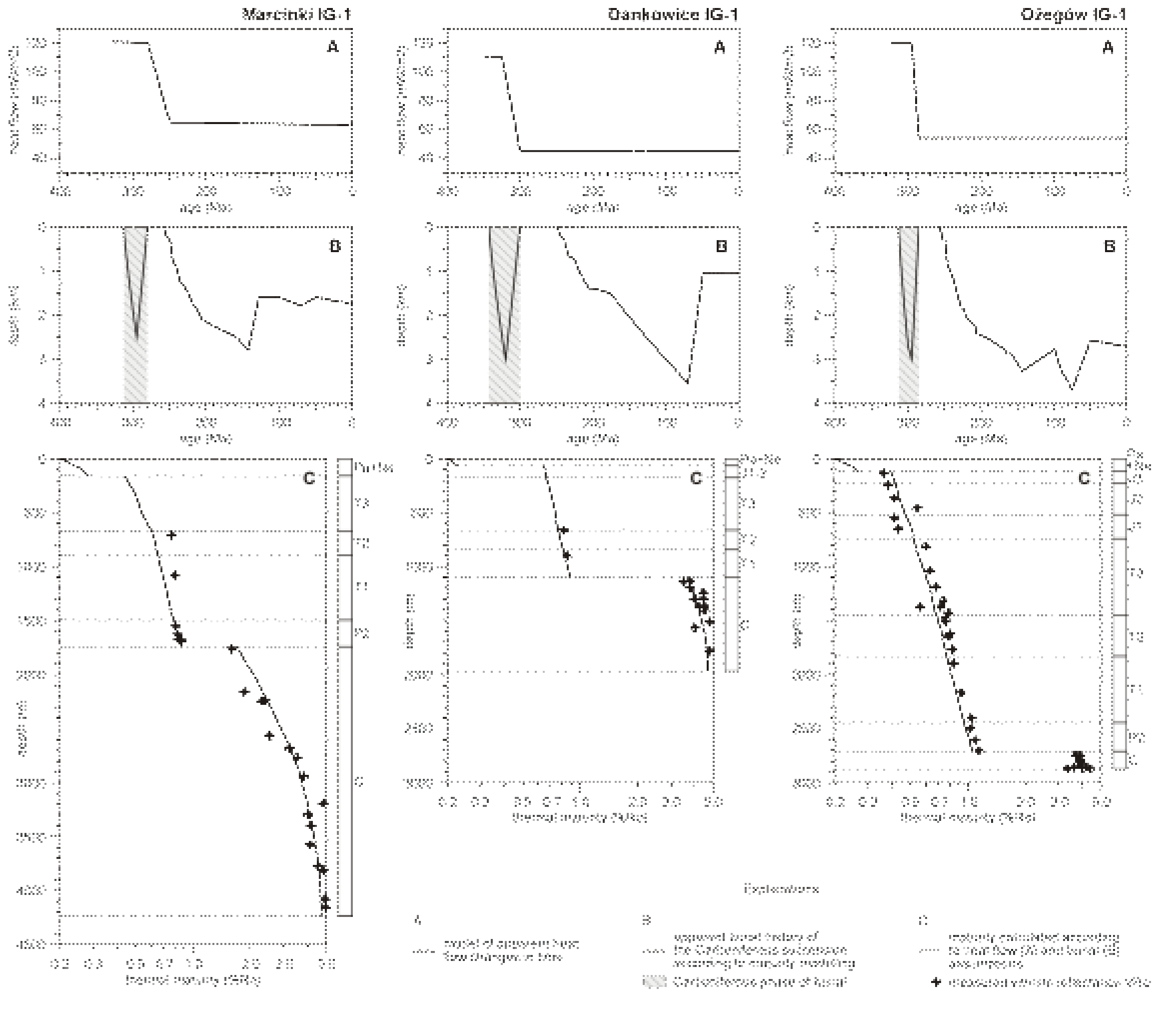

Fig. 4. Reconstructed apparent heat flow histories (A), burial histories (B), and calibration of the relevant thermal maturity models (C) for exemplary well sections from the outer Variscan orogen.

Subsequent uplift and erosion led to elevation of the fossil maturity profile of the Carboniferous succession, thereafter characterised by relatively high values if compare to its burial history (Fig. 5D). The Late Permian-Mesozoic burial and moderate heat flow (Fig. 4A) did not change the maturity of the Carboniferous sediments. As a result of the evolution described above, any calculation of thickness of section eroded prior to the Late Permian from the gradient of thermal maturity results with unrealistically high values (Fig. 5E). It is not certain if the Permian volcanics were originally present also in the eastern part of the analysed area, and therefore if the described model is valid in that zone.

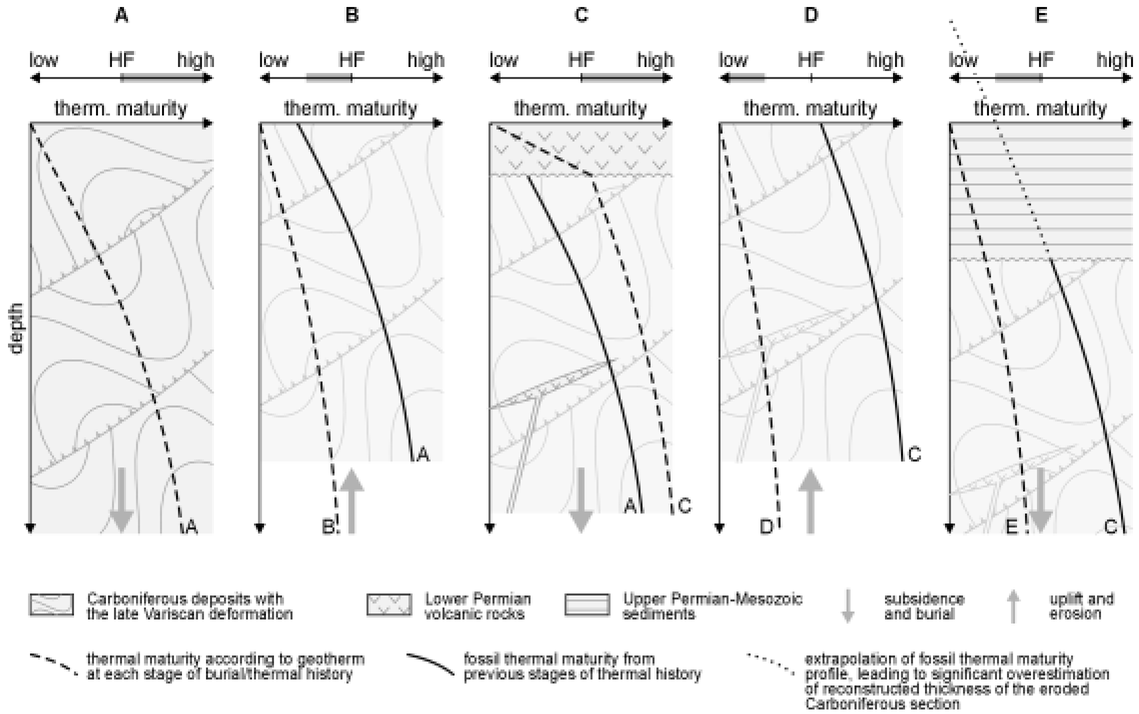

Fig. 5. A cartoon illustrating development of thermal maturity of the Carboniferous succession in the outer part of the Variscan orogen. HF – heat flow. A – Late Carboniferous tectonic burial; B – latemost Carboniferous post-collisional uplift and erosion; C – early Permian development of volcanic traps; D – middle to late Permian uplift and erosion; E – late Permian to Mesozoic burial.

CONCLUSIONS

The Late Carboniferous heat flow in the external zone of the Variscan orogen in the SW Poland was laterally changeable, but relatively high (Majorowicz *et al.* 2002; Speczik, Kozłowski 1987), compatible with the model of the “hot” Variscan orogeny. Palaeoburial, reconstructed from modelling, was very high, particularly in the western part of the studied area. This might be an artefact, caused by impact of Lower Permian volcanic traps on the thermal maturity of the Carboniferous succession beneath, as well as by migration of hot fluids, related to the volcanic activity.

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