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THERMAL HISTORY OF UPPER CARBONIFEROUS SEDIMENTS IN THE SABERO COALFIELD (NW SPAIN): A PRELIMINARY RESULT OF 1-D THERMAL MATURITY MODELING

Summary. In order to reconstruct thermal history of the Upper Carboniferous (Stephanian) strata in the Sabero Coal-field (NW Spain) numerical modeling of thermal maturity has been performed by Fobos software. Paleoheat flow of 102 mW/m^2 was calculated for the time of maximum burial (Late Carboniferous to Early Permian) and a total overburden of 2400m. According to this model, maximum paleotemperatures for the Stephanian rocks ranged between 105 (top of the Perla Formation) and 200 °C (bottom of the Alejico Formation). Based on this modeling it can be shown that coalification of organic matter contained in Stephanian rocks was achieved in Early Permian. It was likely related to several processes such as magmatic activity, high subsidence rate in a pull-apart basin.

EWOLUCJA PALEOTERMICZA UTWORÓW GÓRNOKARBOŃSKICH ZAGŁEBIA WĘGLOWEGO SABERO (NW HISZPANIA): WSTĘPNE WYNIKI MODELOWAŃ DOJRZAŁOŚCI TERMICZNEJ

Streszczenie. W celu rekonstrukcji ewolucji paleotermicznej utworów górnokarbońskich (stefańskich) Zagłębia Węglowego Sabero (NW Hiszpania) przeprowadzono jednowymiarowe modelowania numeryczne dojrzałości termicznej za pomocą programu Fobos. Obliczony paleostrumień cieplny w okresie maksymalnego pogrążenia utworów górnokarbońskich (na przełomie karbonu i permu) wynosił 102 mW/m^2, a całkowita wielkość erozji nadkładu wynosiła około 2400 metrów. Maksymalne paleotemperatury osiągnięte przez utwory górnokarbońskie wynosiły od 105°C (w stropie formacji Perla) do około 200°C (w spągu formacji Alejico). Uwęglenie materii organicznej w utworach górnokarbońskich basenu Sabero nastąpiło w najwyższym karbonie oraz we wczesnym permie. Było ono związane z jednej strony z waryscyjską aktywności magmatyczną, a z drugiej strony z wysokim tempem subsydencji w basenie typu pull-apart.

1. Introduction

There is a long tradition in using the patterns of coalification to reconstruct the thermal history of sedimentary basins (see Yalcin et al. 1997 and references herein). Another approach to study the thermal history of sedimentary basins is by numerical modeling of paleoheat flow and burial history, which has proved an essential tool for petroleum exploration (see Welte et al. 1997 and references herein). The modeling procedure typically starts with a conceptual model, based on recognized geological evolution given basin, such as deposition, non-deposition, and erosion. The validity of such models depends on the quality of input data, which incorporates, e.g. the exact stratigraphical thickness and thermal conductivity of individual layers (Noth et al. 2002). By far the most widely used data for calibration of these models are measurements of vitrinite reflectance, which can be compared with modeled vitrinite reflectance values, such as those calculated by the kinetic EASY %Ro method (Sweeney, Burnham 1990).

In the study presented, thermal history of the Late Carboniferous coal-bearing sediments of the Sabero Coalfield (Cantabrian Zone, NW Spain) has been reconstructed by means of the one-dimensional (1-D) numerical modeling.

2. Methods

Vitrinite reflectance has been measured on coal material close to tonstein horizons well-known in this basin (Knight et al. 2000, Botor 2005). Exact position of these tonstein horizons and location of the samples are given in Botor (2005). Random vitrinite reflectance measurements (%Ro) were carried out on polished grain sections using a Axioskop Opton microscope in reflected white light mode, using (50 x) oil immersion objective, following usual ICCP procedures.

Vitrinite reflectance data were used for calibration one idealized (simplified) model of the pseudo-well. This technique has been explained in detail by Oncken (1982) and Noth et al. (2002). Simulations of paleoheat flow and burial history were performed by Fobos software. For calibration, the kinetic EASY %Ro method (Sweeney & Burnham 1990) was applied. Modelling was carried out by varying the paleoheat flow and erosion values until the best-fit was attained between measured and calculated Ro data. The input data are presented in table 1. The lithology and stratigraphical thickness was taken form Knight (1983).

3. Geological setting

The Sabero coalfield is located in the south of the Cantabrian Zone (Fig. 1). This area constitutes the external zone of the Variscan orogenic belt in the NW of the Iberian Peninsula.

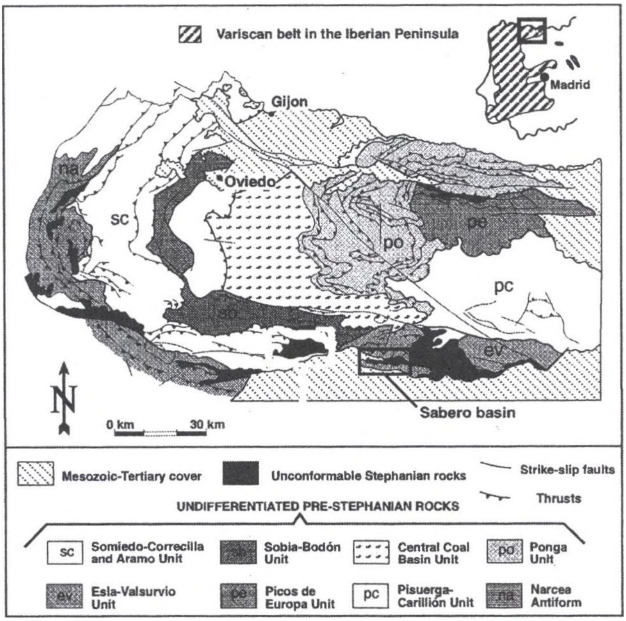

Fig. 1. Geological sketch map of the Cantabrian Zone (after Pérez-Estaun et al. 1988). The framed area encloses the Sabero Coal Basin

Rys. 1. Schematyczna mapa geologiczna strefy Kantabryjskiej (wg Pérez-Estaun et al. 1988). Obszar w ramce obejmuje basen węglonośny Sabero

Two different successions can be recognized in relation to the Variscan deformation: one pre-orogenic and one syn-orogenic. The pre-orogenic sequence is formed by Lower Palaeozoic siliciclastic rocks and Devonian carbonate and clastic formations. The syn-orogenic Carboniferous pile (of up to 8 km thickness) is interpreted as a foreland basin sequence (Julivert 1971; Marcos, Pulgar, 1982). Both successions were complexly folded and thrusted under a thin-skinned tectonic regime between Westphalian B and Stephanian times (Julivert 1971, Bastida et al. 1999). The Sabero basin is a pull-apart, intramontane coal basin located along the Sabero-Gordón fault line, one of the major, E-W trending, strike-slip fault systems of the Cantabrian Zone (Colmenero, Prado 1993). The total thickness of the succession is in excess of 2000 m, and is composed of conglomerates, sandstones, shales and siltstones, with intercalated coal seams with tonsteins.

4. Results and discussion

Results of the vitrinite reflectance measurements of the samples from Sabero Coal-field are given in table 1. Whereas, results of numerical modeling of thermal maturity are given in Figs. 2 – 5.

In this study only one sample is from Unica Formation and has value 1,2 %Ro. Herrera Formation has diversified degree of coalification from 0,89 to 1,38 %Ro. Succesiva Formation has values from 1,08 to 1,28 %Ro. Raposa Formation has values in range 0,82 – 1,18 %Ro (Table 1).

Table 1

Results of the vitrinite reflectance measurements in samples from Sabero Coal-field

Stratigraphy	Reference Level	Sample Code	Formation	Ro (%)	S.D.	N	T
Stephanian B	Level 40	P37 (B15)	Unica	1.20	0.07	30	150
Stephanian B	Level 33	P89 (B17)	Herrera	0.89	0.04	30	126
Stephanian B	Level 32	P142	Herrera	1.40	0.09	30	163
Stephanian B	Level 32	P60 (B27)	Herrera	1.05	0.06	30	139
Stephanian B	Level 31	P85 (C33)	Herrera	1.38	0.10	30	161
Baruaelian	Level 21	P44 (C28)	Sucesiva	1.28	0.07	32	155
Baruaelian	Level 20	P75 (C21)	Sucesiva	1.08	0.09	30	142
Baruaelian	Level 12	P24 (B2)	Raposa	1.18	0.08	30	149
Baruaelian	Level 12	P121 (B39)	Raposa	0.82	0.09	30	119
Baruaelian	Level 1 1	P22A	Raposa	1.15	0.06	30	147

S.D. standard deviation, N number of measurements, T calculated paleotemperature by Barker, Pawlewicz (1994) method

Few data on vitrinite reflectance are given by Knight et al. (2000). An irregular pattern of relatively high reflectances (1,4 – 1,8 %Ro) was found in highly tectonised Unica and Herrera Formations, while more uniform range of lower values (1,2 – 1,3 %Ro) was found in the older sequences of the Sucessiva and Raposa Formations (Knight et al. 2000).

The volatile content of coals of the Sabero basin oscillate between 30 and 18 % volatiles (Colmenero, Prado 1993) (coking coals), which is well into the catagenesis level of organic matter maturation (Welte et al. 1997).

Generally, as limited data exist on thermal maturation of Stephanian rocks. It is difficult and too early to interpret these data in the form detailed coalification pattern. Therefore, this study should be continued.

Recent investigations of the tonstein mineralogy Knight et al. (2000), and illite crystallinity of pelitic rocks (Frings, 2002) confirm the predominantly diagenetic character of these rocks and lower thermal gradients experienced in this coalfield with respect to those of other Stephanian basins of Cantabrian Zone. Ayllon (2003) in his fluid inclusion study of Sabero and Cinera –Matallana basins estimated paleotemperature in Sabero coalfield in range from 73-129 °C up to 164-296 °C in hydrothermal quartz of the diorite sills. Some of these are in close contact to coal-seams. Paleotemperatures calculated by Barker and Pawlewicz (1994) method is from119 to 163 °C (Table 1).

Table 2

Input data for numerical modeling of thermal maturity

Formation Name	Present Thickness (m)	Depth (m)	Major lithology	Tc	Deposition from (Ma)	Age to (Ma)
Perla	490	1	siltstone and sandstone	2.57	301.0	299.0
Unica	280	491	sandstone and siltstones	2.65	302.0	301.0
Herrera	300	771	sandstone and shales	2.48	303.0	302.0
Quemadas	205	1071	shales	1.98	303.9	303.0
Successiva	150	1276	shales and sandstones	2.37	305.0	303.9
Gonzalo	140	1426	shales and sandstones	2.37	305.7	305.0
Raposa	650	1566	sandstone and shales	2.68	306.0	305.7
Alejico	300	2216	conglomerates	2.95	307.0	306.0

Tc - thermal conductivity at 20 °C (in W/mK)

1-D thermal modeling was performed using input data given in table 1. The methodology has been explained in detail by Oncken (1982) and Noth et al. (2002).In order to obtain good fit between measured and calculated vitrinite reflectance values, different scenarios were calculated by iterative method. The time of maximum burial was the most likely in the post-Stephanian (Early Permian), assuming deposition of sediments until early Permian and subsequent erosion (Heward 1978, Julivert 1971, Marcos, Pulgar 1982).

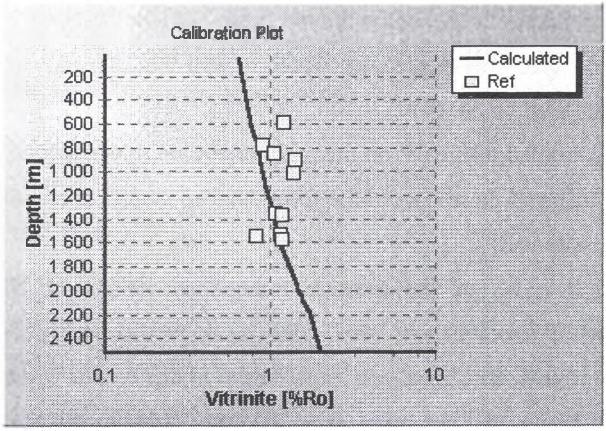

Fig. 2. Comparison between measured Ro and calculated Ro by EASY %Ro method (Sweeney, Burnham 1990). This calibration is shown for the best-fit model

Rys. 2. Porównanie wartości pomierzonych Ro z wartościami obliczonymi Ro za pomocą metody EASY %Ro (Sweeney, Burnham 1990). Pokazano kalibracje najlepszego modelu końcowego

A final good calibration fit was achieved using a paleoheat flow of 102 mW/m^2 for the time of maximum burial and a total overburden of 2400m (Figs. 2 and 5).

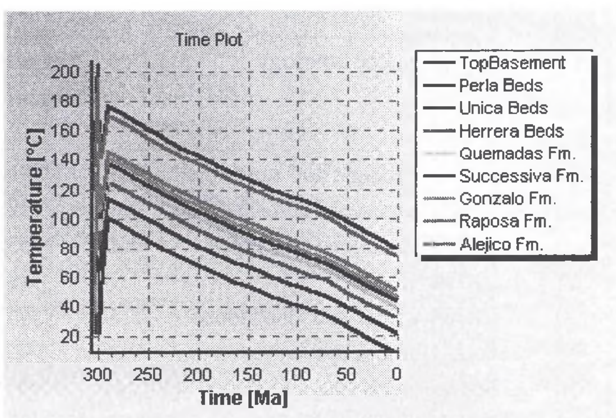

Fig. 3. Temperature history of the Sabero Coal-field

Rys. 3. Ewolucja paleotemperatury w poszczególnych formacjach Zagłębia Sabero

According to this model, maximum paleotemperatures for the Stephanian rocks ranged between ~105 (top of the Perla Formation) and ~195 °C (bottom of the Alejico Formation) (Fig. 3).

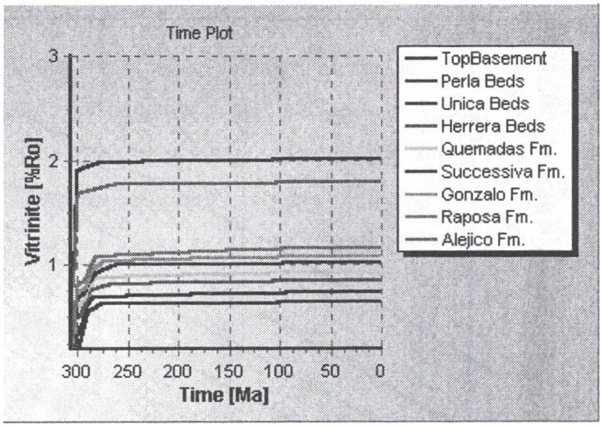

Fig. 4. Timing of coalification. All Stephanian formation in the Sabero Coal-field achieved maximum coalification in Early Permian

Rys. 4. Czas uwęglenia. Wszystkie formacje stefańskie w basenie Sabero uzyskały maksymalne uwęglenie we wczesnym permie

The burial history indicates rapid subsidence occurred during Stephanian to Early Permian times, followed by high erosion rate (Fig. 5). Coalification was at least partially related to very high subsidence rate in Stephanian times. Calculated subsidence rate for this basin is ~0,65 m/1000 a. The similar subsidence rates were calculated for other pull-apart Stephanian basin in Cantabrian Zone (Heward 1978, Frings et al. 2004). It is considered very likely that overburden relates to further sedimentation in latest Stephanain and in Early Permian (Heward 1978, Julivert 1971, Marcos, Pulgar 1982). All Stephanian formation in the Sabero Coal-field achieved maximum coalification in Early Permian (Figs. 4-5). Additional factor, which influence on coalification of organic matter in Stephanian rocks was undoubtly related to syn-sedimentary magmatic acivity in the Late Variscan. It seems that the widespread magmatism at Late Variscan times in the Canabrian Zone relates to delamination of the crust and upwelling of the astenosphere (Munoz et al. 1985, Fernandez-Suarez et al. 2000).

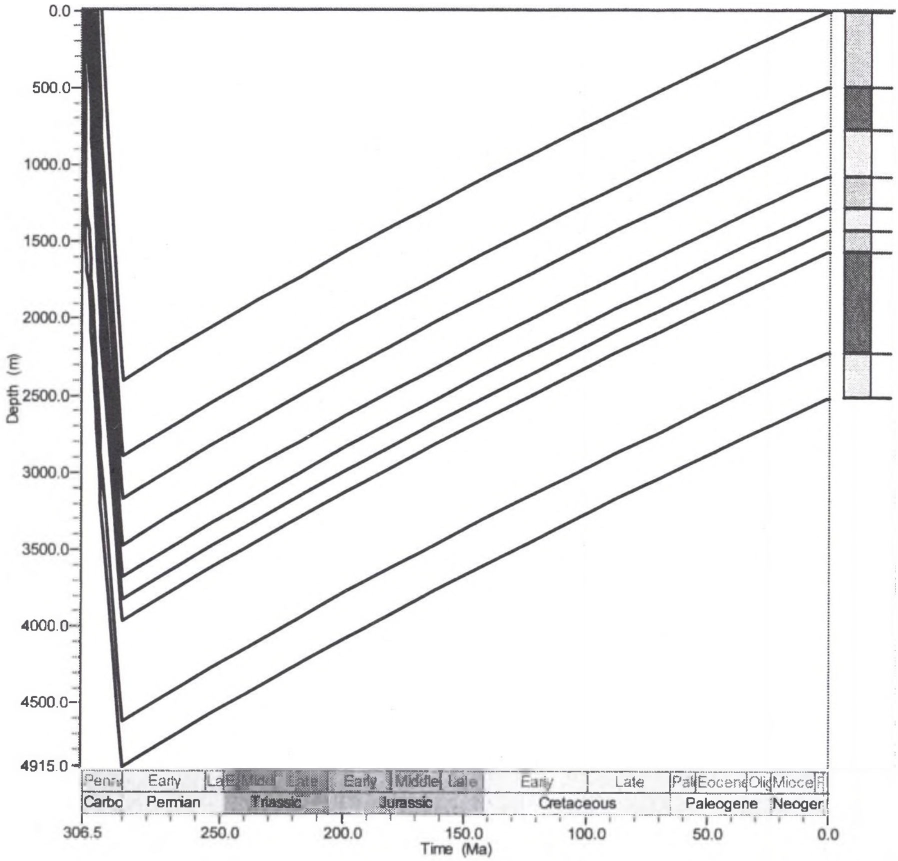

Fig. 5. Burial history for the best-fit model from Sabero Coal-field
Rys. 5. Historia pogrążania utworów karbońskich w złożu Sabero dla najlepiej dopasowanego modelu

5. Conclusions

Paleoheat flow of 102 mW/m^2 was calculated for the time of maximum burial (Late Carboniferous to Early Permian) and a total overburden of 2400m. According to this model, maximum paleotemperatures for the Stephanian rocks ranged between 105 (top of the Perla Formation) and 200 °C (bottom of the Alejico Formation). Based on this modeling it can be shown that coalification of organic matter contained in Stephanian rocks was achieved in Early Permian. It was related to several processes such as magmatic activity, high subsidence rate in a pull-apart basin.

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