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Organic geochemical study of source rocks and natural gas and their genetic correlation in the central part of the Polish Outer Carpathians

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ABSTRACT

Geochemical characteristics of organic matter (quantity, genetic type, maturity and petroleum potential) were determined in profiles of Lower Cretaceous–Miocene strata of the Dukla and Silesian units of the Polish Outer Carpathians in the Tarnów-Dębica-Nowy Sącz-Gorlice-Jasło area. This determination was based on Rock-Eval, isotopic, and biomarker analyses of 159 rock samples. Oligocene Menilite beds reveal the best hydrocarbon potential within the investigated formations (depositional units of the so-called flysch strata) and can be considered as primary source rock in the study area. Marine and mixed marine–terrestrial kerogen present in these rocks is immature in Silesian Unit and mature (oil window) in Dukla Unit, respectively. The Lower Cretaceous–Eocene formations (Veřovice, Lgota, Godula and Istebna beds, Variegated Shales, and Ciężkowice beds) of the Silesian Unit reveal variable amounts of mostly gas-prone kerogen and can be considered as additional source of hydrocarbons. The Upper Oligocene–Lower Miocene Krosno beds and Miocene Chaotic beds have a variable organic matter content, usually over 1 wt %, but very low maturity and low hydrocarbon potential predispose them as a source of microbial methane. Ten natural gas samples from sandstone reservoirs of the Upper Cretaceous–Lower Miocene strata in the Silesian Unit of the Outer Carpathians were analysed for molecular and isotopic compositions in order to establish their origin and role of thermogenic and microbial processes. Thermogenic gases without the admixture of microbial methane were encountered only in one well (Bystra-4) in the block A of Szalowa-Heddy-Bystra gas deposit. Thermogenic gas component was generated at a maturity level of 0.7 to 1.0% of vitrinite reflectance (R_o) scale from mixed Type II/III kerogen dispersed in the Oligocene Menilite beds from a few fields within the Silesian Unit. Microbial methane had been generated earlier from the same organic matter, during microbial carbon dioxide reduction process. A significantly high microbial component occurs mainly in the gases from Kobylanka (gas horizon), Gorlice-Glinik, and blocks C and B of the Szalowa-Heddy-Bystra fields. The microbial gases were generated within the Oligocene Menilite beds and/or Miocene Chaotic beds within local zones in the study area. Carbon dioxide originated both from thermogenic and microbial processes.

1. Introduction

Geochemical characteristics of organic matter (quantity, genetic type, maturity and petroleum potential) of the flysch strata of the Dukla and Silesian units of the central part of the Polish Outer Carpathians, origin of natural gases occurring within the Silesian Unit, and genetic correlation of natural gas and source rocks are discussed in the paper. The study area is located in the Polish Outer Carpathians between Nowy Sącz, Gorlice and Jasło in the south and Tarnów and Dębica in the north and covers about 8500 km^2 (Fig. 1). A total of 159 rock (core and outcrop) samples from the various formations were collected and analysed. The geochemical characteristics of these potential source rocks were carried out by Rock-Eval, biomarker, and stable isotope analyses.

Previous geochemical studies revealed that the main source rocks were the clayey facies of the Oligocene Menilite beds of the Outer Carpathians with total organic carbon (TOC) exceeding 20 percent (ten Haven et al., 1993; Bessereau et al., 1996; Curtis et al., 2004; Kotarba and Koltun, 2006; Matyasik and Dziadzio, 2006; Kotarba et al., 2007). The petroleum potential of this formation was characterised also by Koltun (1992), Koltun et al. (1998), Koester et al. (1998) and Kruge et al. (1996). Moreover, previous organic

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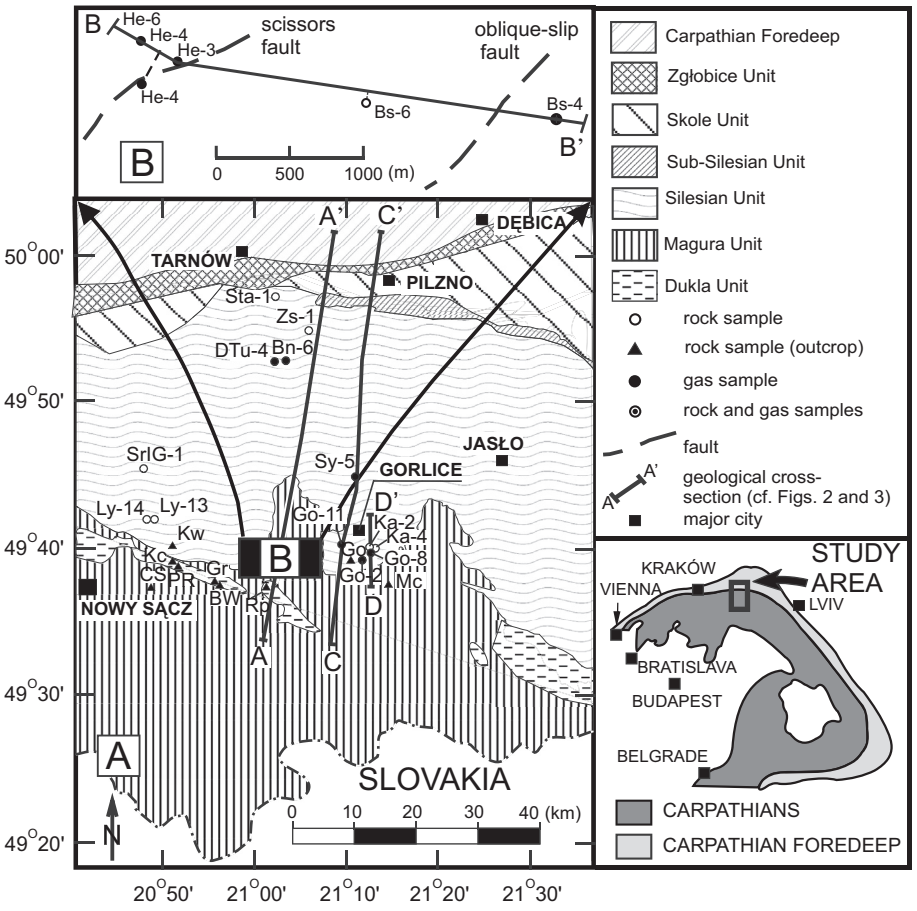

Figure 1. Geological sketch map of the study area modified after Żytko et al. (1988), Jankowski et al. (2004) and Oszczypko (2006) showing the location of rock and gas sampling sites and geological cross-sections.

geochemical and mineralogical studies (Gucwa and Wieser, 1980; Karpiński, 1978; Kotarba and Koltun, 2006; Kosakowski et al., 2009) indicated that petroleum source rocks occur also within the following lithostratigraphic units: black shales of Lower Cretaceous, Veřovice beds, Lgota beds, Gaise beds – Spongiolites, "Manganese", Radiolaria Shales, Siliceous Marls, Istebna beds, Hieroglyphic beds, and Krosno beds. Only a few organic geochemical analyses of potential source rocks in the study area were published up-to-date (Matyasik and Dziadzio, 2006). The results of the recent study on petroleum system in the Gorlice area by Matyasik and Dziadzio (2006) indicate that hydrocarbons were generated from the Menilite beds during last stages of thrusting from the Middle Miocene (ca. 14 Ma) until Holocene (1.5 Ma), at the depths from 2.5 to 3.7 km.

A total of 10 gas samples from sandstone reservoirs of the Upper Cretaceous–Lower Miocene strata of the Silesian Unit of the Outer Carpathians were collected and analysed for molecular and isotopic compositions.

Previous geochemical studies of natural gases associated and non-associated with oil within the Polish Outer Carpathians (Kotarba, 1987, 1992, 1993, 1998; Kotarba and Koltun, 2006; Kotarba et al., 2009) reveal that they have distinct geochemical signatures related to a range of genetic and post-accumulation histories. The origin of natural gases from the Silesian Unit of Bystra-4, Gorlice-8 and Gorlice-11 wells from the study area was considered according to molecular and isotopic compositions (Kotarba, 1992; Kotarba et al., 2009). They represent mainly thermogenic and mixing thermogenic and microbial gases.

The exploitation of oil and gas deposits in the Gorlice area in the Upper Cretaceous–Palaeocene Ropianka Formation strata of Magura Unit started at the end of the 19th century and was finished in 1990s (Karnkowski and Konarski, 1973; Karnkowski, 1999). All petroleum accumulations within this unit are probably a result of migration from underlying Silesian and Dukla units. This migration took place probably during the last overthrusting of the Outer Carpathians (Matyasik and Dziadzio, 2006).

2. Geological setting and petroleum occurrence

The Polish Outer Carpathians belong to the largest petroleum provinces of Central Europe and constitute one of the oldest petroleum-producing regions in the world. Exploitation of oil began in the 19th century and natural gas production started in 1921 (Karnkowski, 1999). Petroleum (oil and gas) accumulations were encountered in the sandstone reservoirs with in almost all lithostratigraphic formations of the Outer Carpathians.

The Outer Carpathians comprise a structurally-complex area which consists of folded and thrust strata of Early Cretaceous to Late Miocene age. A series of imbricated nappe-thrust sheets extends north to northeast covering strata of Late Oligocene to Late Miocene (Sarmatian) age (Golonka et al., 2006; Ślączka and Kamiński, 1998; Ślączka et al., 2005; Enfield et al., 2001; Cieszkowski and Ślączka, 2001).

Five tectonic units are present in the study area (Fig. 1). From north to south, these are the Skole Unit, the Sub-Silesian Unit, the Silesian Unit and the Dukla Unit, over which the Magura Unit is