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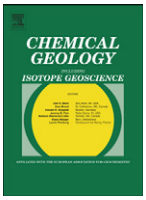

Origin of gaseous hydrocarbons, noble gases, carbon dioxide and nitrogen in Carboniferous and Permian strata of the distal part of the Polish Basin: Geological and isotopic approach

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ABSTRACT

Sixteen natural gas samples collected from Pennsylvanian and Permian (Rotliegend and Zechstein Limestone) strata of the distal part of the Polish Basin in Wielkopolska and Lower Silesia were analysed for molecular composition and stable carbon isotope composition of hydrocarbons (CH_4, C_2H_6, C_3H_8, n-C_4H_{10} and i-C_4H_{10}) and CO_2, stable hydrogen isotope composition of methane, stable nitrogen isotope composition of N_2, and stable isotope composition of noble gases (He, Ne, Ar, Kr, and Xe). Thirteen of analysed hydrocarbon gases reveal complete [$\delta^{13}C(CH_4) > \delta^{13}C(C_2H_6) > \delta^{13}C(C_3H_8)$] and partial inversed isotopic trends from methane to propane thus they have a very complicated generation, migration and accumulation history and range of their source rock horizons. Two source rock horizons occur NE from Wolsztyn Ridge. They contain mixed types III/II and II/III kerogens of Pennsylvanian age and Mississippian and/or Devonian age, respectively. One source rock horizon occurs SW from Wolsztyn Ridge. It contains type III and mixed type III/II kerogens of Pennsylvanian age. The kerogens in all source rock horizons generated gaseous hydrocarbons at two separate maturity stages: about 0.5 to 0.8% in vitrinite reflectance scale at the first maturity stage, and over 1.3% in vitrinite reflectance scale at the second maturity stage. High concentrations of He in analysed gases are mostly a product of α-decay of U and Th enriched in crustal materials. A small contribution of He and Ne of mantle origin to the gas reservoirs was inferred. Radiogenic $^4He/^{40}Ar$ ratios are higher than the average production rate ratio of about 5 for crustal materials, which might have been caused by a selective supply of lighter He through crustal rocks surrounding the gas reservoirs, or higher $(U + Th)/K$ ratio than the crustal average. CO_2 from analysed gases was mainly generated during thermogenic processes of transformation of organic matter, although some gases can contain components from endogenic processes and from thermal destruction of Zechstein Limestone and probably Precambrian carbonates. N_2 was mainly generated during thermal transformation of organic matter and had a large component released from NH_4-rich illites. Very high $N_2/^{40}Ar$ for the gases might be caused by accelerated thermogenic production of N_2 under the condition of high heat flux from volcanic activity at late Pennsylvanian and early Permian age. Deep-seated faults, mainly framing the Wolsztyn Ridge, perform important role in migration and mixed in different proportions of noble gases originated from upper mantle and from mineralisation by radioactive minerals their fault surfaces and occurrence of Pennsylvanian–Lower Permian volcanites in crust as well as hydrocarbon gases, CO_2 and N_2, also from thermal destruction of NH_4-rich illites, from "gas generation kitchens" of source rock horizons to the traps.

1. Introduction

The objective of this study is determining the origin of hydrocarbon and non-hydrocarbon gases based on molecular and stable isotope compositions: $^{12,13}C$ in CH_4, C_2H_6, C_3H_8, n-C_4H_{10}, i-C_4H_{10} and CO_2, $^{1,2}H$ in CH_4, $^{14,15}N$ in N_2, and all stable isotopes of noble gases (He, Ne, Ar, Kr, and Xe) of natural gases.

Gas samples were collected from Pennsylvanian, Rotliegend (Lower Permian) and Zechstein Limestone (Upper Permian) reservoirs of distal part of the Polish Basin in Lower Silesia and Wielkopolska regions (Figs. 1 and 2).

In the Polish Rotliegend Basin dozens of natural gas fields were discovered (P. Karnkowski, 1999). Reservoir rocks are mostly aeolian sandstones of the Lower Permian, but the gas is also in the Zechstein Limestone carbonates and Carboniferous (Mississippian and Pennsylvanian) sandstones. All of the traps within these various reservoir rocks are sealed by Zechstein evaporates. All of these gas fields

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represent one petroleum system (P.H. Karnkowski, 1999). The main areas of gas deposits are concentrated on the south-west (the average depth of gas deposits is about 1500 m) and the north-eastern side of the Wolsztyn Ridge (average depth at 3000 m) (Fig. 1). Most of these gas fields are located in structural traps, but some of them have a stratigraphic or lithological construction.

In 1964 the first gas findings in the Rotliegend sandstone and Zechstein Limestone reservoirs were documented in the Bogdaj–Uciechów gas field (P. Karnkowski, 1999). The resources in this field were estimated to ca. 16 billion m^3. The content of hydrocarbons is 57%, nitrogen – 42.5% and helium – 0.4%. Further exploration in the next years contributed to discovering more than 90 insignificant gas deposits.

2. Geological setting

Gas deposits occur in the Polish Lowlands in the Mississippian (Lower Carboniferous), Pennsylvanian (Upper Carboniferous), Rotliegend and Zechstein Limestone reservoirs (P. Karnkowski, 1999). All of these gas fields are connected with the Polish Basin which began to form in the Late Pennsylvanian. Its main stage of development was finished at the end of Cretaceous, when a basin uplift took place. The Polish Basin is a part of the great European basin which developed in Western Europe in the Variscan foredeep area. In Poland this basin was formed on the Variscan and Caledonian basement. The main tectonic elements determining the origin and development of the basin are the western margin of the East European Craton and the extent of Variscan and Caledonian

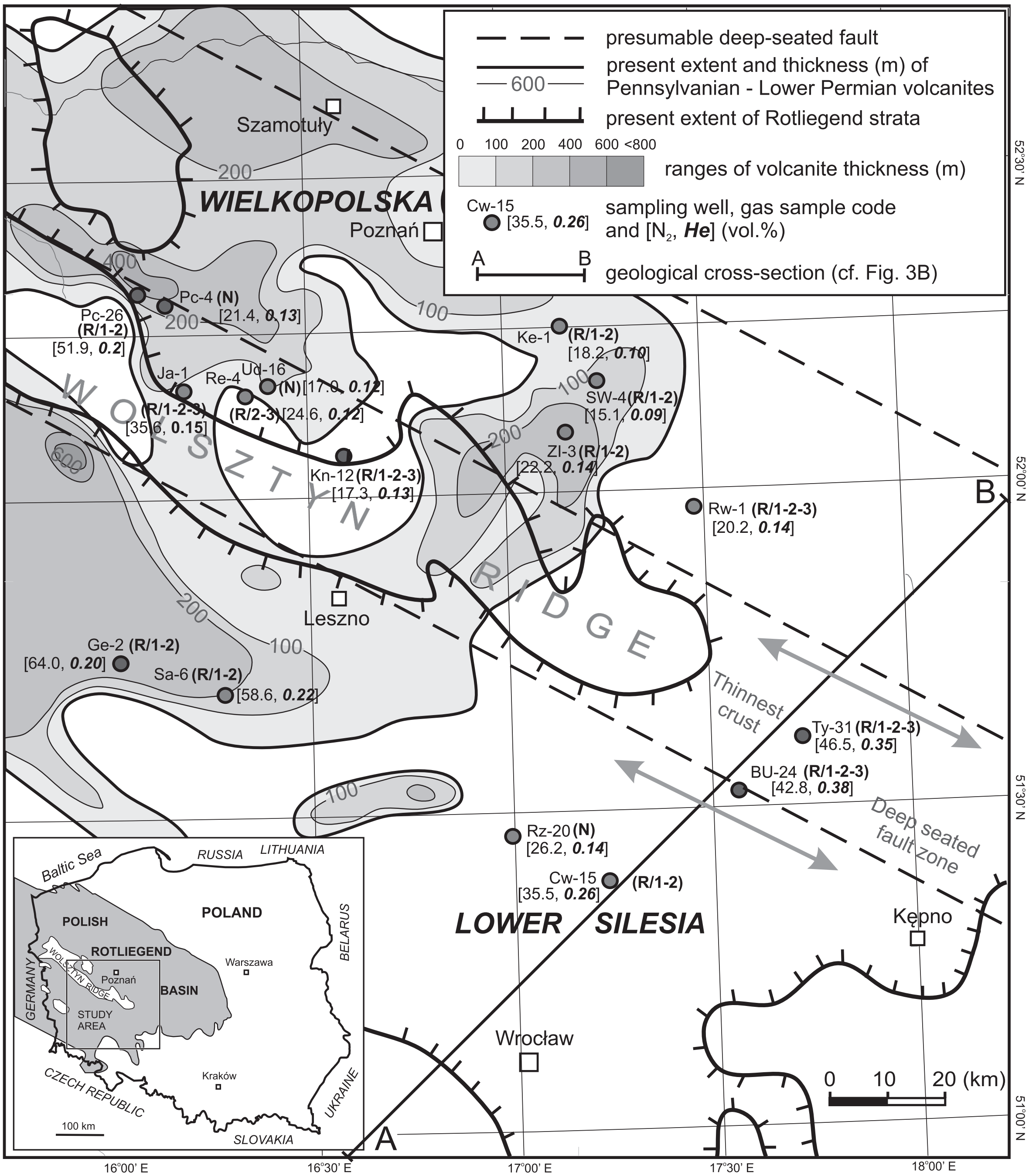

Fig. 1. Sketch geological map of the study area with the location of gas sampling sites. Geology after P.H. Karnkowski (1999b). Stable carbon isotope trend: (N) — normal $\delta^{13}C(CH_4) < \delta^{13}C(C_2H_6) < \delta^{13}C(C_3H_8)$; (R/1–2–3) — complete reversed $\delta^{13}C(CH_4) > \delta^{13}C(C_2H_6) > \delta^{13}C(C_3H_8)$; (R/1–2) — partial reversed $\delta^{13}C(CH_4) > \delta^{13}C(C_2H_6)$; (R/2–3) — partial reversed $\delta^{13}C(C_2H_6) > \delta^{13}C(C_3H_8)$.