Composition and origin of gaseous hydrocarbons in the Miocene strata of the Polish part of the Carpathian Foredeep

Maciej J. Kotarba*

The results of molecular and stable carbon isotope analyses of methane, ethane and propane, and stable hydrogen isotope analyses of methane to explain the origin of gaseous hydrocarbons accumulated in the whole Badenian and Early Sarmatian sequence of the Carpathian Foredeep, at the depths from 161 to 2,670 meters. Composition of tested gases is dominated by methane which concentration usually exceeds 98 vol. %. Methane was generated during carbon dioxide reduction pathway of microbial processes. Higher gaseous hydrocarbons (mainly ethane and propane) which are usually minor constituents (concentrations less than 0.2 vol. %), were generated during diagenetic processes and at the initial stage of the low-temperature thermogenic processes. Only the gas encountered in the Tarnów-45 well, in the bottom part of Upper Badenian sequence a typical, high-temperature, thermogenic gas generated from the oil-prone, marine organic matter (type II kerogen) which remains at transformation level corresponding to 1.1–1.6% in vitrinite reflectance scale. This gas has migrated from the Mesozoic basement where such thermogenic gases were encountered. Natural gas accumulated in the Upper Jurassic carbonate trap of the Lubaczów field is typically microbial and has migrated from the autochthonous Miocene strata along the fault zone.

Key words: *petroleum exploration, natural gas, methane, genesis, stable isotopes, carbon, Miocene, reservoir rocks, Carpathian Foredeep, Poland*

Introduction

Previous molecular and isotopic studies (mainly stable carbon isotope analyses of methane) of the natural gases accumulated in autochthonous Miocene strata of the Polish part of the Carpathian Foredeep revealed that methane which dominated in the composition of these gases was generated during microbial (bacterial) processes (Głogoczowski, 1976; Calikowski, 1983; Kotarba et al., 1987; Jawor & Kotarba, 1991, 1993; Kotarba 1992; Kotarba & Jawor, 1993). The microbial methane is of vital economic importance as its reserves constitute about 20% of overall world gas reserves (Rice & Claypool 1981; Rice 1992).

The studies on molecular composition and stable carbon isotope composition of methane, ethane and propane, and stable hydrogen isotope composition of methane aim to recognize the generation conditions of gases accumulated within the autochthonous Miocene strata of the Carpathian Foredeep.

Totally, 59 gas samples were taken from accumulations within the autochthonous Miocene strata of the Carpathian Foredeep in which: 4 samples from Lower Badenian strata, 25 samples from Upper Badenian strata and 30 samples from Lower Sarmatian strata. Data from 20 wells, mostly the isotopic analyses of methane, has been partly published in Kotarba et al. (1987) and Kotarba (1992). Locations of the gas sampling sites are presented in Fig. 1.

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Geological setting and gas occurrence

The Carpathian Foredeep is one of the largest sedimentary basins in the Central Europe. It is a tectonic through of Alpine age filled with the Miocene marine molasse. The trough extends along the front of the Carpathian orogenic arc from Vienna (Austria) in the west towards the Iron Gate (Danube) in Romania in the south-east (Fig. 1) and partly also underlies the Carpathian nappes. The Carpathian Foredeep is divided into the two basins: outer and inner (Ney et al., 1974; Oszczypko, 1996, 1997) (Fig. 1). The folded Miocene strata of the Stebnik and Zgłobice units known from the inner basin in the Polish part of the Carpathian Foredeep (Ney, 1968; Oszczypko, 1996, 1997) are thought to be unimportant for petroleum exploration. The eastern part of the outer basin (east from Kraków) is filled with Badenian and Lower Sarmatian sediments of the following thicknesses: Lower and Middle Badenian — from 0 to 300 m, Upper Badenian — from 0 to 1,700 m, and Lower Sarmatian — from 0 to 2,900 m (Ney et al., 1974). Most of the known gas fields occur within the Upper Badenian and Lower Sarmatian strata. Both the Upper Badenian and the Lower Sarmatian are represented by clay-sandy, mainly deltaic facies. Sedimentation rate of Upper Badenian sediments was maximum 1,500 m/Ma, and for the Lower Sarmatian ones it reached 5,000 m/Ma. On the other hand, the Lower and Middle Badenian strata comprise shallow-water psammitic, argillaceous and chemical sediments. The autochthonous Miocene sediments of the outer basin of the Carpathian Foredeep have not be affected by Alpine orogenic movements and rest almost horizontally upon the Precambrian–Paleozoic–Mesozoic basement (Oszczypko, 1982, 1996).

The gas fields discovered in the autochthonous Miocene strata of the Polish part of the Carpathian Foredeep contain practically only the methane and small amounts of higher gaseous hydrocarbons. Cumulative production between 1945 and 1997 yielded about $80*10^9$ cubic meters of gas. The remaining proved reserves of about $70*10^9$ cubic meters are available. Undiscovered resources are estimated to be about $190*10^9$ cubic meters. The production of natural gas from the autochthonous Miocene reservoirs has started in 1924 from the Daszawa field (recently in the Ukraine). Since 1945, about 70 gas fields have been discovered in the Polish part of the Carpathian Foredeep, and the most important is the Przemyśl–Jaksmanice deposit of initial reserves about $80*10^9$ cubic meters.

*University of Mining and Metallurgy, Department of Fossil Fuels, al. Mickiewicza 30, 30-059 Kraków, Poland,
email: kotarba@uci.agh.edu.pl

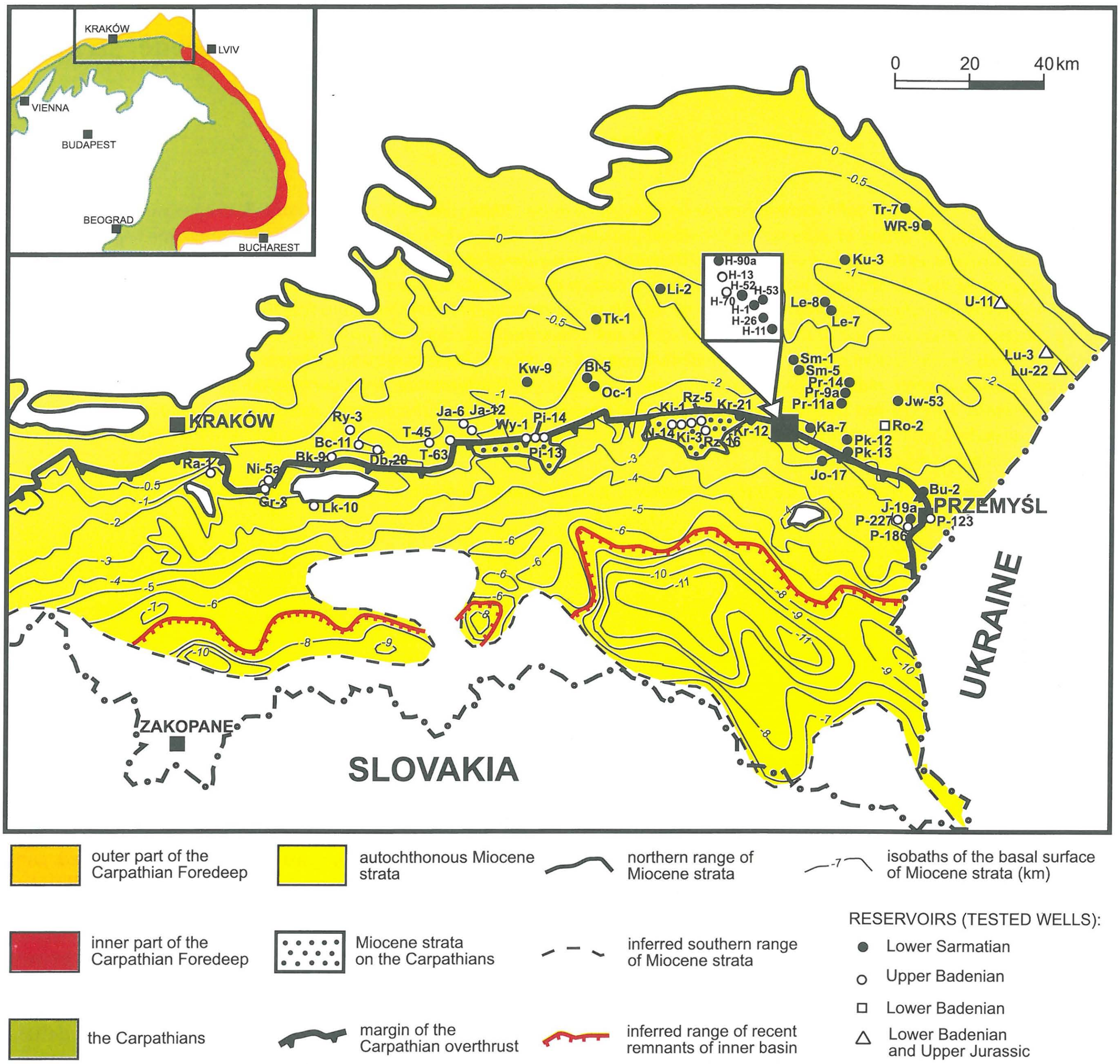

Fig. 1. Sketch map of the central and eastern parts of the Polish Carpathian Foredeep and location of studied wells

Experimental

Gas samples were collected only from the wellheads. Samples were collected to 1 or 2 dm^3 metal containers.

The molecular composition of natural gases was analysed in a set of columns on Helwett Packard 5990, Chrom-5 and Chrom-41 gas chromatographs with flame ionization and thermal conductivity detectors.

Stable isotope analyses were carried on with the Finnigan Delta, Micromass MM 602C and MI-1201 mass spectrometers. The stable carbon and hydrogen isotope data are presented in the δ-notation relative to the PDB and the SMOW standards, respectively. The analytical precision is estimated to be ±0.2‰ for carbon and ±3‰ for hydrogen.

Methane, ethane and propane were separated chromatographically for stable isotope analyses. After separation each gas was combusted over hot copper oxide (850°C). The resulting CO_2 fraction was purified and directly analyzed for $\delta^{13}C$ content, whereas the water resulting from the combustion of methane was reduced to gaseous hydrogen in a uranium furnace at 800°C or with zinc method (Florkowski, 1985).

Origin of natural gases based on molecular and isotopic compositions

Methane is one of chemical compounds in which the stable carbon and hydrogen isotope compositions are sensitive indicators of the gas origin and migration. Carbon in methane shows wide range of $\delta^{13}C$ values. Isotopically heaviest methane was encountered in the gas accompanying the thermal springs in the Yellowstone National Park ($\delta^{13}C$ = -10.4‰, Schoell, 1983, 1988; Whiticar 1994). Diversified chemical, physical and biological processes cause common, significant differences between the isotopic compositions of the source organic matter and the daughter gases. Principal role in the geochemical identification of the gases is played by the genetic factor. Analyses of stable carbon and hydro-

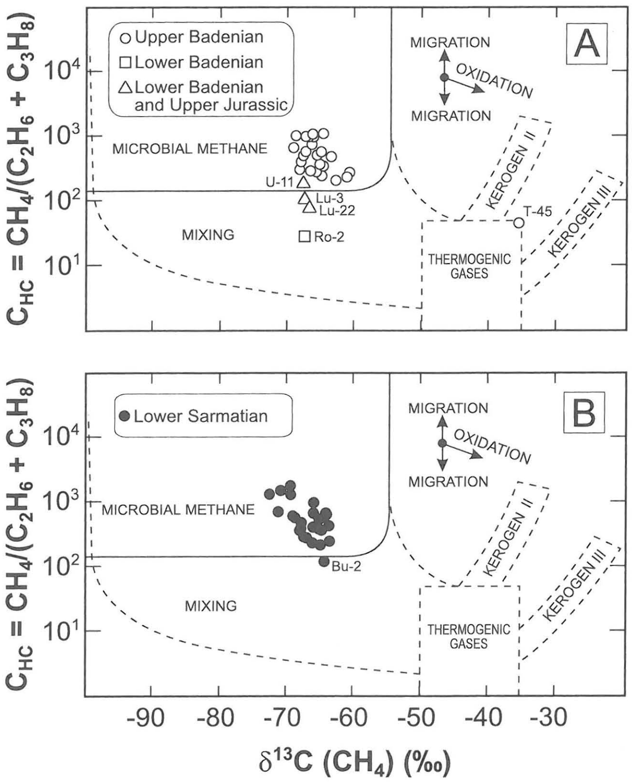

Fig. 2. Genetic characterization of **(A)** Badenian and **(B)** Sarmatian gases in terms of $\delta^{13}C(CH_4)$ versus $CH_4/(C_2H_6+C_3H_8)$. Compositional fields from Whiticar (1994)

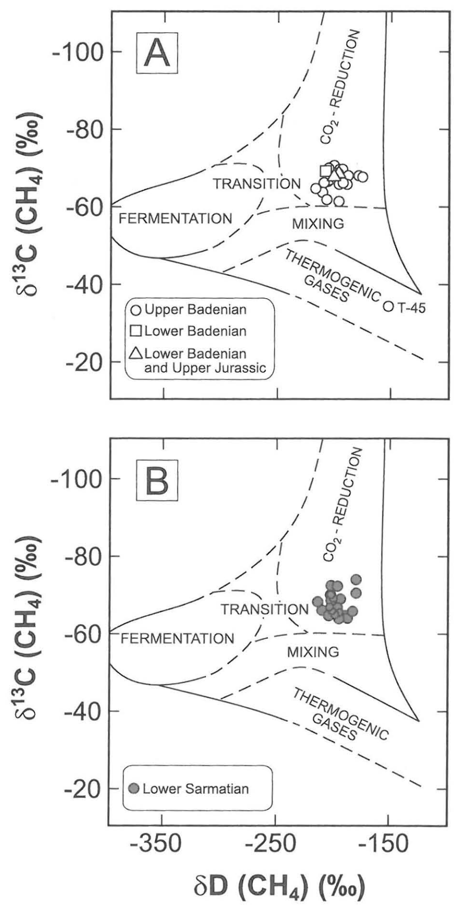

Fig. 3. Genetic characterization of **(A)** Badenian and **(B)** Sarmatian gases from the Carpathian Foredeep in terms of $\delta^{13}C(CH_4)$ versus $\delta D(CH_4)$. Compositional fields from Whiticar et al. (1986)

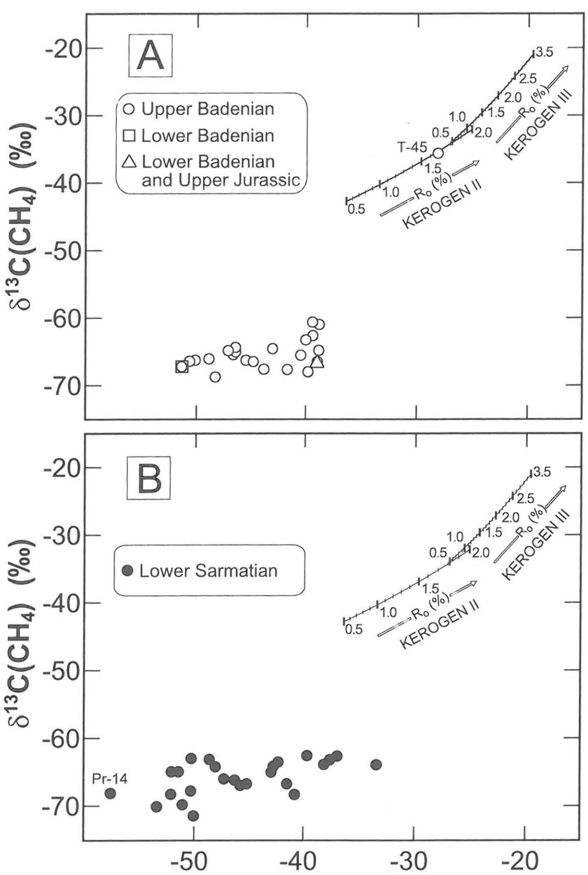

Fig. 4. Genetic characterization of **(A)** Badenian and **(B)** Sarmatian gases from the Carpathian Foredeep in terms of $\delta^{13}C(CH_4)$ versus $\delta^{13}C(C_2H_6)$. Positions of vitrinite reflectance curves for types II and III kerogen after Berner & Faber (1996)

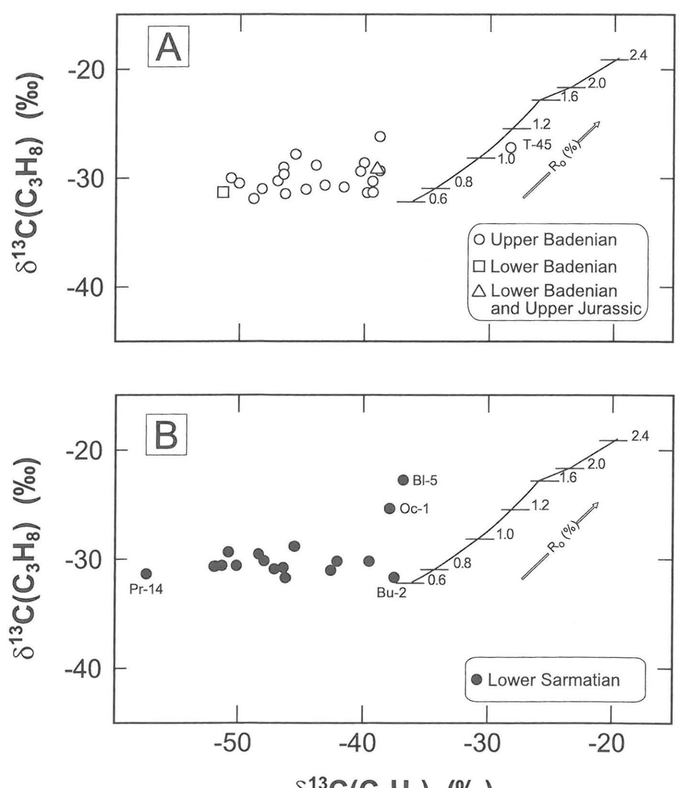

Fig. 5. Genetic characterization of **(A)** Badenian and **(B)** Sarmatian gases from the Carpathian Foredeep in terms of $\delta^{13}C(C_2H_6)$ versus $\delta^{13}C(C_3H_8)$. Positions of vitrinite reflectance curve for types II/III kerogen after Berner & Faber (1997)

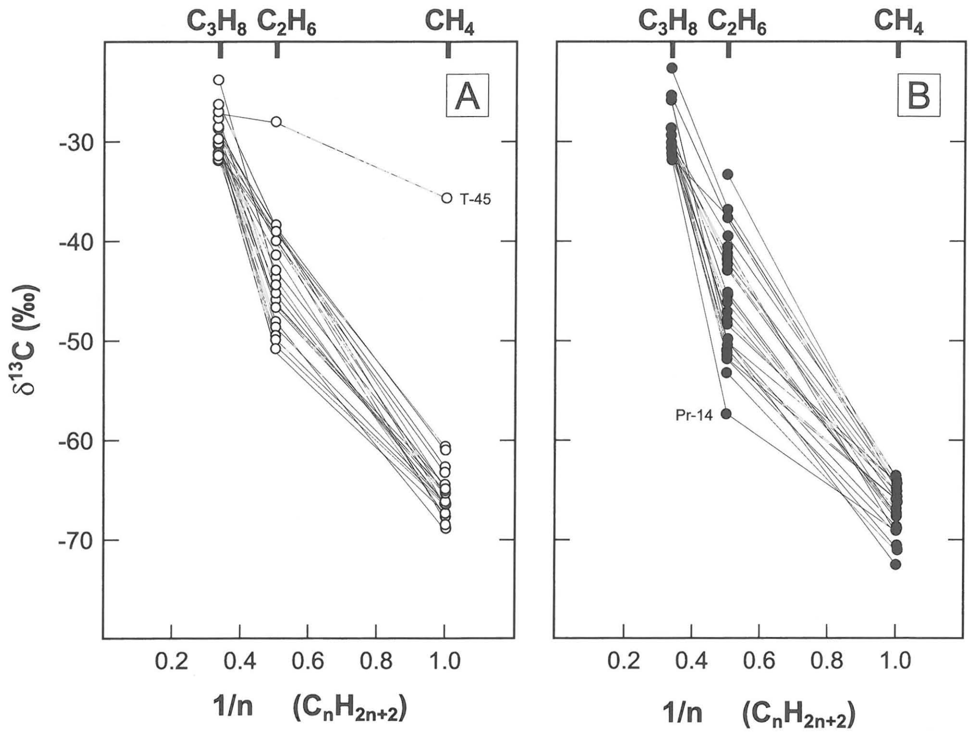

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Fig. 6. Stable carbon isotope composition of methane, ethane and propane of **(A)** Badenian and **(B)** Sarmatian gases from the Carpathian Foredeep

gen isotopes in methane enables the identification of the source organic matter from which gases were generated during microbial or thermogenic processes (e.g., Berner & Faber, 1996, 1997; Kotarba, 1995; Stahl, 1977, 1979). The $\delta^{13}C$ values of methanes generated from the marine (type II kerogen) and the terrestrial organic matter (type III kerogen) differ by 13–14‰ in the full range of transformation processes. This difference results from different chemical structures of both types of the source organic matter. Methane generated during thermogenic processes from the sapropelic organic matter shows $\delta^{13}C$ values from -55 to -30‰ whereas that produced from the humic organic matter has $\delta^{13}C$ from -30 to -20‰. On the contrary, the microbially generated methane reveals typically very low $\delta^{13}C$ values even below -100‰. Microbial gases can be generated in the two processes: methane fermentation and carbon dioxide reduction. Stable hydrogen composition δD of microbial methane varies from -380 to -150‰ (Schoell, 1983, 1988; Whiticar et al., 1986). Correlation of stable carbon isotope composition of methane with the hydrocarbon index $C_{HC} = CH_4/(C_2H_6 + C_3H_8)$ and with the stable hydrogen isotope composition of methane enables the distinction between various genetic types of methane, various generation processes and determines the maturation degree of the source organic matter (Whiticar, 1994).

Results of stable carbon isotope analyses of ethane and propane allowed the preparation of more precise genetic classification of natural gases, i.e. the distinguishing of genetic groups and enabled the identification of migration and mixing of either genetically different gases or gases produced from the same source organic matter but during the successive generation stages (Schoell, 1988; Whiticar, 1994; Berner & Faber, 1996, 1997; Kotarba et al., 1994). Both the ethane and propane are practically absent during microbial processes and appear in larger quantities only during thermogenic transformation of the organic matter. Both gases are enriched in heavy carbon isotope ^{13}C in comparison with the methane generated in the same process. Both the experimental data and theoretical calculation demonstrated that stable carbon isotope studies of methane, ethane and propane are essential for determination of the type and the maturation degree of the source organic matter in vitrinite reflectance scale (Berner & Faber, 1996, 1997; Schoell 1988, Whiticar, 1994).

Results and disscussion

Analytical results shown in Tab. 1 will be commented on separately for the gases accumulated within the Badenian and the Lower Sarmatian strata.

Depth of sampled gas accumulations in the Badenian strata varies from 170 to 2,640 meters (Tab. 1). Values of geochemical parameters for the gas accumulated in Badenian strata from the Polish part of the Carpathian Foredeep are given below:

hydrocarbon index C_{HC} $[CH_4/(C_2H_6+C_3H_8)]$ from 26 to 962, $i\text{-}C_4H_{10}/n\text{-}C_4H_6$ index from 0.5 to 16.0, CDMI index $\{CDMI = [CO_2/(CO_2+CH_4)]\ 100\ (\%)\}$ from 0.01 to 0.94%, $\delta^{13}C(CH_4)$ from -69.0 to -35.7‰, $\delta D(CH_4)$ from -215 to -151‰, $\delta^{13}C(C_2H_6)$ from -50.5 to -28.1‰, and $\delta^{13}C(C_3H_8)$ from -31.8 to -23.8‰.

Most of the analysed gases were collected from the Upper Badenian strata (Tab. 1). Only in the Rożwienica field gas is accumulated in the Lower (and partly Middle) Badenian sequence, in the Lubaczów and Uszkowce deposits it occurs in Lower Badenian strata and in the topmost parts of Upper Jurassic carbonates.

Gases accumulated in Badenian reservoirs of the Carpathian Foredeep are methane-dominated (its concentation usually exceeds 98 vol. %). Results of molecular analyses and stable carbon isotope analyses of methane, ethane and propane, and stable hydrogen isotope analyses of methane (Figs 2A to 6A) indicate that the gaseous hydrocarbons were generated during microbial and diagenetic processes, and in the initial phase of the low-temperature thermogenic processes. The only exception is gas from the Tarnów-45 which is typically thermogenic. This gas was generated from the oil-prone, marine organic matter (type II kerogen) which has

Tab. 1. Geochemical indices and stable carbon and hydrogen composition of natural gases reservoired within autochthonous Miocene strata

Well	Accumulation depth (m)	Geochemical indices			Stable isotopes (‰)			
		C_{HC}	$i\text{-}C_4/n\text{-}C_4$	CDMI	$\delta^{13}C$ (CH_4)	δD (CH_4)	$\delta^{13}C$ (C_3H_8)	$\delta^{13}C$ (C_3H_8)
Reservoirs: Lower Sarmatian								
Blizna-5 (Bl-5)	603– 623	410	4.0	0.08	-63.7	-188	-36.9	-22.8
Buszkowiczki-2 (Bu-2)	2199–2215	123	2.1	0.39	-64.4	-199	-37.6	-31.7
Husów-1 (H-1)	1934–1939	510	2.0	0.20	-65.2	-202	-48.0	-30.1
Husów-11 (H-11)	1882–1901	220	2.5	0.04	-66.0	-197	-42.9	n.a.
Husów-26 (H-26)	1937–1987	380	4.7	0.07	-67.3	n.a.	n.a.	n.a.
Husów-52 (H-52)	965–1055	602	1.8	0.11	-64.3	-204	-48.5	-29.5
Husów-53 (H-53)	1330–1375	457	4.0	0.05	-67.8	-194	-41.5	-30.8
Husów-90a (H-90a)	239– 243	1240	0.5	0.43	-69.4	-202	-52.0	-30.7
Jaksmanice-19a (J-19a)	900–1101	678	2.3	0.10	-66.0	-198	-51.9	-30.7
Jarosław-53 (Jw-53)	1188–1205	274	4.3	0.11	-67.0	-214	-47.2	-30.8
Jodłówka-17 (Jo-17)	2444–2621	234	2.3	0.04	-63.7	-195	-39.6	-30.1
Kańczuga-7 (Ka-7)	1075–1134	275	1.8	0.04	-67.4	-198	-46.3	-31.6
Korzeniów-9 (Kw-9)	161– 164	1270	0.5	0.10	-72.6	-179	-50.0	-25.9
Krasne-12 (Kr-12)	884– 892	928	2.3	0.21	-66.0	-204	-51.4	-30.6
Krasne-21 (Kr-21)	902– 913	372	2.0	0.15	-65.3	-210	-42.7	-31.0
Kuryłówka-3 (Ku-3)	675– 680	208	–	0.11	-65.0	-184	-33.4	n.a.
Leżajsk-7 (Le-7)	420– 485	509	–	0.15	-68.6	n.a.	n.a.	n.a.
Leżajsk-8 (Le-8)	416– 440	539	–	0.47	-68.8	-202	-50.2	n.a.
Lipnica-2 (Li-2)	360– 395	1667	–	0.10	-69.4	-180	-40.7	n.a.
Ocieka-1 (Oc-1)	600– 620	349	–	0.09	-64.9	-196	-38.0	-25.5
Pruchnik-12 (Pk-12)	855– 900	353	6.0	0.08	-68.0	-200	-45.6	-28.8
Pruchnik-13 (Pk-13)	1248–1255	378	10.0	0.06	-67.8	-202	-45.2	n.a.
Przeworsk-9a (Pr-9a)	266– 283	650	–	0.10	-70.8	n.a.	n.a.	n.a.
Przeworsk-11a (Pr-11a)	415– 432	693	–	0.09	-71.2	-201	-53.3	n.a.
Przeworsk-14 (Pr-14)	404– 421	590	3.7	0.11	-69.2	-202	-57.4	-31.5
Smolarzyny-1 (Sm-1)	375– 455	392	5.5	0.04	-66.2	n.a.	n.a.	n.a.
Smolarzyny-5 (Sm-5)	395– 420	390	–	-0.05	-66.5	n.a.	n.a.	n.a.
Tarnogród-7 (Tr-7)	1085–1103	538	1.7	0.07	-64.6	-202	-42.2	-30.2
Trześnik-1 (Tk-1)	188– 190	1450	–	0.13	-70.9	-197	-50.9	-29.4
Wola Różanecka-9 (WR-9)	940– 945	656	2.3	0.08	-64.2	-188	-50.2	-30.6
Reservoirs: Upper Badenian								
Borek-9 (Bk-9)	515– 542	434	1.0	0.05	-63.4	-215	-39.9	-28.6
Brzezowiec-11 (Bc-11)	839– 900	663	3.3	0.04	-66.4	-198	-49.9	-30.5
Dąbrówka-20 (Db-20)	807– 809	186	1.6	0.03	-62.7	-210	-39.2	-31.2
Grabina-2 (Gr-2)	350– 357	856	2.5	0.09	-66.6	-188	-50.5	-30.0
Husów-13 (H-13)	2398–2442	357	2.6	0.01	-67.8	-194	-41.5	-30.8
Husów-70 (H-70)	2419–2455	446	2.9	0.08	-67.6	-195	-43.8	-23.8
Jaśniny-6 (Ja-6)	817– 841	458	2.7	0.05	-65.5	-204	-46.4	-29.1
Jaśniny-12 (Ja-12)	461– 523	889	–	0.05	-68.6	n.a.	n.a.	n.a.
Kielanówka-1 (Ki-1)	2320–2348	218	6.3	0.05	-64.9	-208	-38.7	-26.2
Kielanówka-3 (Ki-3)	2306–2320	217	5.0	0.04	-64.9	n.a.	n.a.	n.a.
Łąkta-10 (Lk-10)	1876–2355	260	3.5	0.10	-66.5	-178	-44.6	-31.0
Nieznanowice-5a (Ni-5a)	310– 388	947	2.5	0.06	-66.2	-175	-48.7	-31.8
Nosówka-14 (N-14)	2300–2520	272	3.4	0.04	-68.1	-204	-39.6	-31.4
Pilzno-13 (Pi-13)	210– 216	868	–	0.11	-67.3	n.a.	n.a.	n.a.
Pilzno-14 (Pi-14)	170– 195	580	–	0.94	-69.0	-199	-48.1	-30.9
Przemyśl-123 (P-123)	2375–2432	253	3.5	0.18	-65.6	-205	-40.2	-29.4
Przemyśl-186 (P-186)	2590–2610	304	2.7	0.48	-64.7	-195	-43.0	-30.6
Przemyśl-227 (P-227)	2597–2640	323	2.2	0.52	-65.2	-192	-46.2	-31.4
Raciborsko-1 (Ra-1)	528– 535	244	16.0	0.07	-60.7	-196	-39.2	-30.3
Rysie-3 (Ry-3)	601– 624	872	–	-0.05	-66.3	-199	-45.4	-27.8
Rzeszów-5 (Rz-5)	2243–2257	497	2.8	0.15	-65.0	-192	-46.8	-30.3
Rzeszów-16 (Rz-16)	2231–2249	394	4.8	0.05	-67.3	n.a.	n.a.	n.a.
Tarnów-45 (T-45)	1365–1384	42	0.5	0.61	-35.7	-151	-28.1	-27.2
Tarnów-63 (T-63)	462– 468	206	1.4	0.10	-61.1	-206	-38.6	-29.4
Wygoda-1 (Wy-1)	592– 625	962	1.5	0.08	-64.6	-189	-46.3	-29.7
Reservoirs: Lower Badenian								
Rożwienica-2 (Ro-2)	1870–1873	26	0.8	0.08	-67.3	-206	-51.1	-31.2
Reservoirs: Lower Badenian and Upper Jurassic								
Lubaczów-3 (Lu-3)	992–1041	102	0.6	0.28	-67.3	-198	n.a.	n.a.
Lubaczów-22 (Lu-22)	1020–1045	76	1.0	0.36	-66.6	-201	-38.8	-29.0
Uszkowce-11 (U-11)	1077–1084	188	1.2	0.53	-67.5	n.a.	n.a.	n.a.

$C_{HC} = CH_4/(C_2H_6+C_3H_8)$; $CDMI = [CO_2/(CO_2+CH_4)]*100$ (%)

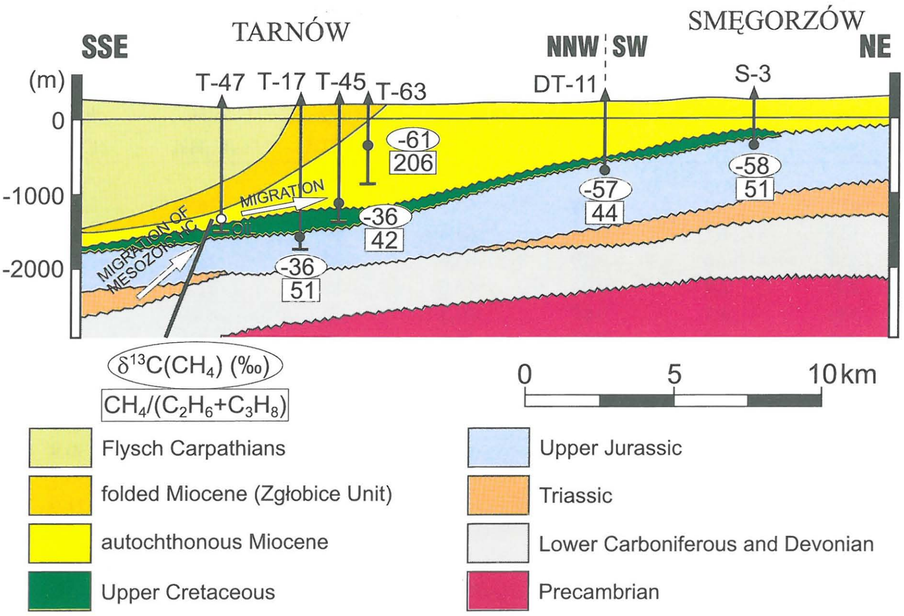

Fig. 7. Geological cross section through the Tarnów, Dąbrowa Tarnowska and Smęgorzów fields with isotopic data after Kotarba & Jawor (1993)

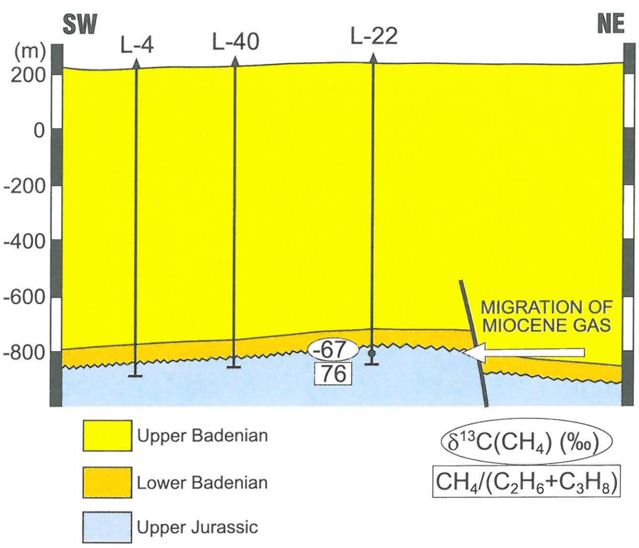

Fig. 8. Geological cross section through the Lubaczów field with isotopic data

attained maturation degree corresponding to 1.1 to 1.6% in the vitrinite reflectance scale (Figs 4A and 5A). The gas has migrated together with the oil to the autochthonous Miocene complex from the Upper Jurassic carbonates (Fig. 7) where several discovered deposits accumulating oil and gas produced from this genetic type of organic matter (Kotarba & Jawor, 1993). In the Tarnów-47 well even the oil shows were encountered in the bottom part of the autochthonous Miocene sequence which is a curiosity in the Carpathian Foredeep (Kotarba & Jawor, 1993). Methane reservoired in the other deposits originated from the microbial carbon dioxide reduction (Fig. 3). In both the Roźwienica (Ro-2 sample) and the Lubaczów deposits (Lu-3 and Lu-22 samples) very small admixture of diagenetic (and/or low-temperature thermogenic) methane has been identified (Tab. 1, Fig. 2A). In the Lubaczów deposit gas filled also the trap in the Upper Jurassic carbonates. Genetically, this gas is typical microbial methane which migrated to the Upper Jurassic trap from the autochthonous Miocene strata along the fault zone (Fig. 8).

Insignificant changes in values of geochemical indices and isotopic ratios (Tab. 1 and Fig. 9) with the depth suggest quite uniform generation conditions of microbial methane in the whole Badenian succession. Moreover, the lack of dependence of stable carbon isotopic compositions of ethane and propane with the depths (Tab. 1, Fig. 9) also indicates the similar generation conditions of these gases within the full Badenian sequence.

Depths of sampled gas accumulations in the Lower Sarmatian strata are between 161 and 2,621 meters (Tab. 1). Geochemical indices and isotopic ratios of the gas reservoired within the Lower Sarmatian of the Polish part of the Carpathian Foredeep are given below (Tab. 1):

hydrocarbon index [$C_{HC} = CH_4/(C_2H_6+C_3H_8)$] from 123 to 1,667, $i\text{-}C_4H_{10}/n\text{-}C_4H_{10}$ ratio: from 0.5 to 10.0, CDMI index {CDMI = [$CO_2/(CO_2+CH_4)$] 100 (%)} from 0.04 to 0.47%, $\delta^{13}C(CH_4)$ from -72.6 to -63.7‰, $\delta D(CH_4)$ from -214 to -179‰, $\delta^{13}C(C_2H_6)$ from -57.4 to -33.4‰, and $\delta^{13}C(C_3H_8)$ from -31.7 to -22.8‰.

Composition of theses gases is also methane-dominated (Tab. 1). Results of stable carbon isotope analyses in methane, ethane and propane, and stable hydrogen isotope analyses in methane (Figs 2B to 6B) point out that the hydrocarbons were generated during the carbon dioxide reduction of microbial processes as well as, sporadically, in the initial phase of thermogenic processes. Methane was produced during microbial carbon dioxide reduction (Figs 2B and 3B). The only exception is the gas from the Buszkowiczki field (Bu-2 sample) where very small amounts of diagenetic and/or low-temperature thermogenic methane was found (Tab. 1, Fig. 5B). Minor ethane and propane were generated in both the diagenetic processes and in the initial phase of the low-temperature thermogenic processes (Figs 4B and 5B). The highest contents of thermogenic propane were reported from the Blizna and the Ocieka deposits (Bl-5 and Oc-1 samples, Fig. 5B) whereas the largest concentration of diagenetic (microbial) ethane was found in the Przeworsk deposit (Pr-14 sample, Figs 4B and 5B).

Similarly to the Badenian gases, minor changes of geochemical indices and isotopic ratios with the depth (Fig. 9) indicate the alike generation conditions of microbial methane within the full thickness of the Lower Sarmatian succession. Additionally, lack of correlation between the stable carbon isotope composition of ethane and propane with the depth (Tab. 1 and Fig. 9D) also points to the similarity of diagenetic and/or low-temperature thermogenic processes in the full thickness of Lower Sarmatian succession.

Conclusions

The Miocene gas deposits of the Carpathian Foredeep are dominated by methane generated by the microbial carbon dioxide reduction. This process, unlike the methane fermentation, occurs in the marine environment. Small amounts of higher gaseous hydrocarbons (mainly ethane and propane) were produced during the initial phase of low-tem-

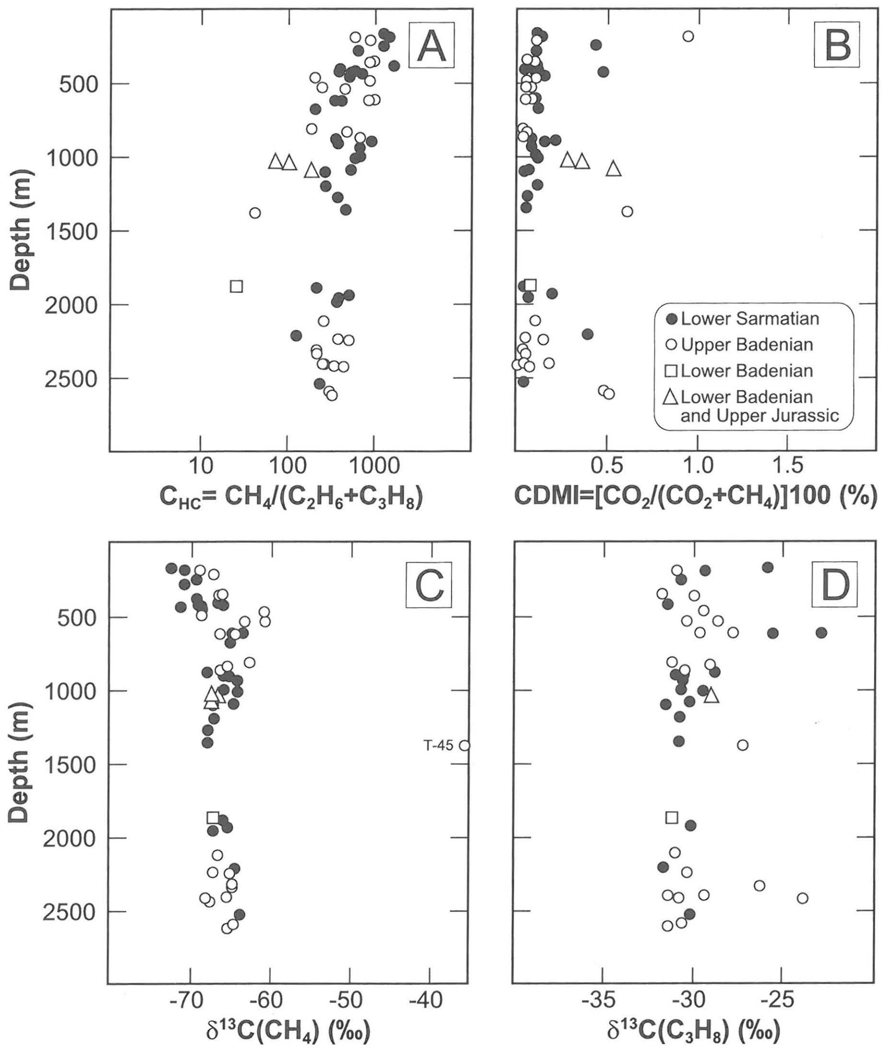

Fig. 9. **(A)** Hydrocarbon index, **(B)** carbon dioxide-methane index, **(C)** $\delta^{13}C(CH_4)$ and **(D)** $\delta^{13}C(C_3H_8)$ versus depth

perature thermogenic and/or diagenetic processes. Both the molecular and isotopic compositions of gases accumulated in the autochthonous Badenian and Lower Sarmatian strata are practically similar which indicates homogeneity of generation processes within the full thickness of Miocene succession. Both the high sedimentation rate and the rhythmic and cyclic deposition of Miocene clays and sands facilitated the gas accumulation and formation of multihorizontal gas fields (Kotarba et al., 1998a). Microbial gases generated in a particular claystone/mudstone horizon migrated to the overlying sandstone horizon which, in turn, was covered by another claystone/mudstone bed. The only exception is the gas from the Tarnów-45 well reservoired in the bottom part of Lower Badenian sequence. This is the typical thermogenic gas produced from oil-prone, marine organic matter (type II kerogen) which remains at the maturation stage corresponding to 1.1 to 1.6% in vitrinite reflectance scale whereas the whole Miocene sequence is dominated by the type III (humic), low-matured kerogen of maximum vitrinite reflectance 0.6% R_o (Kotarba et al., 1998b). Hence, the gas reservoired within the Badenian strata in the Tarnów-45 well had to migrate from the Mesozoic basement where such thermogenic hydrocarbons are common (Kotarba & Jawor, 1993). Natural gas from the Lubaczów field accumulated in Upper Jurassic carbonate trap is therefore, a typical microbial gas which migrated from autochthonous Miocene strata along the fault zone.

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