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Material Composition of Near-surface Section Dispersed Gases as an Indicator of the Genetic Heterogeneity of the Migration Hydrocarbon Flow

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Abstract

The relevance of the work results from the insufficiency of criteria for assessing the oil-bearing potential of territories and local geological features while conducting land geochemical surveys. Geochemical surveys are aimed at identifying surface hydrocarbon anomalies, the genesis of which is associated with microfluid and diffusive migration from oil and gas deposits. However, as the evidence from practice shows, not all hydrocarbon anomalies on the surface identified by the quantitative criteria indicate petroleum accumulations within the earth. Therefore, when interpreting surface geochemical fields to find oil and gas deposits, it is necessary to take into account not only migration intensity indicators but also the material composition of the migration flow. The purpose of the work is to analyze the material composition of near-surface section dispersed gases and identify intercomponent correlations that would help to determine the genesis of detectable components. To solve this problem, the authors subjected core samples from shallow (up to 30 m) wells drilled in an oil and gas-bearing territory of the north of Western Siberia to thermal vacuum degassing and then conducted statistical processing of data on the content of gas components. The obtained results showed the genetic heterogeneity of dispersed hydrocarbon and inorganic gases in the upper part of the sedimentary cover.

Keywords: Hydrocarbon migration, Gas diffusion in sedimentary rocks, Near-surface section gases, Geochemical surveys, Geochemical field.

1 Introduction

Geochemical surveys are aimed at locating hydrocarbon deposits by aureoles of reservoir content dispersion in surface environments: soil, snow, bottom sediments, etc. In the case of a hydrocarbon deposit, one has to deal with a complex multicomponent reservoir system, each component of which migrates in accordance with its physical and chemical properties (1). The concentration fields of various reservoir components do not always coincide because of a wide range of physical and chemical properties of oil components. This implies the importance of choosing geochemical mapping parameters, which will depend on the methodological principles of the technology.

The technological diversity of modern geochemical methods can be summarized in two methodological principles:

a) The *intensity principle* which implies studying the distribution of a small set of oil substances over the area, as a rule, saturated and aromatic gaseous and low-boiling hydrocarbons (2). Approaches to interpreting their spread on the surface are well developed. Areas with the absence of movable hydrocarbons in the section are reliably determined, local marginal zones of formation fluid migration are identified, areas with an effective seal are mapped. Since gas occurrence intensity depends heavily on the fluid permeability of overlying strata, it is difficult to perform an adequate interpretation without additional, as a rule, seismic data.

b) the *matching principle* (Gore-Sorber technology) (3) which considers as the main indicator the match between migration flow composition at each observation point in the area under investigation and migration flow composition in obviously productive and unproductive areas. To implement this approach, the maximum possible number of oil components (up to 80 substances) is determined.

Depending on the degree of matching between gas material composition and a particular standard, each observation point in the area under investigation is assigned an index of matching with either the standard productive area or the standard unproductive one; using this index, the territory is mapped and a forecast of oil potential is done.

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The approach implemented in the Gore-Sorber method is very reasonable, but its use in Western Siberia is not necessarily successful because of the difference in geological conditions of investigated and standard areas.

Practical results (2, 4) showed the insufficiency of each technique applied separately, but they revealed the expediency of a complex approach: the necessity of evaluating both the intensity of the migration flow and its material composition. To implement the complex approach, it is necessary to improve interpretational algorithms – to replace the empirical comparison of the compositions of studied and standard samples by clear geochemical criteria based on the universal characteristics of migration from a hydrocarbon deposit eliminating the influence of dispersed organic matter and diagenesis processes. This can be done by studying the composition of near-surface section occluded hydrocarbons.

2 Materials and Methods

To identify the patterns of dispersed gas distribution in the near-surface section, the authors studied the gas saturation of core samples from eight shallow (up to 30 m) wells drilled in an oil and gas-bearing area in the north of Western Siberia (Fig. 1). Drilling was carried out using the core method without circulating fluid; the core samples were taken at an interval of 0.8-1 m. The samples were represented by permafrost sandy or loamy rocks with ice interlayers.

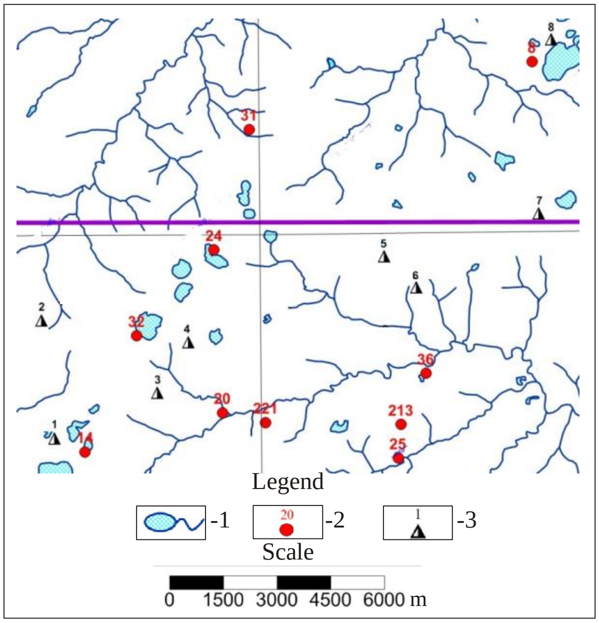

Fig. 1: Location of wells in the prospecting block territory: 1 – hydrographic network; 2 – exploration well; 3 – core well

The core samples were delivered to the laboratory in a frozen form and stored there under refrigeration until degassing. The gas was extracted from the core by thermal vacuum degassing and analyzed using the chromatographic method. The conducted analysis allowed obtaining the data on the content of saturated and unsaturated hydrocarbons from methane to octane, as well as inorganic gases (oxygen, hydrogen, carbon dioxide, and helium) in the dispersed gas extracted from the core samples. In total, 267 samples were studied. To identify patterns in the component composition, statistical data processing was performed. The authors used such statistical tools as two-factor analysis, correlation analysis, and frequency distribution.

3 Results

It was discovered that gas composition is characterized by sharp heterogeneity both between wells and along each hole. Methane was detected in all samples at concentrations from 0.00025 to 52.8% by volume with a modal range of 0.001-0.003% by volume. Maximum values were found in wells Nos. 7 (52.8% at a depth of 7.3 m and 11.4% at a depth of 18 m) and 8 (5.5% at a depth of 22.7 m).

The analysis of methane correlations shows that its content does not depend on the depth: the weak correlation (C = 0.33) was detected only in the well No. 6. Methane correlation with other hydrocarbon gases is very complex and uneven in different wells. For example, in the wells Nos. 2, 3, 5, 6, 7, 8, the methane content is not correlated with the content of its nearest homologs and olefins.

In the well No. 1, methane is correlated with its homologs to pentane inclusive (C from 0.57 with n-C$_5$ to 0.92 with C$_2$); its correlation with ethylene is weaker (C = 0.58). The same can be observed in the well No. 4, but the correlation is weaker, C does not exceed 0.58 (with ethane).

Methane is correlated with the following inorganic components: with CO$_2$ (C = 0.5 in the well No. 1, C = 0.74 in the well No. 3, C = 0.64 in the well No. 8), more rarely with H$_2$ (C = 0.59 in the well No. 1, C = 0.59 in the well No. 4). The expected negative correlation with oxygen (biogenic methane is produced more by anaerobes) is weakly expressed: only in the wells No. 5 and 7, there is a near-significant C -0.37 – -0.41.

Methane homologs from ethane to hexane are identified in all wells in different concentrations. Non-zero values of their concentrations vary from n·10^{-6} to n·10^{-3}%. The common pattern: the average and maximum values of hydrocarbons fall with the increase in the hydrocarbon chain length, the concentration of isoalkanes is less than that of normal alkanes, olefins are less than alkanes with the same number of carbon atoms.

Correlation analysis shows that the content of methane homologs does not depend on the sampling depth. Methane homologs are tightly interrelated: the correlation coefficients vary from 0.75 to 0.98. The correlation between the content of normal alkanes is equally high both between themselves and with branched structure alkanes. Their similar genesis is beyond doubt. The correlation between saturated and unsaturated hydrocarbons is expressed in significant coefficients, which are noticeably lower than those of alkanes between themselves. In other words, each alkane is better correlated with its isomers and homologs than with an olefin even with the same number of carbon atoms.

The stable correlation between the contents of methane homologs and hydrogen is conspicuous. In one form or another, it is observed in all wells. The correlation coefficients of methane homologs and hydrogen are maximal with ethane (C = 0.96 in the well No. 2) and fall with the increase in the hydrocarbon chain length. In the wells Nos. 4 and 8, weakly significant (0.44-0.48) correlation coefficients of methane homologs with carbon dioxide are also observed. Methane homologs are not correlated with other inorganic components.

Olefins with the number of carbon atoms from two to five (from ethylene to pentene) were found in all wells at concentrations varying widely from zero to $8 \cdot 10^{-3}$% by volume. Their content is less than the content of alkanes with the same number of carbon atoms and their average values decrease with the increase in the hydrocarbon chain length.

Correlation analysis shows that olefins are more highly correlated with each other than with saturated hydrocarbons, even if the number of carbon atoms in the olefin and alkane is the same. For example, propylene has a correlation coefficient with butylene of 0.95, and with propane – 0.78.

Their content does not depend on depth. Olefins are correlated with hydrogen better than with any other inorganic components: in all wells except the well No. 6; there is a stable correlation between hydrogen and olefins with C from 0.6 to 0.93. In the well No. 6, the correlation coefficient between olefins and hydrogen is insignificant, but graphical constructions (Fig. 2) show their interdependent distribution over the section.

Carbon dioxide was detected in 100% of samples. The minimum value of 0.072% by volume corresponds approximately to its concentration in the atmosphere. The maximum CO_2 content (46.5%) was found in the well No. 7 at a depth of 11.6 m. In other wells, its content does not exceed 3-4%. The correlation analysis shows that carbon dioxide distribution in near-surface rocks is generally not correlated with other components of the gas mixture. Only in the well No. 8, its content is correlated with hydrocarbon gases – methane, ethylene, pentane, and hexane. In the well No. 4, the CO_2 distribution along the hole is weakly inversely correlated with the depth (K = -0.56) and is correlated with the distribution of olefins.

Hydrogen is found in almost all samples. The zero values of its content are found in the wells Nos. 7 and 8. Its concentrations vary from 0.004 to 6.7% by volume. The maximum is observed in the well No. 7 at a depth of 18 m. As mentioned above, the correlation analysis shows a stable correlation of hydrogen with methane homologs, to a lesser extent – with olefins. In the wells 3 and 5, hydrogen shows a pronounced negative (C = -0.64 and -0.68 respectively) correlation with oxygen, in the wells Nos. 1 and 4 – with methane (C = 0.59 in both wells). A high correlation between olefins and hydrogen is observed along some wells (Fig. 2), which can be explained by the hypothesis of the biochemical origin of H_2, when bacteria decompose organic matter in water-bearing beds. In its turn, the olefin formation process is also directly related to the bacterial activity. At the depths of 20-25 meters, an increased content of hydrogen and unsaturated hydrocarbons is observed, so this interval can be defined as water saturated.

Table 1: The table of paired coefficients of correlation between the dispersed gas components in the near-surface rocks (sampling for all wells)

	depth	CH_4	C_2H_6	C_2H_4	C_3H_8	C_3H_6	iso-C_4H_{10}	n-C_4H_{10}	C_4H_8	iso-C_5H_{12}	n-C_5H_{12}	C_5H_{10}	iso-C_6H_{14}	n-C_6H_{14}	CO_2	O_2	H_2	He
Depth, [m]	1.00																	
CH_4	-0.04	1.00																
C_2H_6	0.10	0.10	1.00															
C_2H_4	-0.07		***0.76***	1.00														
C_3H_8	0.06	0.14	***0.95***	***0.80***	1.00													
C_3H_6	0.02	0.06	***0.88***	***0.93***	***0.89***	1.00												
iso-C_4H_{10}	0.03	0.15	***0.86***	***0.70***	***0.89***	***0.77***	1.00											
n- C_4H_{10}	0.03	0.14	***0.91***	***0.76***	***0.97***	***0.84***	***0.94***	1.00										
C_4H_8	-0.01	-0.02	***0.67***	***0.74***	***0.65***	***0.80***	***0.58***	***0.63***	1.00									
iso-C_5H_{12}	0.05	0.07	***0.55***	***0.32***	***0.51***	***0.41***	***0.72***	***0.57***	0.23	1.00								
n- C_5H_{12}	-0.03	0.11	***0.76***	***0.69***	***0.84***	***0.71***	***0.84***	***0.90***	***0.65***	***0.48***	1.00							
C_5H_{10}	-0.04	-0.04	0.25	***0.34***	0.22	***0.36***	***0.30***	0.21	***0.31***	***0.39***	0.23	1.00						
iso-C_6H_{14}	-0.07	-0.02	***0.38***	***0.36***	***0.41***	***0.37***	***0.49***	***0.50***	***0.46***	***0.29***	***0.56***	0.08	1.00					
n-C_6H_{14}	0.03	-0.03	***0.77***	***0.60***	***0.76***	***0.71***	***0.75***	***0.80***	***0.70***	***0.38***	***0.83***	0.13	***0.50***	1.00				
CO_2	-0.06	***0.35***	0.13	0.15	0.18	0.11	0.16	0.15	0.01	0.09	0.09	0.01	0.01	0.02	1.00			
O_2	-0.02	***-0.28***	***-0.31***	-0.19	***-0.32***	-0.17	***-0.28***	***-0.30***	-0.08	-0.14	-0.23	0.00	-0.11	-0.16	***-0.37***	1.00		
H_2	0.07	0.16	***0.67***	***0.58***	***0.76***	***0.63***	***0.64***	***0.71***	0.25	***0.45***	***0.52***	0.22	0.20	***0.33***	0.23	***-0.43***	1.00	
He	-0.01	-0.06	-0.12	-0.12	-0.12	-0.10	-0.17	-0.14	-0.10	-0.12	-0.13	-0.06	-0.11	-0.10	-0.08	0.15	-0.10	1.00

Oxygen is found in 100% of samples in concentrations from 8 to 22.5% by volume. Correlation analysis revealed no obvious correlation of the oxygen content with other indicators.The oxygen content distribution (Fig. 3) shows that this gas results from a buried atmosphere, there are no non-atmospheric sources of oxygen.

Helium is not found along the well No. 8. In the other wells, its content varies from zero to 0.024% by volume. Its content in the samples is not correlated with other indicators: the maximum correlation coefficients (in the well No. 6 with some alkanes) are 0.34-0.51.

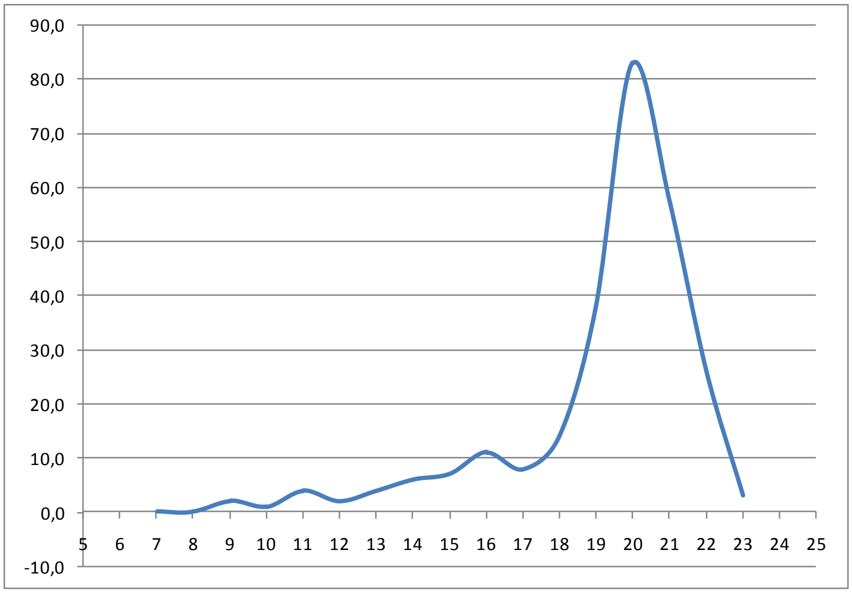

Fig. 3: Frequency distribution of oxygen content values (vol%).

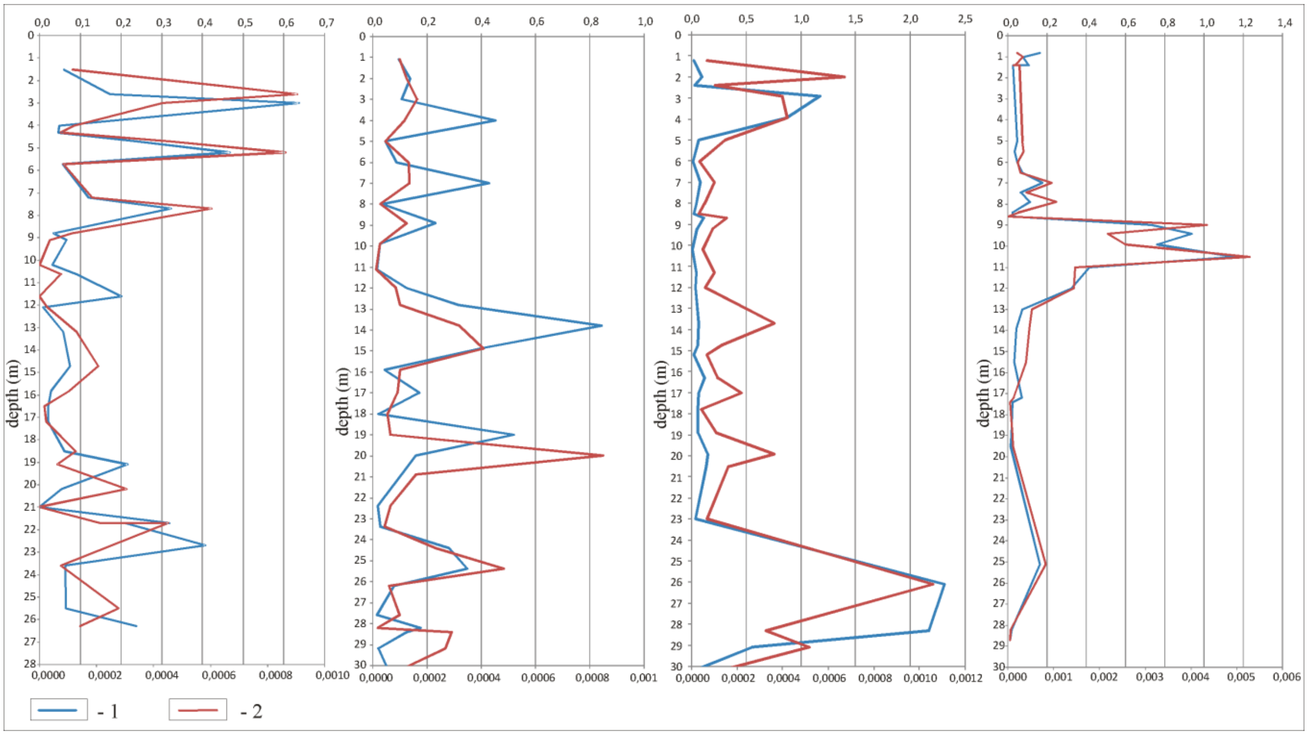

Fig. 2: Distribution of geochemical parameters (H_2, olefins) along the wells Nos. 8 – 6 – 5 – 2. 1 – H_2 content (vol%) – along the upper horizontal axis; 2 – olefins content (vol %) – along the lower horizontal axis.

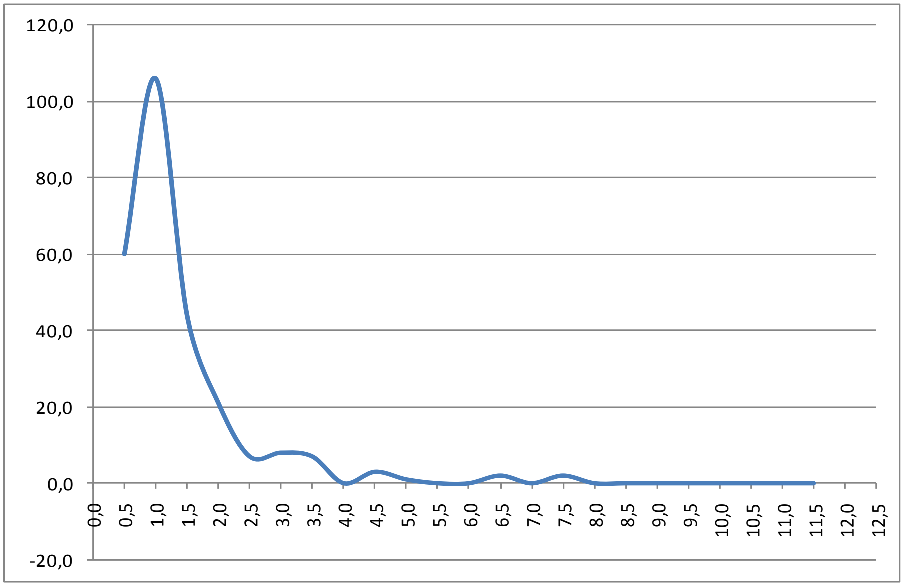

Fig. 4 Frequency distribution of carbon dioxide content values (vol%).

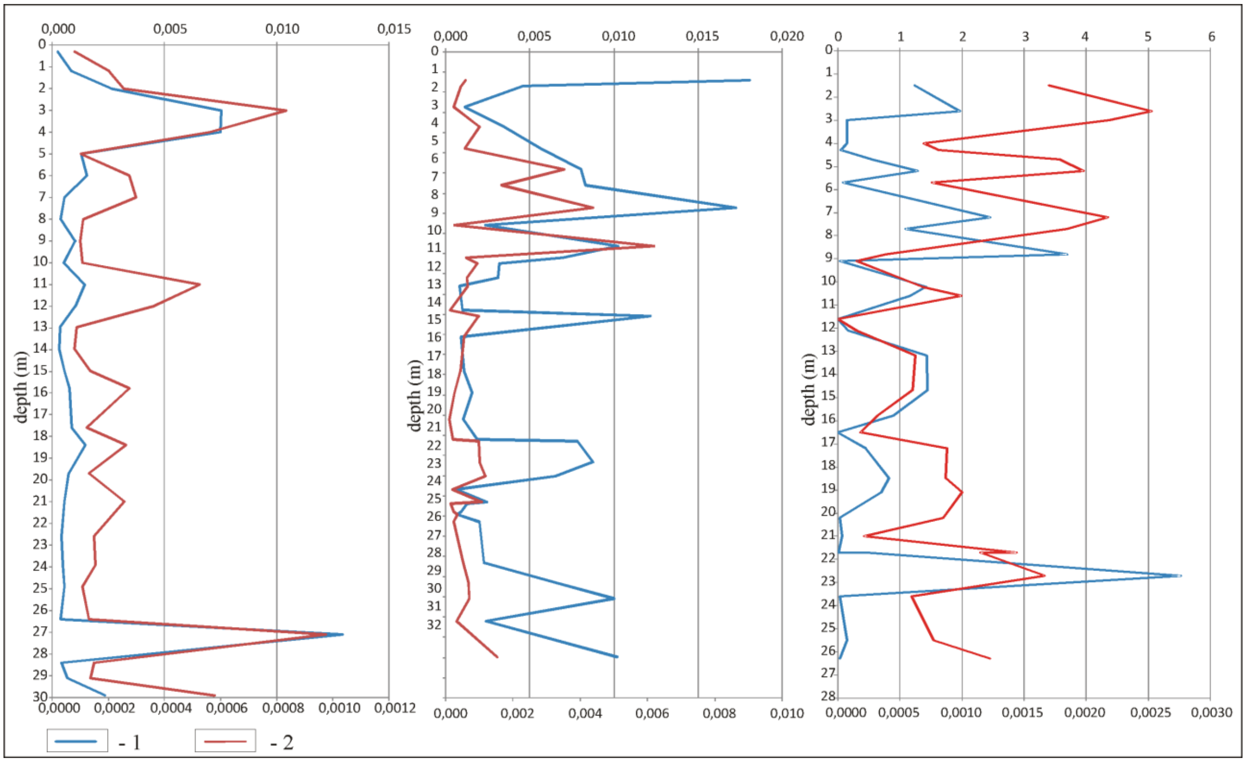

Fig. 5: Distribution of geochemical parameters (methane and methane homologs) along the wells Nos. 8 – 6 – 5 – 2.
1 – content of methane (% vol.) – along the upper horizontal axis; 2 – content of methane homologs $C_2 – C_6$ (% vol.) – along the lower horizontal axis.

4 Discussion

The variations of O_2 concentrations are associated exclusively with its low concentrations relative to the atmosphere, which is explained by its active consumption by microorganisms in weakly aerated interlayers of the near-surface section.

The absence of pronounced oxygen correlation with carbon dioxide, which is typical to the areas of high microbiological activity, indicates the polygenic origin of CO_2.

The modal values of CO_2 (Fig. 4) are higher than its content in the atmosphere, which indicates the presence of other CO_2 sources in addition to the atmosphere.

Obviously, this is microbiological and abiogenic oxidation of organic matter, but there is also a possibility of CO_2 migration from the underlying layers where it is actively released during the diagenesis and catalysis of dispersed organic matter. Since both gases are present in the atmosphere, their content is affected by the degree of aeration, which depends on the lithology and moisture of the rocks above the sampling point.

One should take into account the complex role of the microbiological factor in the formation of near-surface section gases. Methane generation is associated with archaeal activity under anaerobic conditions with $pH < 7$. On the contrary, microbiological reduction of alkanes occurs in an aerobic environment (5).

Oxygen was discovered in all samples, and therefore both catagenetic and biogenic methane is migratory for the studied section with the difference that biogenic methane comes from the anaerobic zone of dispersed organic matter diagenesis.

The analysis of gas distribution across the section (Fig. 5) to some extent confirms the correlation analysis data: in the wells Nos. 1, 4 and (to some extent) 8, there is a joint distribution of methane and its homologs.

The relatively low values of methane in the wells Nos. 1 and 4 show that both methane and other light alkanes have the same source in the catagenesis zone, and it is likely to be a hydrocarbon accumulation. In these wells, the methane correlation with hydrogen is observed. In the well No. 8, the methane content is two orders of magnitude higher than in the wells Nos. 1 and 4.

In the other wells, methane and its homologs are distributed independently, which indicates the presence of a powerful competitive source of methane.

The maximum values of methane are observed in the well No. 7 – more than 50% at a depth of 8 m. Along the rest of the well, its content is also high; the average value is 3.6%. This may be a sign of hydrate formation in permafrost rocks.

5 Conclusion

Statistical indicators of measured components and intercomponent correlations show the complex genesis of gas obtained by degassing samples of the near-surface rocks.

The following processes are involved in the formation of the dispersed gas composition:

- hydrocarbon and inorganic gas migration from the zone of organic matter diagenesis;
- hydrocarbon migration from oil-bearing strata;
- aerobic microbiological oxidation of migration alkanes;
- anaerobic methane generation by archaea;
- formation of gas hydrates in permafrost rocks.

The genesis of hydrogen and olefins is of particular interest. There are practically no olefins in the composition of oil and gas accumulations in the north of Western Siberia, and hydrogen is rarely found and only in small quantities. However, hydrogen is often found in the composition of water-dissolved gases (6). The high correlation of hydrogen and olefins with methane homologs may point to their genesis association with the bioreduction of alkanes in the upper layers of the sedimentary cover.

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