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Comprehensive assessment and analysis of the oil and gas potential of Meso-Cenozoic sediments in the North Caucasus

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Abstract. At the present stage, the development of the oil and gas industry in the Russian Federation is impossible without replenishing the raw material base, so the urgent task is to conduct investigations, prospecting and evaluation of oil and gas bearing capacity prospects in undiscovered areas. The purpose of the investigations is to analyze facies and thicknesses, choose the methodology of prospecting and exploration in reservoirs, make a comprehensive assessment of oil and gas bearing capacity prospects based on experimental investigations and construct a map of oil and gas bearing capacity prospects of the studied sediment structure. The methodology of the conducted investigations was to identify and trace zones of increased fracturing by qualitative interpretation of time seismic sections. Methods for qualitative interpretation of time seismic sections, the model of physical, chemical and geochemical criteria developed by I.A.Burlakov, gas and geochemical surveying and correlation analysis were used in the investigations. A number of prospecting criteria, established based on the analysis of reference seismic materials on well-studied areas in comparison with the results of well tests, were also used. Structural plan for forecast prospects of oil and gas bearing capacity in the studied area was made; zonal and local objects with prospects for oil and gas were identified. Graphical plotting of Eh and pH concentrations distribution and various gas and geochemical indicators allowed identifying zones of possible oil and gas accumulations and starting their detailed survey. Processing of gas and geochemical materials by means of software allowed efficient assessment of prospects for oil and gas bearing capacity of the investigated objects.

***Key words*:** oil and gas bearing capacity; field; productive horizon; reservoir; gas and geochemical survey; facies analysis; fracture zones; structural plan

Introduction. In order to qualitatively assess oil and gas bearing capacity prospects and build a prospect map for the studied sediment structure, it was necessary to analyze facies and thicknesses and determine the specifics of the prospecting and exploration methodology in the reservoirs [12, 18].

During investigations it was required to determine the criteria for oil and gas content in Lower Maikop deposits (based on the experience of field investigations and exploration areas in Stavropol region); refine the schematic structural map of the Lower Maikop roof; analyze facies and thicknesses; determine exploration methods for clay reservoirs known in Stavropol region, based on experimental investigations; construct a prospect map for the studied sedimentary structure.

The methodology used was to identify and trace zones of increased fracturing by qualitative interpretation of temporary seismic sections. Series of search criteria (percentage content of each component in the hydrocarbon gas (HCG) series (C_1-C_5) and ∑HCG, H_2, O_2, N_2 and CO_2; calculation of various oil-gas components ratios), established on the basis of analysis for reference seismic materials on well-studied areas in comparison with the results of well tests, were used. Gas and geochemical survey was also carried out.

Statement of the problem. Investigations began with processing the available geological and geophysical material for the North Caucasus [6, 24], the results of earlier seismic and drilling work, as well as research work on all promising oil and gas structures were summarized and analyzed [8, 11]. At the same time, geological and geophysical material was collected, systematized and generalized.

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All the information was analyzed and included in the data bank on geological and geophysical knowledge, geological structure and oil and gas bearing capacity of the territory in the North Caucasus.

At this stage comprehensive analysis of the conditions and peculiarities of oil and gas structures in the Republic of North Osetia-Alania, in addition to the analysis of all collected geological and geophysical material, included the construction of consolidated schematic structural maps for the roof of oil and gas bearing layers within the selected structures, correlation schemes of reference well sections comparison (separately by structure), thickness and lithofacies maps, lithological scheme of the study area (Fig.1) [9, 13].

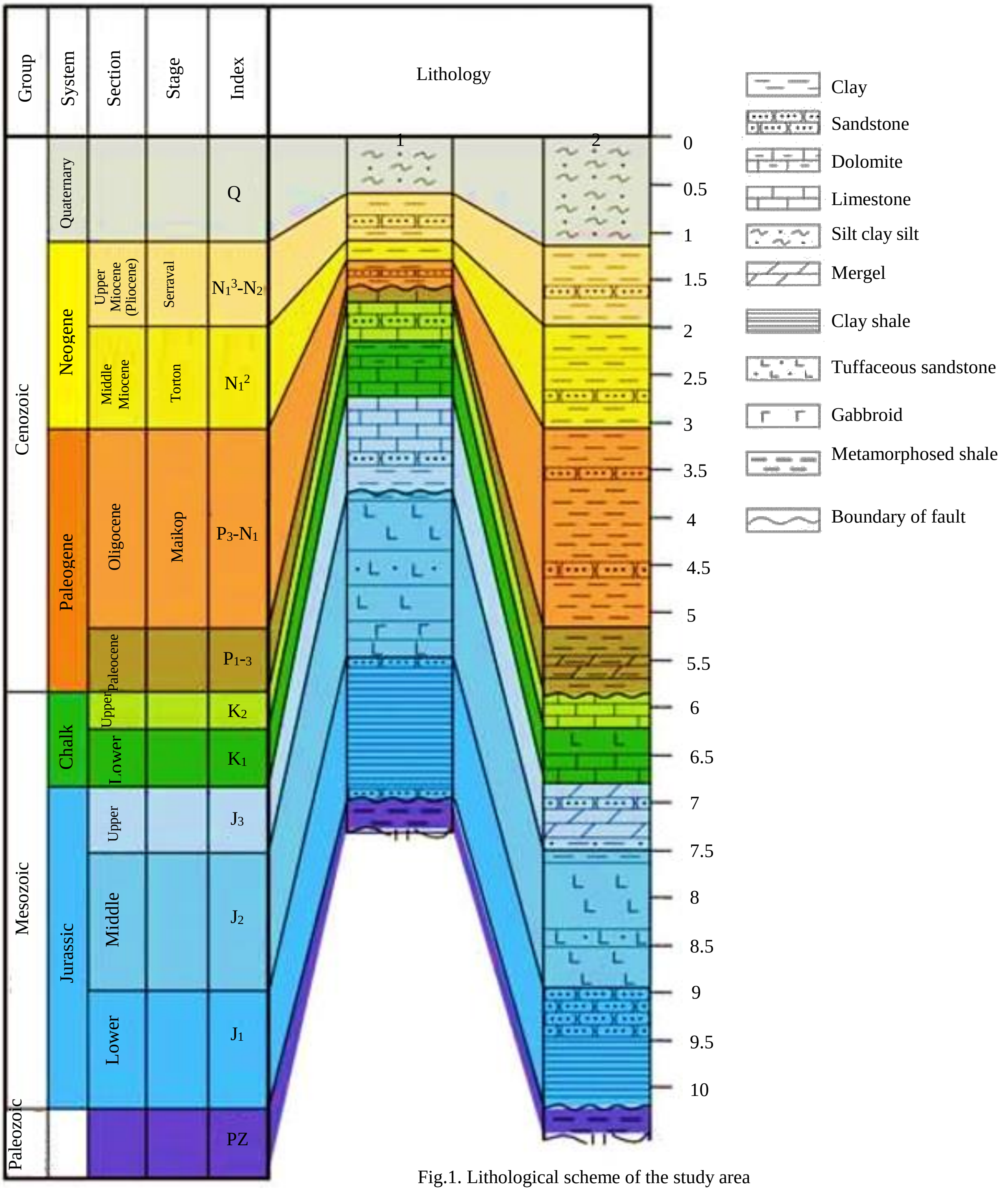


Fig.1. Lithological scheme of the study area

During the analysis of the criteria and qualitative assessment of the oil and gas content perspectives to draw conclusions about the possible oil and gas content of the selected prospective structures, the authors were guided by the data characterizing the conditions of formation and existence of oil and gas deposits [1, 7]. It includes tectonics, stratigraphy (including palaeogeography), lithology (facies analysis and sedimentation conditions), well test data, surface oil and gas signs and gas and geochemical survey data [15, 16].

A comprehensive assessment and analysis of the oil and gas bearing capacity prospects in the Neogene structure was carried out. The site within the Nazran ledge, which is presumably associated with the bay-like spreading and wedging of the Chokrak sandstones, is the most interesting in the structural map (Fig.2) of the reflecting horizon, identified with the middle part of the Chokrak sediments. Structural constructions of two sections in the Chokrak horizon were made: the western section covering the Argudan ledge and the western part of the Osetian depression and the eastern section covering the Nazran ledge.

Oil and gas influxes were recorded in well 13 zmk (from Chokrak sediments, formation XIX, gas flow rate is 788 m^3/day), well 18 zmk (blowout of clay solution and gassing with small water overflow) and well 7 (signs of hydrocarbons in basal sand layer Karagan, during testing water inflow with gas was obtained).

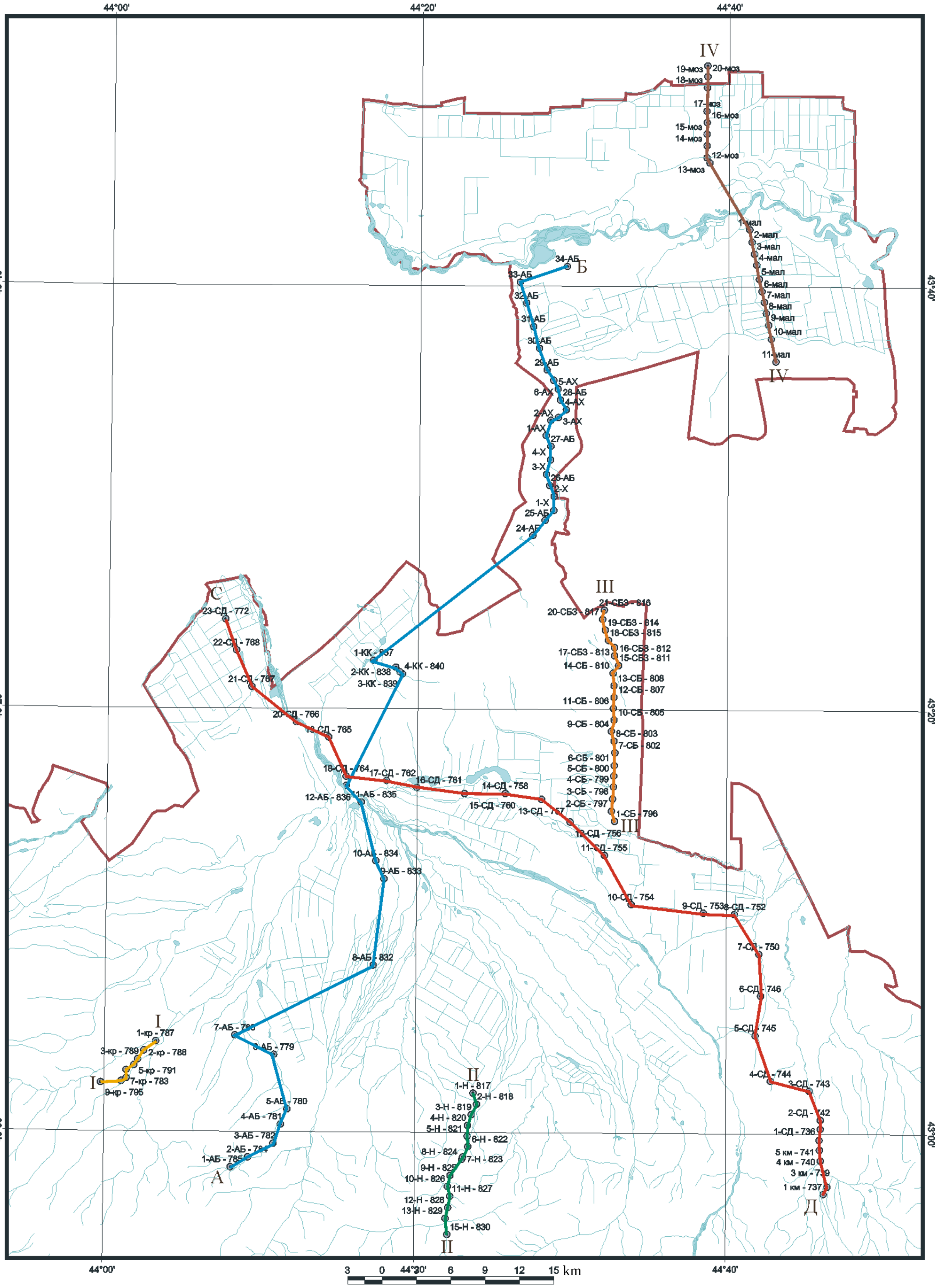
Methodology. The methodology of conducted research considered the identification and tracing of zones with increased fracturing by qualitative interpretation of temporary seismic sections [5, 20, 22]. At the same time, a number of search criteria (percentages of each component in the series of HCG (C_1-C_5) and ∑HCG, H_2, O_2, N_2 and CO_2; calculation of ratios for various oil and gas components), established based on the analysis of reference seismic materials from well-studied areas in comparison with the results of well tests, were used. If the recording is of good quality, zones of oil-prospecting interest can be identified [19, 21]. The scheme for propagation of fracture-dispersed zones over an area is constructed by correlating [28, 35] the same-type signs of wave field disturbance from profile to profile, although this procedure is associated with great difficulty in selecting a reference correlation variant.

Discussion. Computer processing of data obtained by analysis of oil and gas components and Eh-, pH-metry of rocks (including calculation of background field of oil and gas components for the object) [10, 17]; calculation of oil and gas components contrast values for each sampling point; determination of percentages for each component in the series of HCG (C_1-C_5) and ∑HCG, H_2, O_2, N_2 and CO_2; calculation of ratios for various oil and gas components; graphical plotting of distributions for each oil and gas component, for Eh and pH, for ratios of oil and gas components and their contrasts with regional and local backgrounds, as well as for changes in tangent values and rank correlation coefficients, reflecting zones of oil and gas accumulations and deep water unloading along the profiles of the studied area. Physical, chemical and geochemical criteria for local prediction of oil-saturated reservoirs in the Neogene structure are shown in table [3, 17, 27].

Comprehensive analysis of oil and gas components (comparing them with each other) [2, 14] was carried out using the contrast curves of the HCG_{ads} components relative to the calculated background for the investigated object.

Comparison for the distribution of gas concentrations by individual gas vapours (close in concentration levels) revealed their uniformity and marked differences in distribution along the profile line, indicating possible differences in their genesis.

Gas and geochemical investigations along the meridional profile A-B (Fig.3) showed that structures with supposed and established oil and gas content occur along the A-B profile line, which are not sharply distinguished from the background field by levels of HCG_{ads} concentrations, but are reflected in features of HCG_{ads} composition (naphthenic gas type) and individual gas and geochemical indicators [30, 31]. Abnormal values of HCG_{ads} are manifested in the investigated area at points 1, 4, 24, 25, reaching values of HCG_{ads} concentrations of about 0.12 cm^3/kg, while points with values of about 0.07 cm^3/kg are also noted in this area (Fig.4).



Sampling scheme
Scale 1:300 000

А — Б Submeridianal profile A-B with Karjisk (КК), Harbizen (Х) and Achlov (АХ) structures
С — Д Sub latitudinal profile C-D with Kambileev structure (км)
I — I I-I – profile on the Korin structure (кр)
II — II II-II – profile on the Nartov structure (Н)
III — III III-III – profile in the Starobatakayurt-Zamankul area (SB (СБ), SBZ (СБЗ))
IV — IV IV-IV – profile in the Mozdok-Malgobek area (moz (моз), mal (мал))

Fig.2. Structure map and sampling points

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Physical, chemical and geochemical criteria for local prediction of oil-saturated reservoirs in the Neogene structure

Parameters	Non-reservoir	Reservoir
Open porosity, %	< 10.5	>10.5
Volumetric mass, g/cm^3	> 2.4	< 2.4
Lime content, %	> 8-10	0-4
Pseudofracture number, m^{-1}	0-500	1500-4000
HB content, %	< 0.5	> 0.5
HB content in open cavities, %	< 0.2	> 0.2
Bitumen content HB+DSBB, %	< 0.1-0.8	> 0.8
Redox potential Eh, mV	>70	< 40
Hydrophobicity coefficient K_{hpb}, units	> 0.17	< 0.17
Diffusion-adsorption activity, mV	> 35	30-35
Cation exchange capacity Q, mg eqv/100 g	12.5-22.0	4.2-8.1
$K^+Na^+/Ca^+Mg_2^+$	>1.0	< 1.0
Luminescence	A very faint disappearing ring of light blue colour	Spot of intense light blue
Colour of the hydrocarbon extract	Colourless to the eye, light blue under the luminescope	Light straw to brown in colour to the eye, intensely blue to dark blue under the luminescope

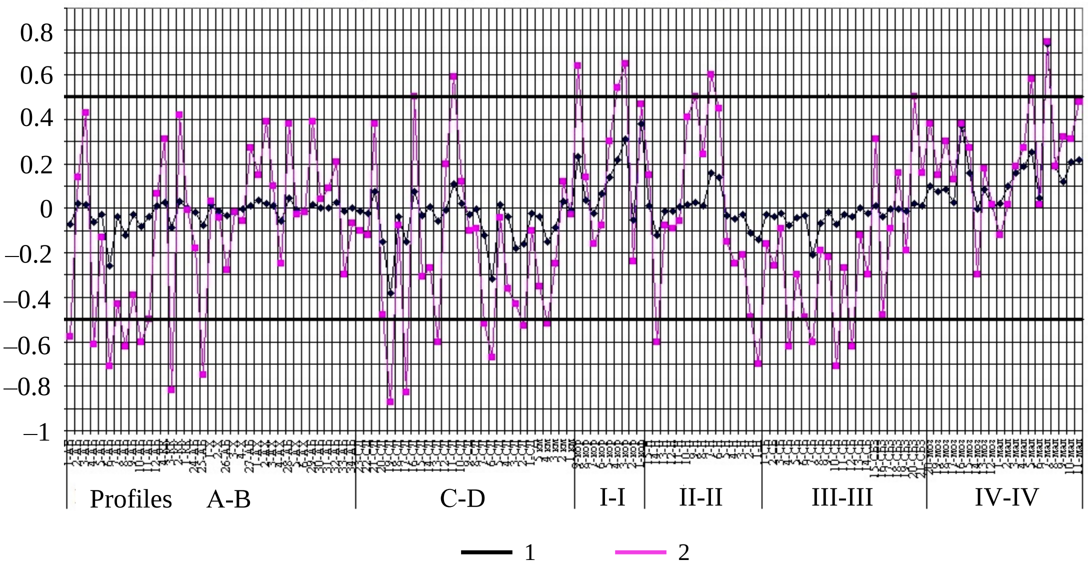

Fig.3. Distribution of gas and geochemical indicators reflecting oil and gas accumulation zones and deep-water unloading zones along the profiles of the study area

1 – tangent; 2 – rank correlation coefficient

In addition to these abnormal HCG_{ads} manifestations, the A-B profile line also highlights more contrasting anomalies in the southern part of the profile (points 4-7) and at its northern end (points 31-34), but these HCG_{ads} anomalies are characterized by deep water unloading type gases with an elevated gas-oil ratio.

In terms of the methane percentage in the HCG, the A-B profile line is dominated by relatively light gases (CH_4 is about 20 %), the HCG_{ads} percentage in the sum of all oil and gas components (% HCG of $\sum$G) is low. This is due to the very high total share of carbon dioxide (CO_2 is about 99 %). In addition, H_{2ads} is almost an order of magnitude higher than the HCG_{ads} on the A-B profile line, even in the areas of oil and gas field expansion [33, 34]. In the mountain-foothill areas H_2 and CO_2 are more actively supplied from the depths because the upward migration routes along the section are more favorable there (presence of a deep fault along the Terek river bed). Therefore, more active inflow of gases from deep zones of the Earth crust occurs along the deep fault, also connected with unloading of waters with increased gas-oil ratio.

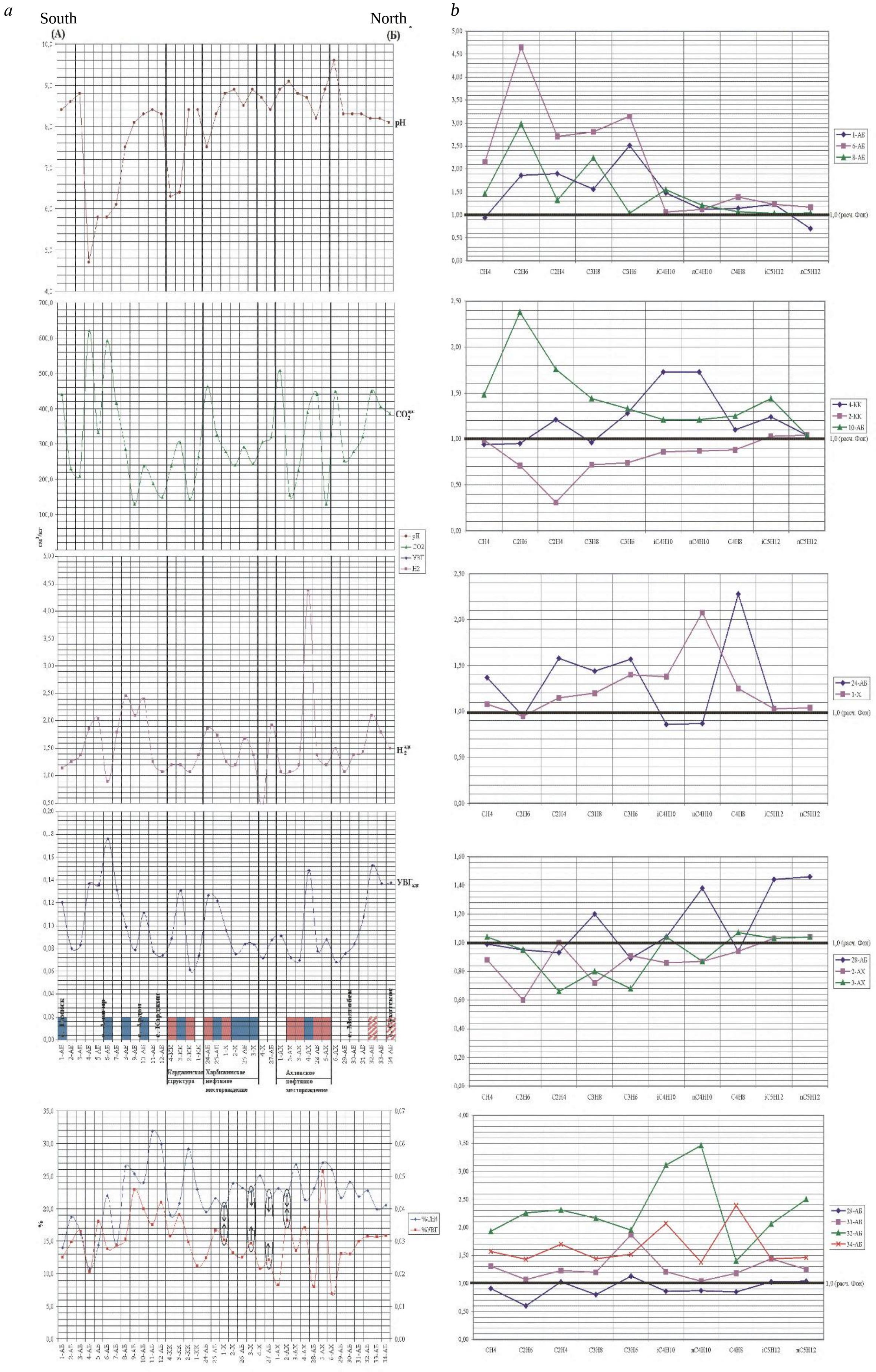

Fig.4. Gas and geochemical characterization of the A-B meridional profile of the study area:
a – distribution of gas and geochemical parameters; *b* – contrast curves

Fig.3 shows sharp changes in Eh and pH in the southern part of the profile and their smooth expansion in the northern part. For the southern zones of the profile, which are located closer to the mountains, a sharp decrease in pH values (up to 5-6), i.e. with the release of an acid environment, is characteristic. Presumably, it is connected with the fact that rock fracturing and fracture tectonics are more active closer to the mountains, contributing to powerful inflows of deep gases and formation of additional CO_2. Indeed, at points 3-8, there is a sharp decrease in pH, an increase in redox potential Eh (50-200 mV), and increase in concentrations of CO_2, HCG, and, to a lesser degree, H_2. The composition of HCG is the heaviest here (CH_4 about 15 %). Next to this zone at points 8, 7, 12, 17 the HCG composition is much lighter (CH_4 25-30 %). The general tendency for lightening of HCG_{ads} (increase of CH_4 share in ∑HCG) from south to north in southern part of A-B profile can be a ground for assumption about tectonogenesis activity near mountainous areas. On the right bank of the Terek river there is a general decrease in the concentrations of all gases and development of consistently high (about 8.5) pH values with Eh around 50 mV. In the smooth background field of gases, there is only a particular increase in concentrations of HCG_{ads}, H_{2ads} and CO_{2ads} associated with oil manifestations in the study area. The naphthic type of gases, characteristic for areas with oil and gas accumulations, is also observed here. Only in this part of the A-B profile there are sampling points with naphthic manifestation of CH_4 and HCG coefficients, when a decrease of CH_4 coefficient values is observed with an increase of HCG coefficient values. This is due to the fact that when the background field is disturbed by gases from oil and gas accumulations, the share of HCG in the sum of the investigated gases increases, while the composition of HCG becomes heavier (the share of CH_4 decreases). The points with naphthic type of gas (tendency of increase of contrast of components of HCG_{ads} from light to heavy homologues of methane) are fixed within the limits of development of oil-and-gas bearing capacity of the investigated territory with the help of a contrast curve for HCG_{ads} components (Fig.4). The southern part of the profile A-B is characterized by the manifestations of gases of the water unloading type with an increased gas-oil ratio (points 1, 6, 8, 10), when the contrast curves of the HCG_{ads} components show a trend of increasing contrast from heavy to light homologues of methane [25, 26].

Thus, the A-B (south-north) submeridional profile line shows zones of intense water unloading with an elevated gas-oil ratio in the southern part and low levels of gas concentrations in the middle part with individual manifestations of high gas concentrations within the spread of oil and gas areas. There is a marked increase in gas concentrations in the northern part of the A-B profile, which may be related to approaching the oil and gas bearing structure [23, 32].

The established level of the calculated background gases for the study area by points of the meridional gas and geochemical profile A-B belongs to the category of reduced values of HCG_{ads} concentrations of (0.08 cm^3/kg), H_{2ads} (1.2 cm^3/kg) and CO_{2ads} (232 cm^3/kg). The background pH values are about 8 and Eh is about 50 mV.

Conclusion. The following results were obtained in the research:

• criteria for the oil and gas content of Lower Maikop sediments (in the fields and exploration areas of the North Caucasus) are defined;

• schematic structural map of the Lower Maikop roof is refined;

• facies and thicknesses are analyzed;

• specifics of prospecting and exploration in reservoirs are defined (based on research known in the North Caucasus);

• comprehensive assessment of the oil and gas potential and a structural plan of the oil and gas bearing capacity of the study area was made [27, 29].

The conducted analysis for distribution of hydrogen sulfide content in dissolved gas at oil deposits of Valanginian-Berrias in a part of the investigated territory and beyond its limits has revealed the increase of hydrogen sulfide concentration in formation fluids with depth increase of sulfate-bearing rocks. It is clearly traced in the direction from sides of Tersko-Caspian foredeep to its most submerged part where hydrogen sulfide content in Valanginian-Berrias sediments reaches 8 %.

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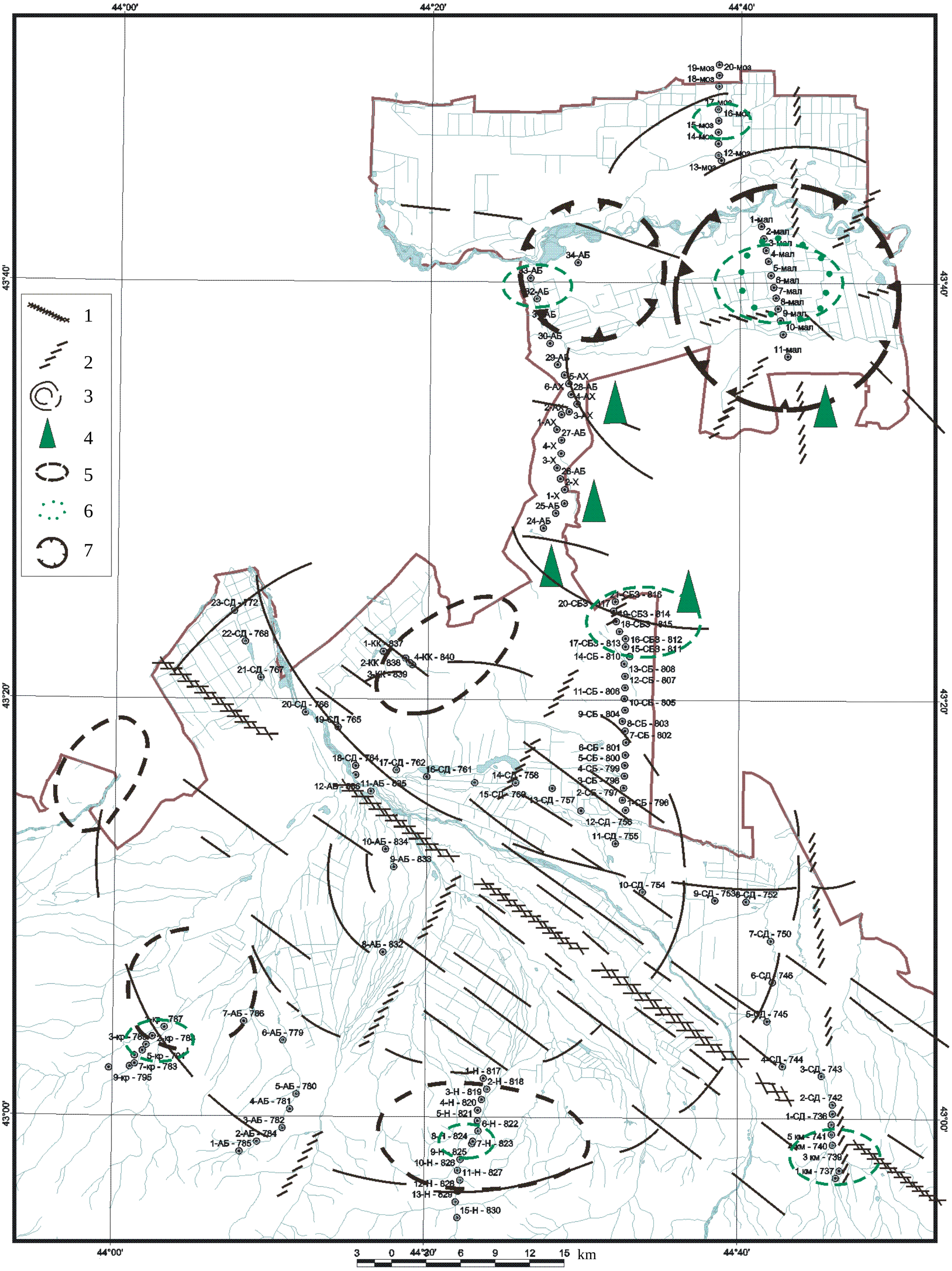

Sampling scheme
Scale 1:300 000

1 – Axis of the transcontinental tectogen
2 – Regional transversal lineament
3 – Nodal concentric structures
4 – Oil fields
5 – Seismic structures
6 – Gas and geochemical anomaly of the naphthic type
7 – Circum depressed morphostructure

Fig.5. Structural plan of the oil and gas bearing capacity of the study area

Investigations showed that the background concentrations of the gas field in the study area are characterized by a low level. On a submeridianal profile A-B fluctuations of background concentrations of HCG_{ads} are 0.08-0.12 cm^3/kg, for the sublatitudinal profile C-D (see fig. 3) these fluctuations reach 0.16-0.26 cm^3/kg, which is a favorable factor for identification of objects with oil and gas accumulations.

Graphic plotting of Eh and pH concentrations and various gas and geochemical indicators allowed to identifyzones of possible of oil and gas accumulations and to start their detailed survey (Fig.5). Processing of gas and geochemical materials by means of applied software, made it possible to unbiasedly estimate the prospects for oil and gas bearing capacity of investigated objects.

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