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Geology

Shales of Georgia: Shale Gas Mining Context

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ABSTRACT. Far-reaching changes in global energy market, triggered by the so-called "shale revolution" and related worldwide activities push into the forefront the problem of investigation of shale resources of Georgia. In the paper a brief survey of shale deposits of Georgia is presented in the context of the prospects of shale gas (SG) mining. The primary tasks are set, aimed at improved understanding of the starting geological and environmental situation. Based on some initial conditions within the still unlicensed territory of the country, the Kazbegi-Omalo Region (KOR) with record concentration of shale-bearing rocks and advantageous geographical location is recommended as an area for primary research. It is shown that available geological data base is still insufficient for reliable evaluation of SG mining prospects. The investigation of the degrees of metamorphism of different sections and layers of existing huge shale mass remains the main problem. More detailed data on the total organic content (TOC) and some other characteristics of shale rock also are necessary. Given rigorous environmental standards set worldwide for SG mining, the necessity for additional hydrogeological studies is pointed out. Investigation of rock samples from extensive outcrops of the zone is defined as the way for outlining the territorial distribution of potentially gas-bearing rocks and identification prospective areas for SG mining. Further, based on experience of US Antrim and Sweden Alum Shale zones, preliminary stage of low-cost exploration drilling of upper layers of the identified areas (to the depths 500-800 m) can be performed using existing traditional technical means. The summarized data on geological studies and preliminary exploration drilling can be used through decision-making on high-cost exploration drilling using modern technologies. *© 2013 Bull. Georg. Natl. Acad. Sci.*

Key words: *shale, shale gas, metamorphism, vitrinite reflectance, total organic content, natural fracturing, water resources.*

Shale is widespread worldwide. It is a low permeability sedimentary rock with volumes of natural gas (NG) stored in its fractures and pores or adsorbed onto its mineral or organic components [1]. Low permeability of shale rock creates the need in artificial improvement. That is why breakeven point for large-scale industrial production of shale gas (SG) was achieved as late as the end of the 20th century with technological breakthrough made in the USA (another supporting factor was the increased market prices of NG).

Even at the current stage, when the industry is localized in North America, SG already has exerted a tangible influence on the world energy market. Currently, wide activities targeted at exploration and development of abundant shale reserves are in progress all over the world.

Discussion of the problem of development of the domestic SG potential of Georgia was initiated in 2010 [2]. Further geological survey of some shale outcrops has been carried out [3] and a preliminary study for feasibility analysis of shale gas exploration in Georgia has been conducted [4].

Below, based on the Geological Map of Georgia [5] and taking into account some other circumstances, within the still unlicensed territory of the country, the Kazbegi-Omalo region (KOR) is recommended as an area for primary research. It is shown that the available geological data base still is insufficient for reliable evaluation of SG mining prospects. Investigation of the degrees of metamorphism of different sections and layers of the existing huge shale mass remains as the main problem. More detailed data on total organic content (TOC) and some other characteristics of shale rock also are necessary. The need for additional hydro-geological studies is pointed out.

Investigation of rock samples from extensive outcrops of the zone is defined as the way for outlining the territorial distribution of potentially gas-bearing rocks and identification of prospective areas for SG mining. Further, based on the experience of US Antrim and Sweden Alum Shale zones, preliminary stage of low-cost exploration drilling of upper layers of the identified areas (to the depths 500-800 m) can be performed using existing traditional technical means. The summarized data on geological studies and preliminary exploration drilling can be used through decision-making on high-cost exploration drilling using modern technologies.

General framework: main shale deposits and the area for primary research

An important feature of shale geology is the continuous formation of shale deposits in various parts of the world's oceans over geological history, which reduces the importance of geological periods as a tool for the characterization of shale deposits [6]. The main shale-bearing deposits of Georgia belong to Early and Middle Jurassic. Some other deposits belong to Upper Miocene (Sarmatian), Oligocene, Lower Miocene (Maikopian). Geological assessment is made by direct comparison of the available characteristics of shale deposits in Georgia with the characteristics of the North American shale deposits. The geologic history and natural fracturing of the most promising shale-bearing deposits of Georgia also are taken into account.

For brevity, the term "shale" is used as common for the terms "shale" and "black shale" often used to refer to the same geological structures.

In terms of general geologic research, shale-bearing deposits of Georgia have been studied, starting intensively from the early 19th century. Practically all geological aspects have been covered, including stratigraphy, tectonics, petrology, hydrogeology, petroleum and engineering geology [5,7-18]. At the same time some specific characteristics of shale-bearing deposits immediately linked to SG mining (e.g., gas content, rock permeability and others) still remain to be studied.

According to the fundamental geological survey [7] and the geological map [5] shale deposits are available almost on two thirds of Georgian territory.

Especially significant reserves are located in Chkhalta-Laila (Racha-Svaneti) (Western Georgia) and Kazbegi–Lagodekhi (Eastern Georgia) tectonic zones of the southern slope of the Greater Caucasus where the upper boundary of shale-bearing deposits with thickness up to several kilometers approaches the earth's surface. In other regions of Georgia, as a rule, shale-bearing deposits are thinner.

During past decades geological research was focused on the problem of exploration of conventional oil and gas resources. In this context, the main shale-bearing deposits of Georgia naturally were considered as unpromising in terms of mining of hydrocarbons. That is why the oil-geological zoning of Georgia [12] leaves the strip adjacent to the northern bor-

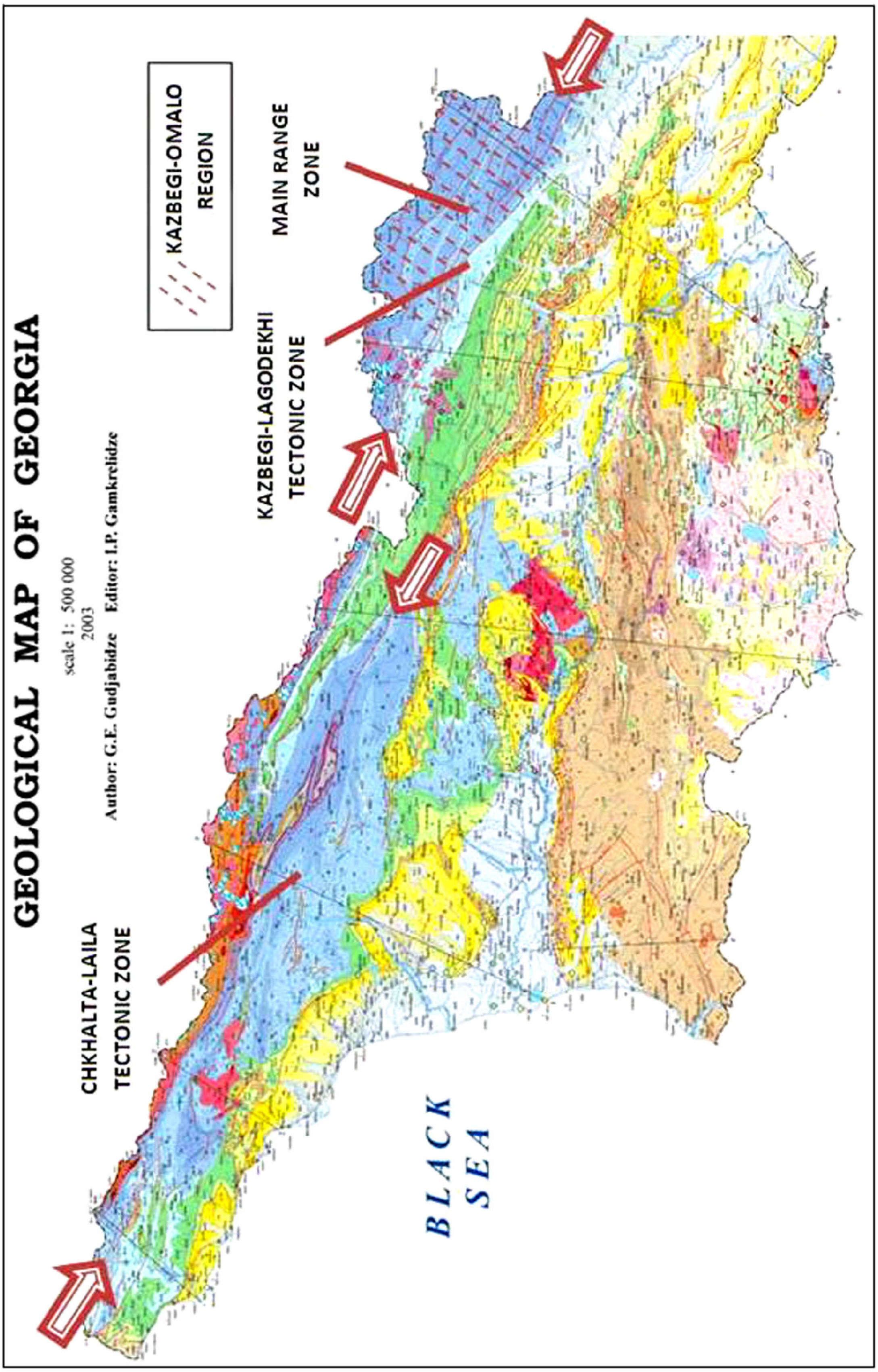

Fig. 1. Geological map of Georgia [5].

der of the country aside the territory presenting interest in terms of mining of oil and NG. These regions have also left aside the oil and gas license blocks of Georgia (except Mtiani Kakheti).

Since all oil and gas licenses already are granted to foreign companies, Georgia currently possesses two potential blocks for bidding for shale gas mining: the first - the Racha-Svaneti zone and the second - the western part of the Kazbegi–Lagodekhi zone named below as the Kazbegi-Omalo region (KOR) (the KOR also covers the main range zone of the Greater Caucasus Fig. 1).

In this connection it is natural to identify two parallel tasks: one relative to the license blocks, where foreign companies are already drilling for oil and gas (and the problem is reduced to the optimum interaction of the corresponding structures with them), and other relative to the Racha-Svaneti zone and the KOR.

Below we focus on the second task, which clearly revealed the need in the wide enough additional geological research before deciding on the exploration drilling.

In the general geological context, it should be noted also that the shales of the Georgian part of the southern slope of the Greater Caucasus are equally matched by similar deposits of the same slope in neighboring Azerbaijan. In this regard, the problem of developing the shale resources may be another area in the strategic partnership between Azerbaijan and Georgia.

The stratigraphy of shale-bearing deposits is presented in the Geological Map of Georgia [5] (Fig.1) which is based on the network of reference wells covering the entire territory of the country. The map exhibits total thicknesses of the Racha-Svaneti and Kazbegi-Lagodekhi shale-bearing deposits, mainly, in the range 1.5 - 5 km and with a maximum thickness up to 7 km in the KOR.

According to the map [5] (Fig. 1) the KOR contains deposits of Aalenian, Toarcian, Pliensbachian and Sinemurian Stages of the Early and Middle Jurassic Series. Among them, Aalenian and Toarcian deposits are mainly formed by shales, Pliensbachian deposits - by slates and shales, Sinemurian deposits - by basal conglomerates and shales.

Finally, taking into account that, in addition to a record concentration of shale rocks, the KOR nears Tbilisi and the South Caucasus energy corridor and is intersected by the NG pipeline “North-South” and tarmac road, it was recommended as the area for primary research.

Mineralogical, chemical and mechanical characteristics

Mineralogical, chemical and other characteristics of shale rocks of Georgia are studied quite widely [8-14]. Shale of the southern slope of the Greater Caucasus is typically composed of variable amounts of clay minerals and quartz grains and is intensively folded. Its color varies from dark gray to black. The main rock-forming minerals of the Georgian shales are illite (29-40%), quartz (22-33%), chlorite (15-22%) and ilbit (2-20%). It also contains calcite, pyrite, muscovite, rutile, anorthite, apatite, titanite, oligoclase, tourmaline.

According to [19] the main mineral components of the shale rock of North American Woodford, Barnett and Caney shale plays are quartz (31-39%), illite (18-29%), kaolinite (4-24%) and chlorite (11-16%). It also contains illite/smectite, calcite, pyrite, dolomite, plagioclase, potassium feldspar. Typical mineral components of the shale rock of Devonian-Mississippian Strata in the Western Canada Sedimentary Basin are quartz, albite, calcite, dolomite, illite, kaolinite, chlorite, pyrite [20]. At the same time, among different minerals, quartz, calcite and illite always make a significant share of North American shale rocks.

Average chemical composition of shale samples from all shale-bearing zones of the southern slope [9] is presented in Table.

Comparative analysis of the above data and chemical composition of Lower Cretaceous Shales of Northern Eastern British Colombia [21] allows the conclusion on mutual accordance of Georgian and North American shale rocks within the usual dispersion of shares of various minerals and chemical com-

Table 1.

Average chemical composition of Georgian shale rocks [9]

SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	SO_3	P_2O_5	H_2O	PSC	Total
57.58	0.77	20.76	2.23	4.09	0.14	1.23	1.95	1.28	3.70	0.32	0.31	0.35	5.06	99.92

PSC - Percent share of other constituents

ponents (regardless of affiliation to completely different geological periods). By the way, a similar conclusion was reached in [9] using comparative analysis of shale rocks from the southern slope with different occurrences around the world.

In addition, it is also possible to conclude mutual accordance of Georgian and North American shale rocks with respect to porosity and density.

For instance, in the KOR, porosity and density of shale rock varies in the range 4.0÷9.0 %, density makes 2.60÷2.75 ton/m^3 [8,10].

At the same time, porosity of shale rock of the US shale plays varies in the range 2-14% [1,22-24]. The core measurements [25] indicate the range 1-12% of effective helium porosity. Porosity of shale rock from Devonian-Mississippian Strata in the Western Canada Sedimentary Basin varies in the range 3-7% [26]. Density of shale rock varies in the range 2.0-2.75 ton/m^3 [11].

At the same time some other characteristics of Georgian shale rocks, such as permeability and brittleness, still remain to be studied.

Total organic carbon

In terms of successful SG mining special attention is attached to the total organic carbon (TOC) that is represented by the weight percent of carbon bound in organic compounds available in shale rock.

Gas shale usually is considered as rich in organic material. According to the Oilfield Glossary [27] the minimum TOC corresponding to such “richness” is 2%. Based on [1] Wikipedia indicates the minimum value 0.5%.

In terms of SG mining the organic carbon has two functions in the shale rock.

The first is the function of the source material for the generation of NG. The second is also the important role of adsorbing matter during long-term storing of NG. In parallel, the same function is carried out by the mineral illite representing a significant part of any shale rock (as indicated above, illite represents 29 – 40 % in shale rocks from the southern slope). That is why the primer [1] equally attaches the role of adsorbent of NG to “mineral or organic” components of shale rock.

Available data on the TOC of Georgian shales cover both regions of interest.

According to [12], the values of the TOC of shale rocks of the Racha-Svaneti zone are in the range 0.17 – 2.80 % (average value 1.19 %).

According to [13] the average value of the TOC is 1.07 % in the KOR. According to [11] the TOC measured in 6 well kerns from the KOR varies in the range 1.33 - 2.05 % (average value 1.73 %). According to the same [11] the TOC varies in the range 0.42 - 2.05 % in the Kazbegi-Lagodekhi zone as a whole. Besides, the average for 20 samples TOC is 1.35 %. In contrast to the above data, somewhat greater values of the TOC (4 – 5 %) are indicated for the KOR in [10].

Quite a wide range of existing data on the TOC of shale rocks from the southern slope (0.17–5 %) can be associated with the very large thickness of shale deposits. Therefore, the problem becomes very relevant linking the measurements of the parameters, dependent on the geochemical changes in the course of geological time, to the corresponding strata of any deposit.

Finally, based on all the above said, we must conclude that the shale rocks of the southern slope cannot be classified as very rich in organic matter, although the fixed values of the TOC do not preclude successful SG mining.

Degree of metamorphism

In terms of the preliminary assessment of gas content of shale rock exceptional importance is attatched to the degree of metamorphism. Only *s*hale rock at the stage of late metagenesis (far short of alteration into slate) can serve as one efficient source of SG. The parameter which correlates with a degree of metamorphism or thermal maturity of mother rock is vitrinite reflectance (Ro) – optical characteristic of coal-type component of shale rock.

Based on the results of earlier studies, in [12] the conclusion is made that "although analytical TOC and vitrinite reflectance data are limited, it is clear that TOC is adequate along the southern slope to generate hydro-carbons, although paleo-temperatures are high, tending toward gas generation".

However, this rather optimistic conclusion is refuted by the most systematic study carried out by the Caucasian Institute of Mineral Resources in 1980. According to the map of metamorphism developed by the Institute the eastern parts of the southern slope (beginning from Mamisoni) is mainly a dead-zone for gas.

At the same time, the primary data of the same study (the range of R_0 in shale samples) cover almost the entire range of thermogenic gas window. Similar, fairly wide range of R_0 was also identified for Mtiani Kakheti [14].

In terms of resolution of controversies arisen, serious interest should be attached to the existing data on the influence of R_0 on the productivity of operating SG wells and the data on the variability of R_0 with depth of bedding of shale rock as well.

Estimate of dependence of SG well productivity on R_0 of the US Barnett play vertical wells [28], the ranges of R_0 characteristic of the US Woodford, Marcellus and Fayetteville shale plays [24] and the data for Mamisoni (the Racha-Svaneti region), KOZ and Mtiani Kakheti [13] are plotted in Fig. 2.

According to the diagram of geothermal diagenetic criteria [26], the range R_0=1.0–4.0 is the most favorable for generation of thermally derived methane and, partly, for generation of oil and gas condensate (R_0 is measured in oil). Besides, the range R_0=2.0–4.0 corresponds to generation of only methane and covers all types of kerogen. The zone R_0>4.0 corresponds to fully metamorphosed rocks.

As follows from Fig. 2, the well productivity corresponds to the diagram [25]. As regards Georgian shale rocks, they not only go well beyond late metagenesis, but also cover the most productive zone.

The averaged curve of the dependence of R_0 on the depth in the US Barnett area [28] is presented in Fig. 3. As follows from the diagram, R_0 changes 4-5 times at vertical distance 2-2.5 km. Therefore, one cannot exclude that similar and even more significant changes can occur in much thicker formations of the southern slope.

Thus, as in the case of the TOC, the problem becomes very relevant of linking the measurements R_0 to the specific strata of any deposit. Besides, the unique fold system of the southern slope of the Greater Caucasus, due to the steep slope of the typical fold and large number of intense rock outcrops, can allow defining the distribution of the TOC and R_0 in different sections and layers of existing huge shale mass. This will significantly reduce the cost of exploration, allowing, together with predicting the feasibility of mining, to implement targeted drilling.

Natural Fracturing

An important feature of the southern slope is associated with the tectonic background of the region and intense natural fracturing of rocks [17]. That is why this factor becomes topical in terms of SG mining. In this context, the examining of the experience gained in Appalachian Basin shale plays is desirable.

Ideas about the role of shale rock fracturing in SG mining tangibly changed along with the development of the mining technology.

Although previously natural fracturing mainly was considered as a factor of continuous migration of methane from shale rock with corresponding reduction of gas-in-place, further significant positive role of natural fractures in shale gas mining has been revealed [29-31]. At present, natural fracturing is in-

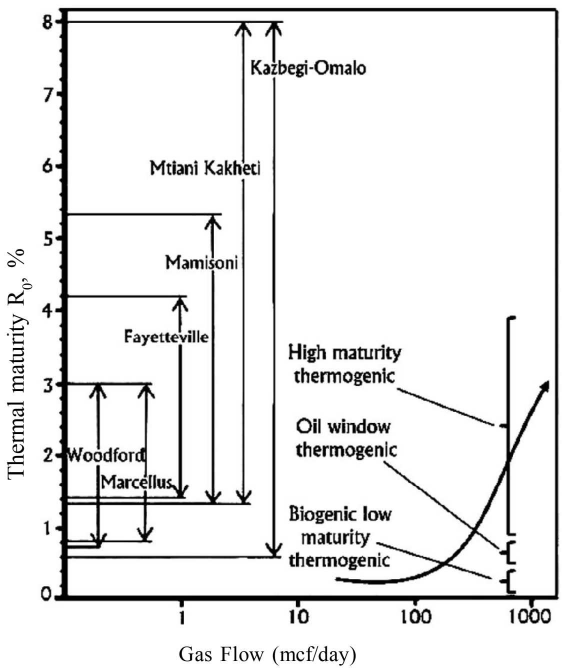

Fig. 2. Dependence of SG well productivity on R_0 (the US Barnett play), the ranges of R_0 characteristic of the US Woodford, Marcellus and Fayetteville shale plays and the ranges of R_0 of Georgian shale rocks.

dicated among mechanical properties of shale rock important for successful mining.

In this context, the experience of operation of the US Appalachian Northern Antrim shale play [32], is also nothworthy where, thanks to variably spaced intense natural fractures, on the part of the wells SG is mined without artificial stimulation.

According to [29], formation of natural fractures in the US Woodford shales took place through the influence of a range of factors, including regional tectonic stress, local effects of major faults and folds, stress release during uplift (all of them are characteristic of the southern slope as well).

Taking into account the above context, it is necessary to carry out additional geological survey of natural fracturing of shale rocks of the southern slope and typological comparison with shale deposits of the Appalachian Basin, including Antrim shale.

Hydrogeological context

Hydrogeological and hydrological context of SG mining involves three aspects: ensuring the mining process by required volumes of water, reliable protection of natural water resources and investigation of the content of methane and other gases in groundwater in perspective areas. At that the second and third matters are topical from an environmental point of view.

Since in the particular situation of the southern slope, with numerous mountain rivers and streams, the adequacy of water supply capacity in the mining process is not in doubt, below, we will focus on the SG-related environmental aspects.

The main environmental problem advanced worldwide relative to shale gas mining is a reliable protection of an aquifer from entering the technological mixture fed into the well [1]. Accordingly, the intersection of the aquifer by well bore is considered as an area of the main risk.

The southern slope represents a system of mountain gorges between the spurs of the Greater Caucasus Range. That is why a continuous aquifer generally is not the case for this region. Here the areas of formation and movement of groundwater and surface waters are altered with anhydrous spaces the scale of which is usually quite sufficient to prevent, by proper choice of drilling location, the need to cross water-bearing zones.

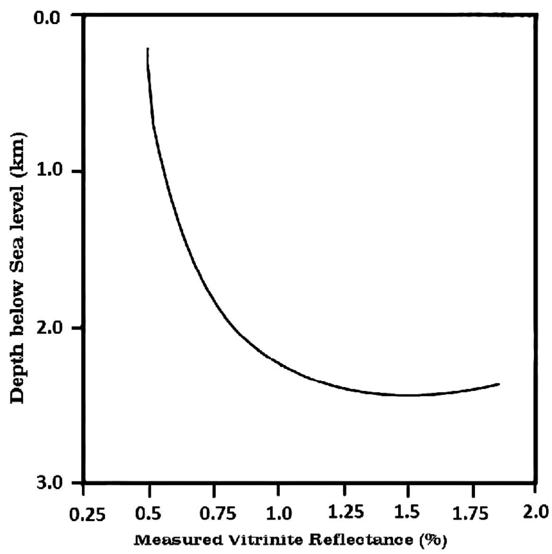

Fig. 3. Dependence of the vitrinite reflectance on the depth relative to sea level.

Naturally, a similar drilling tactic would greatly facilitate solution of water-related environmental problem. Hence the first target of the hydro-geological support of SG mining emerges clearly: identification of anhydrous spaces among small aquifers of various types in prospective areas for exploration drilling.

Another target is investigation of the chemical composition of gases and, in particular, content of methane dissolved in groundwater in the same prospective areas. Availability of such data is important from the point of view of objective assessment of possible changes in the release of methane and other gases from the land surface after the start of SG mining. At the same time, the chemical composition of the gases dissolved in groundwater in various areas of the southern slope may help to identify some of the important geological features.

Within the western part of the southern slope, beginning from the Aragvi gorge to the west, mainly chlorhydric-alkaline mineral springs are spread. In gas composition of these springs, both in natural escapes and in boreholes, carbon dioxide is the dominant gas component. It is an area of carbon dioxide dominance.

To the east of the Aragvi gorge an absolutely different situation is observed. Here we have not carbon dioxide mineral springs at all. Gas composition of mineral springs of the eastern part of the southern slope is represented by nitrogen and especially by hydrogen sulfide and methane. The fact is established by numerous chemical analyses carried out in different periods. In the judgment of hydro geologists, along the Aragvi gorge, a deep regional fault passes the boundary areas of carbon dioxide and hydrogen sulfide and methane ground water spreading.

Another feature is that natural escapes of typical mineral springs of the eastern slope, such as “Torghvas abano”, “Lagodekhis abano”, etc., always are connected with the places of intersection of regional deep faults of common Caucasus course with the local transversal faults of lesser scale. This phenomenon creates more or less favorable conditions for exploration drilling on SG without damage to environment. The main object is to avoid the mentioned tectonic junctions. Substantively it is quite accessible because of the distance between tectonic junctions (i.e. between the natural escapes of mineral springs) makes up several kilometers.

Conclusions

1. In terms of the current global trends in unconventional resources of NG and long-term energy security of Georgia, the problem of effective use of rich shale resources of the country acquires strategic importance. At the same time the need arises of choosing the optimal strategy to address the problem.

2. Given the situation in Georgia, two parallel approaches were identified: one in respect to the licensed areas, where foreign companies are already drilling for oil and gas (and the problem is reduced to the optimum interaction of the structures corresponding with them) and, the other, relative to rich shales southern slope of the Greater Caucasus clearly needed in the wide enough additional geological research by the goal of predicting the feasibility and determining the strategy of exploration drilling.

3. An overview of the geological studies of the southern slope (including the KOR that is recommended as an area for primary research) shows correspondence, in general, of deposits existing there to North American shales. The same overview highlights the need to deal with uncertainty in the study of the most important in terms of SG mining parameters, such as R_0 and the TOC, probably, associated with variation of these parameters with height. Some other mining parameters related to SG, such as permeability and brittleness are also not known.

4. Although there are no data precluding successful mining of SG from the southern slope, conducting a complex research to solve the above uncertainties and some other issues and bridge the above gaps seen as a necessary preparatory stage for decision-making on exploration drilling.

5. Linking the measurements R_0 and the TOC to the specific strata of any deposit while sampling the rocks from extensive outcrops is defined as the main way for defining the distribution of these parameters in different sections and layers of existing enormous shale mass. Then, such data should be used in determining the likely spatial distribution of gas-bearing rock and identification of prospective areas for SG mining.

6. Further, based on the experience of US Antrim and Sweden Alum Shale zones, preliminary stage of low-cost exploration drilling of upper layers of the identified areas (to the depths 500-800 m) can be performed, using existing traditional technical means. The summarized data on geological studies and preliminary exploration drilling can be used through decision-making on high-cost exploration drilling using modern technologies.

7. Given the tectonic background and intense natural fracturing of the southern slope, the necessity is pointed out of additional geological survey of natural fracturing of shale rocks and typological comparison with the shale rocks in the Appalachian Basin, including the regions with unstimulated SG wells.

8. Given the importance of reliable protection of natural water resources, additional hydrogeological studies of the southern slope are advised, including identification of anhydrous spaces among the aquifers of various types to choose the most appropriate drilling locations.

გეოლოგია

საქართველოს თიხაფიქლები: შეილგაზის მოპოვების კონტექსტი

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გლობალურ ენერგეტიკულ ბაზარზე ე.წ. "თიხაფიქლების რევოლუციის" მიერ გამოწვეული შორსმიმავალი ძვრები წინა პლანზე აყენებს საქართველოს თიხაფიქლების კვლევის პრობლემას. სტატიაში მოცემულია საქართველოს თიხაფიქლების მოკლე მიმოხილვა მათი ბუნებრივი გაზის (შეილგაზის) მოპოვების კონტექსტში. დასახულია ნაბიჯები საწყისი გეოლოგიური და ეკოლოგიური ცოდნის გაღრმავებისათვის. რიგ გარემოებათა გამო, ქვეყნის ტერიტორიის ჯერჯერობით არალიცენზირებულ ნაწილში პირველი რიგის კვლევის არედ ყაზბეგ-ომალოს რეგიონი არის რეკომენდებული. შემდგომ გაფართოებას მოითხოვს მონაცემთა ბაზები სხვადასხვა სექტორებისა და სიღრმეების თიხაფიქლების კატაგენეზის დონეზე, ქანების მთლიან ორგანულ მდგენელსა და სხვა თვისებებზე. შეილგაზის მოპოვებისადმი წაყენებული მკაცრი ეკოლოგიური მოთხოვნებიდან გამომდინარე, ნაჩვენებია დამატებითი ჰიდროგეოლოგიური კვლევების ჩატარების აუცილებლობა. ძირითადი ინსტრუმენტის როლი ზონის ტერიტორიისა და სიღრმის მიხედვით გაზშემცველი ქანების განაწილების დადგენაში ქანების მძლავრი გაშიშვლებებიდან აღებული ნიმუშების ანალიზმა უნდა შეასრულოს, რაც შემდგომში საძიებო ბურღვის სტრატეგიის განსაზღვრის საფუძველი უნდა გახდეს.

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