21126

Classification and discriminant functions of alpha- beta radioactivity parameters in oil and gas geophysics

***O. Shabatura** *(Taras Shevchenko National University of Kyiv)*, **S. Vyzhva** *(Taras Shevchenko National University of Kyiv)*, **V. Onyshchuk** *(Taras Shevchenko National University of Kyiv)*, **I. Onyshchuk** *(Taras Shevchenko National University of Kyiv)*

SUMMARY

The specific alpha and beta activity (Aα and Aβ, respectively, in Bq / kg) of core samples from sedimentary rocks of Runovshchyna area (Ukraine, Poltava region) were performed in during of the petrophysical investigations. The active role of sulfur, water and chlorine was revealed by regression model of Aα from the composition. These components are responsible for changing the redox conditions under which uranium is immobilized. As well K2O and H2O are leading component affecting the Aβ. The factorial experiment of regression coefficients revealed its interrelated influence but only H2O can be formally considered an independent feature of model. The ratio Aα:Aβ can be used to classify the clastic rocks. The claye of sandstone is better efefcted in Aβ values rather Aα. Sandstones without of the obvious claye/carbonation evidances have the Aβ value of 816, whereas in clay varieties the average value is 1924. Carbonated sandstones, on the contrary, it decreases slightly to 803. Samples of rocks with a high content of carbonized residues usually have negative correlation between Aα and Aβ. The proposed discriminants and classification dependences of Aα and Aβ can be used as independent geophysical parameters for exploration purposes of oil and gas geology.

Introduction

The specific α and β activity (A_{α} and A_{β}, respectively, Bq/kg) of core samples from sedimentary rocks of Runovshchyna Square (Ukraine, Poltava region) were performed in during of petrophysical studies. This is done through a small background UMF-2000, and XRM for determination of chemical composition. Data on the presence of organic components in rock samples were collected via macro- and micropetrographic description. Almost half of the total number of samples shows the presence of various kinds of organic matter. The predominant type is spot or interspersed carbonization, the content of which varies from particles to several tens of percent. Another diagnostic feature was the odor of hydrocarbons, which was graded as "available", "moderate", "strong" and "sharp" (coded from 1 to 4).

The purpose of the research is to establish diagnostic, discriminant or classification values of α- and β radioactivity of sedimentary rocks, which can be used as independent parameters in petrophysical analysis of core material in oil and gas exploration.

Alpha and beta emitters

An important feature of the families of uranium and thorium is that the share of uranium decay products located in the chain of transformations to radium accounts for only 2% of the total γ-radiation. There are mainly α- and β emitters. Moreover, the total α-activity of its energy spectrum of the uranium and thorium families is approximately the same. The α-activity of the actinium series (in the natural mixture of uranium) is 5% of the total α-radiation of the uranium series. The total intensity of β-radiation of the uranium and thorium families do not differ significantly. In the middle of families, β-emitters are distributed between the initial and final decay products relatively evenly, which have small half-lives. Natural β emitters are radioactive isotopes of ^{40}K (0.0119%, T = 1.25·109 years) and ^{47}Rb (Vyzhva et al., 2019a, 2019b). ^{47}Rb is much less common and its activity is usually neglected.

Radioactivity of sedimentary rocks is associated with the presence of K, U and Th-containing minerals, adsorbed elements (Kobranova, 1986). In general, the combination of these factors fluctuates the values of A_{α} and A_{β} in a wide range with a significant overlap of different geological objects on the age, rock, facial principle etc. (Figure 1).

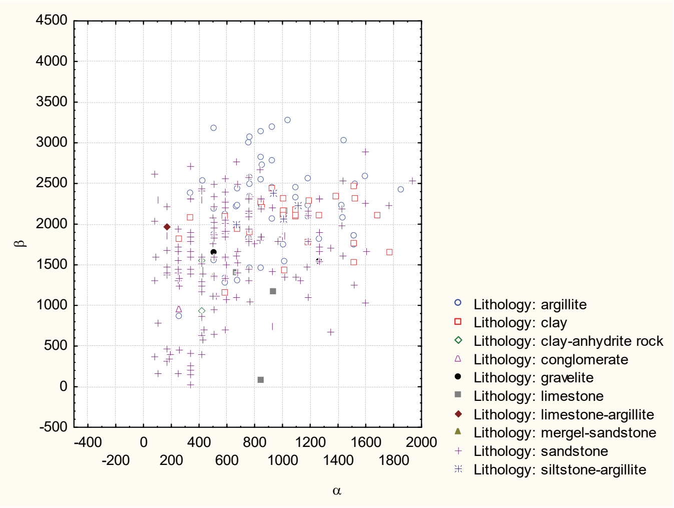

Figure 1 *Lithological types of sedimentary rocks of Runovshchyna area in the area of* A_{α} *and* A_{β} *coordinates*

Regression model

Linear regression analysis was used to establish the informativeness of predictors (chemical composition), obtaining the regression dependence of A_{α} and A_{β} with composition (Table 1).

Table 1 *Selected elements of linear regression model of A_α and A_β of the samples of Runovshchina area (statistically significant features are highlighted in red, N is a number of samples, Multiple R is the coefficient of multiple determination)*

Parameters	SiO_2	TiO_2	CaO	MnO	P_2O_5	K_2O	S	H_2O	Cl
A_α (Multiple R=0,45, N=79)									
b* in		0,31					-0,38	0,18	0,10
Partial		0,23					-0,27	0,17	0,11
Semipart		0,21					-0,25	0,15	0,10
A_β (Multiple R=0,62, N=79)									
b* in	-0,45	-0,31	-0,24	0,50	-0,31	0,81	-0,15	0,37	
Partial	-0,16	-0,20	-0,17	0,18	-0,10	0,45	-0,14	0,40	
Semipart	-0,10	-0,12	-0,11	0,11	-0,06	0,31	-0,09	0,27	

Both the representation and the magnitude of the regression coefficients show the different nature of the influence of the chemical composition on the type of radioactivity. Such volatile components as sulfur (the most active), water, chlorine are significantly effected on α-radioactivity. They are responsible for changing the redox conditions under which the immobilization of uranium compounds take place. The presence of titanium in this association is a reflection of the different geochemical behavior of thorium and uranium. While in highly oxidized media uranium actively migrates, thorium follows to the mechanical transportation and sorting of clastics. Accordingly, the presence of TiO_2 in model is the effect of thorium content in sandstones and other clastic rocks.

The revealed signs of influence on A_β are quite obvious: K_2O transmits the gross content of potassium-containing minerals, and hence ^{40}K geochemically close to it. Rock-forming oxides SiO_2, TiO_2, CaO are responsible for the influence of the mineral matrix of rocks, MnO is a facial indicator of salinity of sedimentation basins, and P_2O_5 - the presence of geochemical calcium-iron barriers.

The linear regression model is not optimal for the prediction of radioactive properties from the chemical composition, as evidenced by low coefficients of multiple determination (Multiple R). For A_α is Multiple R = 0.42 and slightly increased for A_β (0.62). That is fact the most of the variability in A_α and A_β is not related to the influence of the composition, but is controlled by other factors. In general, the linear regression of the compositional features on A_α and A_β reveals their complex interdependent influence on the formation of the radioactivity. Only sulfur for A_α has an increased correlation of predictor and response in the case of a constant level of action of other predictors (estimated by the Semipart parameter); and K_2O and H_2O for A_β, respectively. Partial Correlation Coefficient (PCC) conveys the degree of influence of one predictor on the response in the case of a constant level of action of other predictors. Using PCC distribution we can deduce that practically all predicator influences on a regressor do not show the expressed independence. Only water regarding to A_β shows a slight excess over the coefficient b * in (where b * in is the degree of influence of one predictor to respond in case of arbitrary action of other predictors). All these calculations allow us to speak only about the regulatory role of the aquatic environment for the formation of β-radioactivity of the studied rocks.

Correlation model

High positive correlation coefficients (CC) between A_α and A_β are due to the joint presence of α and β emitters. From this position it follows that the variation lines of the CC will transmit the direction of the relative content of α and β emitters in the studied association of rocks. All the main lithological species of the rocks of Runovshchyna area (clays, argillites, sandstones), which belong to different chronostratigraphic groups, are characterized by variables CC values (Table 2). Note the clear following of CC to A_β, which may indicates its greater variability in the correlation model.

Table 2 *Correlation coefficients between specific α- β-activity in chronostratigraphic groups of Runovshchyna area rocks*

age/rocks	**argillites**	**argillites with mica**	**argillite with carbonates**	**siltstone-argillite**	**clays**	**limestones**	**claye sandstones**
J-					-0,87 (**KZ**)		-0,90 (J)
T_1		0,67	-0,59	0,48	0,36	-0,73	0,70
T_2-T_3	-0,06				0,08		0,71
C_3	-0,56	-0,40			0,58		0,11 – 0.34 (C_2)

The carbonate component increase leads to the appearance of negative CC values. So such carbonate rocks as limestones have high negative and statistically significant values of CC. Sandstones generally have positive CC with significant values for the Triassic age rocks, and high-negative CC for Jurassic clay species. The younger clays the high negative CC. In contrast to the positive CC values of Carboniferous and Triassic clay deposits.

The variation curves of CC in the coordinates A_α and A_β (Figure 2) have a complex configuration. The field of figurative points of sandstones overlaps the fields of other lithological species. Only the field of limestones is clearly separated by its low radioactivity. Figurative points of limestones are formed along the A_β axis, which indicates a constant or background (of clark) content of α emitters. Low α-radioactivity led to conclusion tat increasing or decreasing of A_β is connected with impurities of clay minerals and possibly of mica. The hypercenters of the fields of lithological species of the Runovshchyna rocks follow the mutual direction of growth of A_α and A_β in approximately the following sequence: limestones - gravelites and conglomerates - sandstones - clays - argillites. The larger capacity of sandstones relative to mechanical impurities causes the fields of clay and argillite are more compacted compared to the field of sandstones.

Alpha and beta radioactivity factors in sedimentary rocks

Consider the most common processes that lead to significant changes in A_α and A_β: changes in the particle size distribution of sandstones, claye and carbonization with organic matter.

In a number of relative increases in the grain size of sandstones (fine-grained differences - fine-medium-grained - medium-grained - medium-coarse-grained - coarse-grained) there are noticeable trends of changes in A_α and A_β. A_α in this series has average values of 1098 - 718 - 721 - 578 - 591 - 870, A_β 1553 - 1512 -1817 - 1612 - 1681 - 1884. You can see monotonous (except for a group of fine-grained sandstone species) dependence. The slightly declining values of A_α and A_β for mixed groups are obviously related to the heterogeneity of granulometric determination within these groups. But a more indicative trend is the behavior of the ratio A_α: A_β, which is quite sustained and acquires values: 0.707 - 0.474 - 0.397 - 0.257 - 0.354. In sandstones radioactive elements usually contained in the form of isomorphic impurities in minerals of the heavy fraction, so change of granulometric types of rock more important then changes of chemical conditions of its origin.

Increasing the clay content of sandstones increases its α and β radioactivity due to adsorbed radioactive elements or the presence of potassium minerals (Kobranova, 1986). Claye is most evident in the growth of A_β. Species of sandstones without obvious claye or carbonation signs have an A_β value of about 816, whereas in claye species the average value is higher (about 1924), and carbonated ones, on the contrary, it decreases slightly to 803. The low radioactivity of organogenic limestones is due to oxidative environmental conditions, which do not contribute to the deposition of uranium, but the clay may slightly increases it.

Comparisons of the samples containing organic residues with radioactive parameters are displayed at Figure 2. Points of high-organic samples are located in a field of significant variability of A_β and more compacted in A_α. The more organic content in samples, the more compact of the field on (being in the A_α range of 400-1500, A_β 600-2500 (Figure 2a)). Highly organic samples usually have negative CC values.

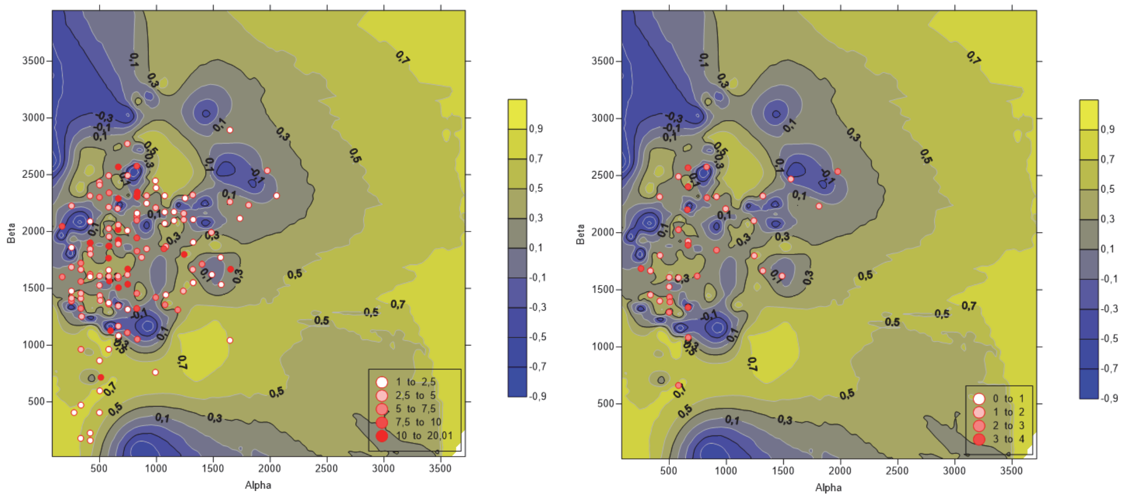

__Figure 2__ Composite layout of samples of sedimentary rocks of Runovshchyna area with average content (%) of carbonized substance (a) and organoleptic feature of explosives (scale condition) (b) in the field of coordinates of specific α- (Alpha) and β (Beta) radioactivity and isolines of CC (colour scale)

The best discriminant function of A_{β} is detected with the organoleptic characteristics of the samples. Samples of rocks with a pronounced odor (code 4 Figure 2b) occupy a wide range of values 600 – 2600 (A_{β}), while a narrow band near 700 (A_{α}). The deposition of U compounds is intensive run under reduction condition and in the presence of organic substances and sulfides. That is why organic matter adsorbs uranium from the medium, reduces it from mobile to insoluble forms. The presence of sulfides in this process can be evidenced by the active role of sulfur according to regression analysis (Table 1).

Conclusions

The regression model of α-radioactivity from the compositional features revealed the active role of sulfur, water and chlorine, which are responsible for changing the redox conditions under which uranium compounds are immobilized. The most significant features in the formation of β-radioactivity of rocks according to the regression model are K_2O and H_2O. The factorial experiment of regression coefficients revealed its interrelated influence and only H_2O can be formally considered an independent feature. A clear connection of CC to A_{β} may indicates greater variability of A_{β} in the correlation model, and hence its higher informativeness. The ratio $A_{\alpha}:A_{\beta}$ can be used to classify of the clastic rocks. The influence of claye of the sandstones is better effected in A_{β} values rather A_{α}. The species of sandstones without obvious claye/carbonation signs have an A_{β} value of about 816, whereas in claye ones the average value is about 1924. The carbonated species, on the contrary, it decreases slightly to 803. Highly organic samples usually have negative CC.

Therefore, the proposed discriminants and classification dependences A_{α} and A_{β} can be used as independent geophysical parameters for exploration purposes of oil and gas geology. Because clayey rocks generate microoil and gas, which are then extracted and localized in other rocks, the use of the obtained petroradioactive dependences will help in the classification and separation of reservoirs, oil-source bed rocks or the identification of oil-bearing rocks.

References

Kobranova, V.N. [1986] Petrophysics. Textbook for universities. - 2nd ed., M., Nedra. - 392 p. (in Russian).

Vyzhva, S., Shabatura, O., Mizernaya, M., Onyshchuk, V. and Onyshchuk, I. [2019] Discrimination of lithological types of the Runovshchyna area for alpha and beta activity. MODS`2019, Chernihiv National University of Technology, Chernihiv, Ukraine, June 24-26.

Vyzhva, S., Shabatura, O., Onyshchuk, V. and Onyshchuk, I. [2019] Alpha and beta-activities of sedimentary rocks of the Runovshchyna area as an indicator of the conditions of their origin. 18th Inter. Conf. on Geoinformatics - Theoretical and Applied Aspects.