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ENGINEERING GEOLOGY & GEOTECHNICS

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GEOCHEMICAL PROPERTIES OF TERRIGENOUS ROCKS AS INDICATORS OF SEDIMENTATION CONDITIONS CLINOFORM BY THE EXAMPLE OF ACHIMOV COMPLEX (WESTERN SIBERIA)

Ass. Igor Afonin

Assoc. Prof. Gennadiy Tatyanin

Assoc. Prof. Platon Tishin

Regional Research Tomsk State University, **Russia**

ABSTRACT

In view of ambiguous understanding of conditions of formation of clinoform complexes there are different ways to interpret their structure. Main methods of diagnostics are bio- and seismostratigraphic ones, but they do not always allow realizing correlation of stratigraphic units. Therefore we take up possibility of use of methods of lithogeochemistry.

Achimov complex of Urengoy region has been chosen as a subject of inquiry. There samples of argillites and aleurolites which divide sandstone strata Ach-BU9, Ach-BU10, Ach2- BU11, Ach-BU12, Ach1-BU12, Ach3-BU12 have been collected. Geochemical features of these rocks have been studied relying on 52 measurements of petrogenic oxides contents realized by use of X-ray fluorescence analysis and trace elements contents by use of ICP-MS. Petrochemical moduli and geochemical indicators have been used for lithogeochemical typification of rocks.

Distribution of basic petrochemical parameters reflects normative mineral composition of sediments. In spite of considerable variance of majority of parameters it has been stated that stratum Ach-BU10 is enriched with normative illite and feldspars. Normative composition of sediments of Ach-BU9, Ach1-BU12 and Ach3-BU12 strata conform to chlorite-hydromica association. Normative composition of sediments of Ach2-BU11 and Ach-BU12 strata conform to chlorite-montmorillonite-hydromica association.

Relying on trace elements distribution all these sediments have been divided into two geochemical groups. The first one include argillites and aleurolites of Ach2-BU11 and Ach-BU12 strata, for which low level of REE accumulation (102-195 and 178-206 g/t respectively) with La/Yb variations from 10 to 14, increased value of Eu/Eu* (0,53-0,86), low value of Ce/Ce* (0,90-1,07) with local increases up to 1,23-1,24 are characteristic. The second group include Ach1-BU12, Ach3-BU12, Ach-BU9 and Ach-BU10 strata, which are distinguished by higher content of REE (154-293 g/t), increase of Ce/Ce* (1,08-1,58), La/Yb (10,1-24,07) values and decrease of Eu/Eu* value (0,43-0,59). At the same time vertical variations of Fe/Mn, Sr/Ba in Ach1-BU12 and Ach3-BU12 state increase of Sr/Ba up to 0,44-0,56 and Fe/Mn up to 90-140 at upper hypsometric levels pointing to transgressive conditions of sedimentation. For Ach-BU9 and Ach-BU10 inverse relationships of Sr/Ba and Fe/Mn distribution have been stated. That points to regressive conditions of strata formation.

Thus, this research allows to state that there was polygenic regime of formation of Achimov clinoform complexes. It's characterized by consecutive change from north-western transgression (Ach1-BU12, Ach3-BU12) to deep-sea sedimentation (Ach2-BU11 и Ach-BU12) and then to following south-eastern regression of sea basin (Ach-BU9, Ach-BU10).

Keywords: clinoform, geochemical coefficients, sedimentary rocks

INTRODUCTION

In last years in Western Siberia there are attempts to involve new geological objects with traps of non-anticline type in exploitation for the purpose of maintenance and increase of oil and gas production extent. One of potentially promising objects in this region is neocomian clinoform complex. In terms of stratigraphic position these deposits are en echelon lenticular bodies located at the base of cretacerous part of profile in varying stratigraphic range from berriasian at the eastern part to lower hauterivian at the western. Rather complicated composition and complex relation with host rocks are typical for clinoforms. This is because of active geodynamic regime of sedimentation. There are a lot of patterns of clinoforms, but we can emphasize three of them: deltaic, megacross-stratified and catastrophic ones.

Best of all deltaic model analysis is presented by Yu.N. Karogodin, S.V. Ershov and V.S. Safonov [1]. According to their opinion deposits of neocomian producing complex are constituted by sediments of alluvial-deltaic plain, avantdelta and prodelta, which have formed due to rhythmic lateral accretion of clinoforms. Authors of megacross-stratified model (M.M. Binshtok, Yu.V. Braduchan, O.M. Mktrchyan et al.) tell that in berriasian and valanginian ages West Siberian mare basin was a starved basin, which had been filled with debris during rhythmic-translational shelf moving to the basin center for a long time. Clinoforms have formed as a result of shoreline moving to the west due to filling of basin with sediments [1]. According to opinion of F.G. Gourary many researchers underestimate role of climate in sediments formation history and clinoforms may have been formed because of catastrophic processes. Avalanche-like delivery of detritus might be caused by earthquakes, rainfalls, typhoons. Such processes took place rather infrequently, but they led to washout and moving to the sea of large amounts of sediments.

Because of uncertain understanding of conditions of clinoform complex formation there are different approaches to interpretation of structure of the complex. This exacerbates issues of stratigraphic dissection of these deposits. Main and usually used methods of such kind of research are biostratigraphic and seismic stratigraphic analyses; however they do not always allow carrying out correlation of deposits because of fauna relics absence in sediments, disunity of prospect holes net and complexity of interpretation of obtained information. For this reason lithogeochemical methods have been proposed for the search of reference indicators [2].

LITHOFACIES CHARACTERISTICS OF THE OBJECT OF RESEARCH

Achimov complex of Urengoy region have been chosen as the object of research. Samples of argillites and aleurolites, which partition sandstones beds Ach-BU9, Ach-BU10, Ach2-BU11, Ach-BU12, Ach1-BU12, Ach3-BU12, have been taken out of it (Fig. 1). Obtaining the results of analysis of structure of rocks associations and strata,

structural and textural features, material composition of sandy and silty clay rocks allow to evaluate lithofacies of the profile.

It has been stated that Ach3-BU12 layer is made of three subfacies of turbidites, which cyclically replace each other [3,4]: fine-grained turbidites (T3), debris flow deposits at erosionous accumulation slopes (T4) and hemipelagites (T5). These sediments consist of aleurolites, aleuroargillites and argillites with hydromicas. Layer textures with marks of slides and deformations and average or poor sorting are characteristic for these rocks. Profile of Ach1-BU12 layer consists of two parts. The lower one consist of interstratified aleurolites, aleuroargillites and hydromica containing argillites of turbidite subfacies T3 – T4 [4]. The upper part of the layer consists of poorly sorted mesomictic and arkose sandstones of coarsely stratified massive turbidites (T1) [3].

Structure of Ach-BU12 layer is determined by alternation of finely stratified graded horizontally and cross-bedded sanstones of T2 subfacies and fine-grained turbidites (T3) [3,4], which are composed by aleurolites, argillites and hydromica containing aleuroargillites with greywacke and arkose sandstones in minor quantities. Parallel, finely stratified, sloping wavy, lenticular and graded textures and poor or average sorting are characteristic for these rocks.

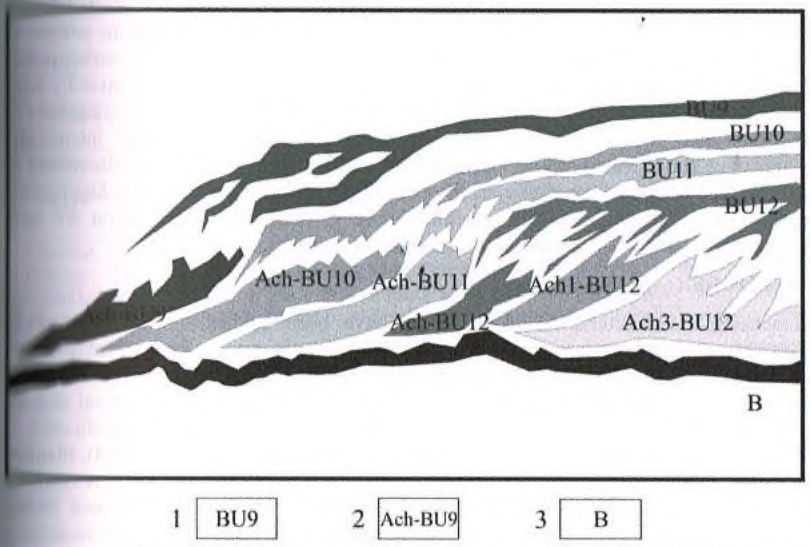

Fig. 1. Schematic profile of achimov complex of Urengoy region: 1 - shelf bed index; 2 - elinoform index; 3 - bazhenovskaya suite [1].

Overlying Ach2-BU12 layer with its structure resemble Ach1-BU12. Herewith lower part of its profile is characterized by interstratifications of fine-grained and medium-grained sediments of T2 and T3 lithofacies, which on a direction to the top change to unsorted coarse-grained sandstones (quartz and feldspar containing, greywacke, arkose and mesomictic sandstones) of turbidite subfacies T1 with characteristic gradually stratified, lenticular textures with marks of slides [3,4].

On the basis of lithofacial composition Ach-BU10 layer resemble Ach3-BU12 one. It's composed of unsorted oligo-, mesomictic, quartzose aleurolites, hydramicaceous argillites, aleuroargillites of T3 and T4 subfacies [3,4].

Poorly sorted mesomictic sandstones, aleurolites, hydramicaceous argillites and aleuroargillites, which formed in conditions of subaqueous channel bars and nearshore shoal of gulfs and lagoons of epicontinental basin [3], are distinguished in composition of Ach-BU9 layer.

On the basis of what's mentioned above, one should conclude that analyzed rocks formed within the bounds of dejection cone of deltas of epicontinental marine basin areas and perimarine and marine environments with intense hydrodynamics.

Regardless of position in the profile all of the studied silty clay sediments were transformed at cata- and metagenesis stages. Rocks, which were lithified during the process of diagenesis, retain considerable quantities of pelitic matrix in their composition. With temperature and pressure increasing in aleurolites processes of quartz regeneration, hydromicazation and chloritization of smectites take place the same way as in sandstones. Zones of interlayering of different kinds of deposits (aleurolites, argillites, sandstones) undergo destruction under the action of strain. At first this express in bedding-plane joints occurrence. Such joints usually are related to contacts between layers with different physical characteristics and therefore responding to tension in different ways (for example, sandstone – aleuroargillite or aleurolite – carbonaceous interlayer contacts). Exactly to such zones hydromicazation, selective layer-by-layer carbonatization, hydrocarbons migration are adhered. Along these zones replacement of feldspars and rocks fragments with secondary minerals occur more intensively. Aggressive fluid treatment and leaching lead to significant secondary replacements of components of rocks (especially sandstones). Such changes make precise highlighting of criteria of lithologic profile partition more difficult. In this situation we have attempted to reveal lithogeochemical attributes of correlation.

METHODS

Geochemical characteristics of the rocks have been studied on the basis of 52 measurements of petrogenic oxides using XRF analysis, trace elements analyses and inductively coupled plasma mass spectrometry (ICP-MS). Investigations were carried out using the equipment of collective use center "Analytical center of natural systems geochemistry" of Tomsk State University (TSU). For lithogeochemical typification of the rocks following values have been calculated: hydrolyzate modulus (HM), titanium modulus (TM), femic modulus (FM), alumosilicious modulus (AM), normalized alkalinity modulus (NAM), geochemical coefficients (such as La/Yb and Fe/Mn characterizing facial environments of sedimentation, $\sum Ce/\sum Y$ and 1/TM characterizing the climate, Sr/Ba, Ce/Ce* and Eu/Eu* characterizing conditions of sedimentation). Also a number of discrimination diagrams have been built: FM-NA, which allow to systematize clay sediments, LREE-MREE-10*HREE, which characterize different sedimentation environments, Th-Hf-Co and La-Th-Sc, which specify composition of deposits (table 1) [2, 5-11]. Also chondrite-normalized rare earth elements (REE) plots have been made up (fig. 2).

Table 1. Minimal, maximal and average values of geochemical and petrochemical modules for achimov complex.

Coefficients	Layer					
	Ach-BU9	Ach-BU10	Ach2-BU11	Ach-BU12	Ach1-BU12	Ach3-BU12
Fe/Mn	100,6-130,1 115,4	94,3-172,4 133,4	34,2-87,5 60,9	81,2-136,4 108,8	90,3-112,6 101,5	100,6-140,5 120,6
La/Yb	13,8-17,6 15,6	10,2-17,2 13,7	10,3-14,8 12,5	12,3-14,3 13,3	13,2-24,1 18,6	8,1-17,3 12,7
Ce/Ce*	1,08-1,18 1,13	1,11-1,39 1,25	0,90-1,24 1,07	1,01-1,09 1,05	1,10-1,51 1,30	1,11-1,58 1,35
Eu/Eu*	0,73-0,54 0,49	0,45-0,59 0,52	0,53-0,66 0,59	0,57-0,62 0,59	0,47-0,51 0,49	0,44-0,51 0,47
∑TR	164,3-293,7 229,0	161,3-271,7 216,5	102,5-195,9 149,2	178,9-206,4 192,6	154,3-262,6 208,4	174,6-228,9 201,8
Sr/Ba	0,33-0,40 0,37	0,25-0,44 0,35	0,43-2,02 1,36	0,38-0,41 0,40	0,27-0,55 0,41	0,31-0,57 0,44
HM	0,32-0,57 0,44	0,52-0,64 0,58	0,36-0,48 0,42	0,40-0,56 0,48	0,34-0,56 0,45	0,44-0,54 0,49
TM	0,03-0,05 0,04	0,02-0,04 0,03	0,04-0,07 0,06	0,04-0,05 0,045	0,03-0,06 0,04	0,03-0,05 0,04
IM	0,33-0,49 0,41	0,32-0,48 0,40	0,36-0,52 0,44	0,35-0,51 0,43	0,38-0,47 0,43	0,33-0,43 0,38
FM	0,14-0,27 0,20	0,20-0,30 0,25	0,15-0,21 0,18	0,19-0,25 0,22	0,14-0,21 0,18	0,18-0,24 0,21
NAM	0,34-0,61 0,47	0,28-0,46 0,37	0,27-0,38 0,32	0,29-0,41 0,35	0,31-0,42 0,37	0,34-0,47 0,41
AM	0,20-0,38 0,47	0,37-0,46 0,41	0,24-0,33 0,28	0,29-0,38 0,33	0,24-0,36 0,30	0,30-0,37 0,34
AM*	0,53-0,94 0,74	0,18-1,06 0,62	0,55-1,11 0,83	0,46-0,99 0,73	0,73-1,43 1,08	0,57-1,02 0,80

Comment: numerators – minimal and maximal values; denominator – average value; HM-Hydrolizate modulus – $(TiO_2+Al_2O_3+Fe_2O_3+MnO)/SiO_2$; TM – Titanium modulus - TiO_2/Al_2O_3; IM – iron modulus – $(Fe_2O_3+MnO)/(TiO_2+Al_2O_3)$; FM – femic modulus – $(Fe_2O_3+MnO+MgO)/SiO_2$; NAM- normalized alkalinity modulus – $(Na_2O+K_2O)/Al_2O_3$; AM - alumosilicious modulus - Al_2O_3/SiO_2; AM* – alkaline modulus - Na_2O/K_2O.

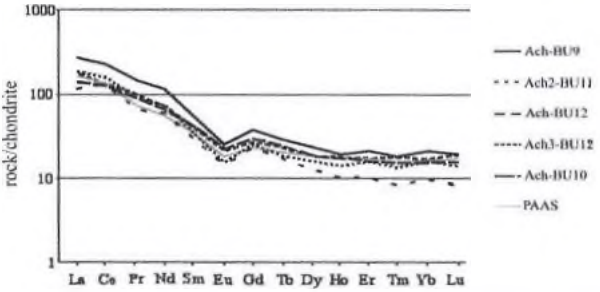

Fig. 2 Typical spectra of chondrite-normalized analyzed rocks and PAAS (standart postarchean australian argillite slate) [6].

RESULTS AND DISCUSSION

Distribution of main petrochemical parameters reflects mineral composition of sediments and is determined in many respects by epigenetic transformations. In spite of high level of dispersion of most part of indicators it has been stated that Ach-BU10 consists of deposits with higher hydromica content and considerable feldspar content. Deposits of Ach-BU9, Ach1-BU12 and Ach3-BU12 layers contain chlorite and hydromica, ones of Ach2-BU11 and Ach-BU12 layers – chlorite, montmorillonite and hydromica [5]. Such trend is proved by thermal analysis results.

Trace elements analysis is more informative in respect of geochemical distinction of parts of the profile. Sediments under study have been divided into two geochemical groups on the basis of trace and rare earth elements distribution. The first group include argillites and aleurolites of Ach2-BU11 and Ach-BU12 layers, for which low level of REE accumulation (102-195 and 178-206 g/t respectively) is typical. La/Yb ratio varies from 10 to 14, Eu/Eu* ratio is increased (0,53-0,66), Ce/Ce* ratio is low (0,90-1,07) with local increases to 1,23-1,24. Paleoclimate indicator $\sum Ce/\sum Y$ varies in narrow range from 3,28 to 4,10. This is inherent for semiarid-semihumid conditions of rocks formation. Also all these geochemical parameters point to deepwater regime of deposits formation [5,8,9].

The second group include Ach1-BU12, Ach3-BU12, Ach-BU9 and Ach-BU10 layers, which have higher level of REE concentration (154-293 g/t). Ce/Ce* (1,08-1,58) and La/Yb (10,1-24,07) ratios are increased, Eu/Eu* ratio (0,43-0,59) is decreased. Meanwhile vertical variations of Fe/Mn and Sr/Ba indicators in Ach1-BU12 and Ach3-BU12 profiles indicate increase of basin paleosalinity (Sr/Ba 0,44-0,56) and chemogenic sedimentation (Fe/Mn 90-140) at the upper hypsometric levels. This testify progressive regime of sediments genesis (fig. 3) [8]. Ach-BU9 and Ach-BU10 layers show inverse relationship: Sr/Ba (0,33-0,40) and Fe/Mn (100-130) ratios are higher at the upper horizons and lower at the underlying ones (Sr/Ba=0,25-0,44 and Fe/Mn =94-139 with abnormal value leap up to 172 at the bottom of the profile). This indicates regressive regime of deposits formation (fig. 3). $\sum Ce/\sum Y$ coefficient amount to 2,67-5,15, what allows to conclude that climate was humid for the most part [5,8].

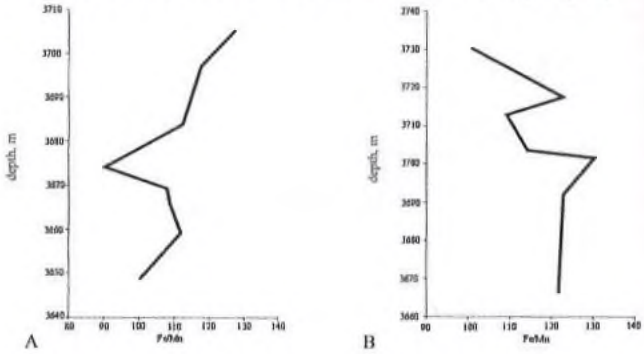

Fig. 3. Fe/Mn ratio change during depth increase: A. transgressive regime; B. regressive regime.

Obtained results are shown at LREE-MREE-10*HREE diagram [7, 11]. Figural points of Ach2-BU11 and Ach-BU12 deposits distinctly appear at deepwater sediments area. Surrounding deposits composition makes up a linear trend, which show presence of regressive and transgressive sedimentation regimes (fig. 4 a, b).

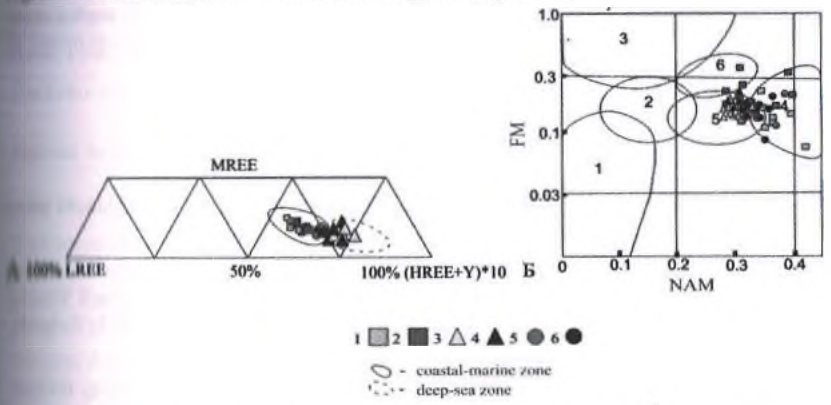

Fig.4. A-REE distribution in achimov complex [7] ;Б - Modulus plot for clay sediments systematization [5].
1 - Ach-BU9; 2 - Ach-BU10; 3 - Ach2-BU11; 4 - Ach-BU12; 5 - Ach1-BU12; 6 - Ach3-BU12.
1 - kaolinic component prevalence;2 - montmorillonite prevalence;3 - chlorite with iron hydromica admixture prevalence; 4 - «standard two-component mixture of chlorite and hydromica»; 5 - «standard three-component mixture of chlorite and monmorillonite and hydromica»; 6 - hydromica with considerablę feldspar disperse particles prevalence [5].

CONCLUSIONS

In such a way, conducted research allows to define polygenic regime of achimov clinoform complex development. Sequential change from north-western transgression (Ach1-BU12, Ach3-BU12), deepwater sedimentation (Ach2-BU11 and Ach-BU12) to following south-eastern regression of marine basin (Ach-BU9, Ach-BU10) has been stated.

Revealed features of paleoclimate of area where studied rocks formed most probably are consequences of basin subsidence and not of change climate as such, but of temperature condition change as a result of depth increase. Such changes register with use of geochemical indicators.

Also it's important to note that strata with different age have different values of geochemical indicators. This allows to carry out dividing of clinoform complex profile into leastwise bed series on the basis of La/Yb, Fe/Mn, Sr/Ba, Ce/Ce* ratios combination.

According to petrochemical study results it has been stated that main volume of sediments is represented by pseudosiallites and pseudohydrolizates; also presence of alkalites has been noticed. This all point out wide distribution of chlorite-

montmorillonite mineral complex with micas and feldspars. There is some genetic signification in it.

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