Mineralogical and geochemical heterogeneity of the Bazhenov suite

I V Afonin, A V Hitara

Tomsk State University, Tomsk, 634050, Russia

E-mail: heaven05@list.ru

Abstract. In this work, using one of the reference well the mineralogical and geochemical features of the Bazhenov suite of the Krasnoleninsky arch are considered. Based on the results of X-ray diffraction and X-ray fluorescence analysis, a number of mineral specific associations were established. This allows us clearly to define the order of the change in the chemistry of bassen expressing the change in oxidation-reduction and acid-alkaline sedimentation regimes.

1. Introduction

Bazhenov suite is one of the most considerable objects of petroleum geology in Russia. For a long time it was thought that its resources are inapplicable, but the opinion have changed since traditional petroleum sources run low. At the present moment this is the most promising object for petroleum industry of West Siberia. The purpose of this work is to define chemical characteristics of sedimentation basin and to model conditions of sedimentation with use of geochemistry methods.

Objects of the study are core samples of bazhen-abalak complex (U0 and U1 beds) rocks taken from one of oil wells of Em-Egorovskoe deposit.

Sedimentary rocks making up the U0 bed are clay-silicious ones with some pyritization and enriched with organic component. The bulk is clay-silicious (30-60%), with organic matter (10-47 %) and pyrite (up to 25 %). There are some fragments of terrigenous sediments (up to 8 %), some biogenic component made up of carbonates and phosphates (up to 10 %), glauconite grains are rarely observed (up to 1 %).

There are layers of clay-carbonate and carbonate rocks found throughout the section. Clay-carbonate (dolomite) rock consists of carbonates (up to 56 %), clay matter (up to 25 %), silicious matter (up to 5 %), organic matter (up to 15 %), pyrite (up to 5 %) with insignificant admixture of terrigenous fragments (up to 1 %), glauconite (up to 1 %) and biogenic component (3 %). Carbonate rock consists of clasts of primarily clastic carbonate rock (85 %), so a repeated clastation took place, and of fine-grained calcite clasts (up to 10 %), which are irregularly pigmented with finely dispersed organic matter with petlomorphic clay matter admixture (2 %).

The U1 bed consist of carbonate rocks interlayered with argillites. Carbonate rock consist of 74-93 % of carbonates and some insignificant admixtures as silicious matter (up to 2 %), organic matter (0,5-5 %), pyrite (1-4 %), terrigenous sediment fragments (0,5-3 %), sometimes galuconite (3-10 %) and clay matter (7 %) and also occasional biogenic fragments (1 %).Argillite mainly consists of clay material (41,5-60 %) and glauconite (18-40 %), then secondary carbonate (10 %), some of silicious matter (0,5%), organic matter (4-5 %), pyrite (3-5 %), terrigenous fragments (0,5-4 %).
2. Methods
This work is based on 93 determinations of petrogenic oxides contents with use of X-ray fluorescence analysis, trace elements contents with use of inductively coupled plasma mass-spectrometry and bulk mineral composition with use of X-ray diffraction analysis. The study was held at the Laboratory of Geochronology and Geodynamics of Tomsk State University. X-ray fluorescence analysis was carried out with use of OXFORD ED 2000 energy-dispersive X-ray fluorescence spectrometer («OXFORD Instruments Analytical»). ICP-MS analysis was carried out with use of Agilent 7500cx spectrometer (Agilent Technologies). X-ray diffraction analysis was carried out with use of XPERT PRO diffractometer (PANalytical). BCR-2, SGHM-1, SG-3, SSL-1 were used as internal and corrective standards.

Following modules were calculated for lithogeochemical typification of the rocks: hydrolyzate modulus (HM), titanium modulus (TM), femic modulus (FM), alumosilicious modulus (AM), normalized alkalinity modulus (NAM). Also geochemical coefficients, which characterize: facial environments of sedimentation – La/Yb; sedimentation environments –Ce/Ce*, Eu/Eu* were calculated. Cr/Ni, Cr/Cu are topofacies indicators [1-8].

3. Discussion
According to U0 bed bulk composition study results it was stated that the main mineral is quartz, which content varies from 7 to 98 %. Also there is pyrite (2-84 %) making up the intensely pyritized interval (sample № 1-13) and local pyritization emergences further down the section. Sodium feldspar is less widespread: its content counts from trace levels up to 14 %. There is potassium feldspar found in two samples (15 – 3 %; 16 – traces). Carbonates presented are calcite (2-88 %), dolomite (4-76 %) and siderite (2-13 %). Calcite makes up the thick carbonatized layer11-26, dolomite makes up thin lens-like layers. There is 15 % of apatite in sample № 64, also there is barite in samples following: 1 – 38 %, 5 – 70 %; 7 – 9 %.

Clay component content varies from trace levels to 12 %. Clay minerals are kaolinite (10-100 %), hydromica (10-100 %), mixed-layered ones (7-47 %). There is no clay component found in samples № 1-7, 18, 20, 22-24, 27, 30, 32, 33, 45, 47, 48, 49, 53-55, 60, 64, 66.

UK1 bed composition is characterized by prevalence of quartz (4-82 %); quartz content decreases, as a rule, are taking place at intensive carbonatization intervals and limestone layers. Sodium feldspar content varies from 2 to 9 %. Almost all of the samples contain some amount of pyrite (2-21 %), also there is a slightly pyritized interval (samples № 75-78). Carbonates are calcite (2-4 %) and siderite (2-58 %), the latter occurs throughout the whole section.

Clay component content varies from traces to 31 %. It increases since № 76 sample, so there is higher clayiness further. Clay minerals are kaolinite (7-80 %), hydromica (14-49 %), mixed-layered minerals (4-46 %), chloride (2-12 %)

There is presence of organic component and amorphous silica in all of the samples.

On the basis of minerals distribution it was stated that there is cyclical composition of the section with a few assemblages alternation: quartz, clay-quartz, pyrite-quartz, pyrite-clay-quartz, carbonate-quartz, carbonate-clay-quartz pyrite-carbonate-quartz (figure 1). Separation of the assemblages was carried out according to minerals contents: more than 20 % for total amount of carbonates and about 10 % for pyrite and total clay minerals contents.

According to X-ray fluorescence analysis results 5 main associations of elements were defined: silicious, aluminum-silicious, calcium–silicious, iron-calcium-aluminum-silicious and iron-aluminum-silicious ones. This separation was carried out according to dispersion values (elements with dispersion value less than 5 were not taken into consideration) and median values (CaO=9%, Al2O3=15 %, Fe2O3=10 %), silicon dioxide was counted for each association as the main component of rocks matrix (figure 2). Associations variations correspond to cyclicity of sedimentation processes, match with previously separated mineral assemblages almost completely and indicate changes of physical and chemical parameters of sedimentation basin.
1. Silicious association – silicon dioxide predominance among all the oxides. Match with quartz mineral assemblage. Probably formed in conditions of normal marine basin with decreased alkalinity; this caused precipitation of silica from solution and led to amorphous silica and quartz formation.

2. Aluminum-silicious association – combination of silica and alumina corresponds to bulk rock clay-silicious composition. The association is supposed to be formed in conditions of normal marine basin with calm sedimentation regime and stable physical and chemical parameters (sea coast environments are also considered).

3. Calcium-silicious association – it formed at geochemical barrier that appeared due to carbon dioxide content increase in the sea water. That, in turn, may be caused by basin depth increase or CO₂ input by sea current. Also carbonatization could take place due to biogenic causes.

4. Iron-calcium-aluminum-silicious (Iron-calcium-silicious) association – its formation may be interpreted dualisticly: on the one hand, sediment sideritization could take place, on the other hand, carbonate sediments pyritization also was possible. The formation probably took place in conditions of marine basin with reductive sedimentation regime. In case of pyritization contamination with hydrogen sulphide probably took place.
5. Iron-aluminum-silicious (Iron-silicious) association has much in common with the one described above. It formed due to pyritization of clay-silicious bulk.

There is association 5 in the top of U0 bed, in other words there are intensively pyritized rocks. There is paragenesis frequent change with carbonates prevalence in general in the middle part of the bed. The lower part consists of the first, the fifth association combination, where the latter two represent pyritization and carbonatization of silicious sediment. The U1 bed has well developed associations, in which calcium and iron take part. At that there are all of the 5 associations present within the bed.

According to classification by E. Y. Yudovich and M. P. Ketris, there are silites (HM <0.30), siallites (HM=0.31-0.55) and pseudosiallites (MgO>3 %), siferlites (HM=0.31-0.55, FM=0.75) and pseudosiferlites (MgO>3 %), hydrolyzates (HM>0.55) and pseudohydrolyzates (MgO>3 %) present in studied rocks. Meanwhile there is clear zonality in rocks types’ distribution. For the upper and middle parts of the U0 bed there is siallites, hydrolyzates and their magnesial kinds alternation due to dolomite presence; the lower part mainly consists of silites with small amounts of siallites, pseudosiallites, hydrolyzates and pseudohydrolyzates. Pseudohydrolyzates are exceptionally widespread within the U1 bed, that may be caused by pyritization and sideritization of the sediment with chlorite forming.
At the same time there is general nonconvergence of clay minerals amounts and aluminum content. This is caused by underestimating of clay minerals content due to their low crystallinity and high contents of amorphous silica and kerogen, so in case with Bazhenov suite we can apply X-ray diffraction analysis results only for qualitative study but not for quantitative one.

Analysis of distribution of geochemical indicators values allows detecting cyclicity of studied beds composition. Microcycles bounds were defined by sudden symbatic indicators change, with further cycles’ enlargement with close geochemical characteristics (figure 3).

Figure 3. Distribution of geochemical indicators on section

U1 bed is composed of two cycles (figure 3). The lower one formed in conditions of marine basin with sea water and fresh water mixing areas; that is confirmed by values as Ce/Ce*=0.83-1.16 and Eu/Eu*=0.81-1.48 (the latter indicates reducing environment). Sedimentation processes took place at the same time with general regression of the sea basin that is confirmed by La/Yb, Cr/Ni, Cr/Cu values. There are similar variations of indicators’ values (Ce/Ce*=0.77-1.19, Eu/Eu*=0.87-1.11) for the second cycle sediments, so it is possible to conclude that there were similar conditions of sedimentation [2, 3, 6]. The main difference is in La/Yb, Cr/Ni, Cr/Cu values decreasing, so there was a transgression.

U0 bed consists of four parts (figure 3). There are some local U/Th ratio increases up to more than 10, which are probably caused by postsedimentary transformations that led to uranium redistribution.
These values were not taken into account. Lowest cycle sediments formed in conditions of marine basin (\(\text{Ce/Ce\*}=0.77\text{-}1.19\)) with reductive regime (\(\text{Eu/Eu\*}=0.87\text{-}1.11\)) at the same time with increasing transgression (gradual \(\text{La/Yb, Cr/Ni, Cr/Cu}\) values decreasing from bottom to top).

Overlying sediments of the second cycle formed in similar conditions in general (\(\text{Ce/Ce\*}=0.79\text{-}1.11, \text{Eu/Eu\*}=0.76\text{-}1.37\)), but sedimentation area was located further from the shoreline (there is symbatic \(\text{La/Yb}\) (lanthanides chemogenic concentration increases), \(\text{Cr/Ni, Cr/Cu}\) values decrease). Third cycle sediments probably formed in conditions of transgression maximum that is confirmed by \(\text{Ce/Ce\*}=0.66\text{-}0.95\) values (marine basin conditions only), \(\text{Eu/Eu\*}=0.93\text{-}3.36\) (reductive environment only), \(\text{La/Yb}=4.88\text{-}7.99\) (chemogenic sedimentation) and \(\text{Cr/Ni, Cr/Cu}\) indicators’ consistent behaviour. Overlying sediments of the fourth cycle presumably formed in conditions of regression starting that is confirmed by \(\text{Ce/Ce\*}\) and \(\text{La/Yb}\) values slightly increasing [2, 3, 6].

4. Conclusion

On the basis of obtained results it’s possible to conclude that studied rocks formed in following way. U1 lower cycle sediments formed in coastal-marine environment with possibility of fresh water influence at the same time with regression of sedimentation basin; U1 upper cycle sediments formed in almost similar conditions, but there was transgression. U0 first, second and third cycles sediments formed during further transgression. At the same time there was change of physical and chemical characteristics of sedimentation basin: environment became more reductive, chemogenic sedimentation became prevalent. Fourth cycle formation took place at the same time with beginning of regression. In such a way, nonuniformity of Bazhenov suite rocks is caused by sedimentation conditions changes, which cause mineralogical heterogeneity: quartz, clay-quartz, pyrite-quartz, pyrite-clay-quartz, carbonate-quartz, carbonate-clay-quartz, pyrite-carbonate-quartz assemblages alternation. Each of these assemblages corresponds to some specific physical and chemical parameters of sedimentation.

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