Features structure of iron-bearing strata's of the Bakchar deposit, Western Siberia

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Abstract. The ore-bearing strata's of Bakchar deposit have complicated structural-textural heterogeneity and variable mineral composition. This deposit is one of the most promising areas of localization of sedimentary iron ore. The ore-bearing strata's are composed mainly of sandstones (sometimes with ferruginous pebbles, less often conglomerates), siltstones and clays. The ironstones are classified according to their lithology and geochemistry into three types: goethite–hydrogoethitic oolitic, glauconite-chloritic and transitional (intermediate) type iron ores. The mineral composition includes many different minerals: terrigenous, authigenic and clayey. Ironstones are characterized by elevated concentrations of many rare and valuable metals present in them as trace elements, additionally alloying (Mn, V, Cr, Ti, Zr, Mo, etc.) and harmful impurities (S, As, Cu, Pb, Zn, P). There are prerequisites for the influence of numerous factors, such as prolonged transgression of the sea, swamping of paleo-river deltas, the appearance of a tectonic fracture zone associated with active bottom tectonics and unloading of catagenetic waters, regression and natural ore enrichment due to the re-washing of slightly-iron rocks. These factors are reflected in the structure of the ore-bearing strata in which rhythmic cycles of ore sedimentation with successive changes in them are distinguished by an association of different mineral composition.

1. Introduction

Oolitic formations of iron ores are well known in many countries, and relate to sedimentary rocks of the Phanerozoic and Cenozoic age [1–5]. The iron ore strata's of Western Siberia were discovered in the 1950s and investigated at that time by [6, 7]. Since 2005 the Bakchar field again began exploration and evaluation of minerals. The average iron content of up to 37.4 % and probable reserves of tens of billions of tons, but there are setback in the technological processing of ore due to the presence of harmful impurities (mainly phosphorus and sulfur), which are present in the finely dispersed state in the form of REE phosphates (monazite, kularite) and sulfids [8–11]. The detailed lithological and geochemical structure and genesis of the Bakchar oolitic iron ore are the matter of this article.

2. Geology

Bakchar deposit is part of the West-Siberian iron ore basin, which is a broad band of Cretaceous-Paleogene coastal-marine clastic sediments with oolitic brown ironstone on the eastern edge of the Western Siberian plate. Iron ores are overlapped by Neogene-Quaternary sediments 160–200 m in width [6]. The iron-bearing strata range varies from 2 to 40 m. The iron ore horizons are traced throughout the entire area of the deposit, as well as outside its borders and are separated by the barren

and weakly ferruginous rocks that overlap each other often with washouts [7]. The Bakchar field is divided into two parts – West and East. The area of the ore field in the contours of wells is about 520 km^2, the average width of 20 m.

3. Sampling and methods of analysis
Sample from iron-bearing strata of the Bakchar deposit were collected from West and East part section and investigated by a variety of mineralogical, chemical and spectroscopic techniques. The micromorphological characteristics and chemical composition of the oolitic iron ore were investigated using a VEGA II LMU field emission scanning electron microscope attached to an Energy-dispersive X-ray spectroscopy INCA Energy (OXFORD Instruments Analytical, Great Britain). The bulk mineralogical composition of ironstone was performed on powdered samples by using X'Pert Powder (PANalytical, Netherlands) powder diffractometer. Chemical analyses were performed on whole rock powders by X-ray fluorescence OXFORD ED 2000 (OXFORD Instruments Analytical, Great Britain). The whole rock trace and rare earth elements were measured by ICP-MS Agilent 7500 cx (Agilent Technologies, USA). All experimental studies were carried out at the Center for collective use "Analytical Center geochemistry of natural systems" National Research Tomsk State University.

4. Lithology and mineralogy
The ore-bearing strata of the formation form takes time an interval from the Turonian to the Eocene and lie with unconformity on the marine sandy-argillaceous sediments of Kuznetsov suite (Cenoman - Turon). The productive layers of the Bakchar deposit are confined to three stratigraphic levels – the sandy sequences of the Late Cretaceous, Paleocene and Eocene age: Narymskiy (Santon), Kolpashevskiy (Maastricht) and Bakcharkiy (Paleocene-Eocene) ore horizons [7, 10].

The ore-bearing stratum is composed of coastal-marine and marine sediments containing horizons of oolitic iron ores: sandstones of quartz-chlorite-siderite, quartz-chlorite-clayey composition, siltstones, clays, sands, gravels (Figure 1). The ores lie horizontally with a barely noticeable immersion of them to the east.
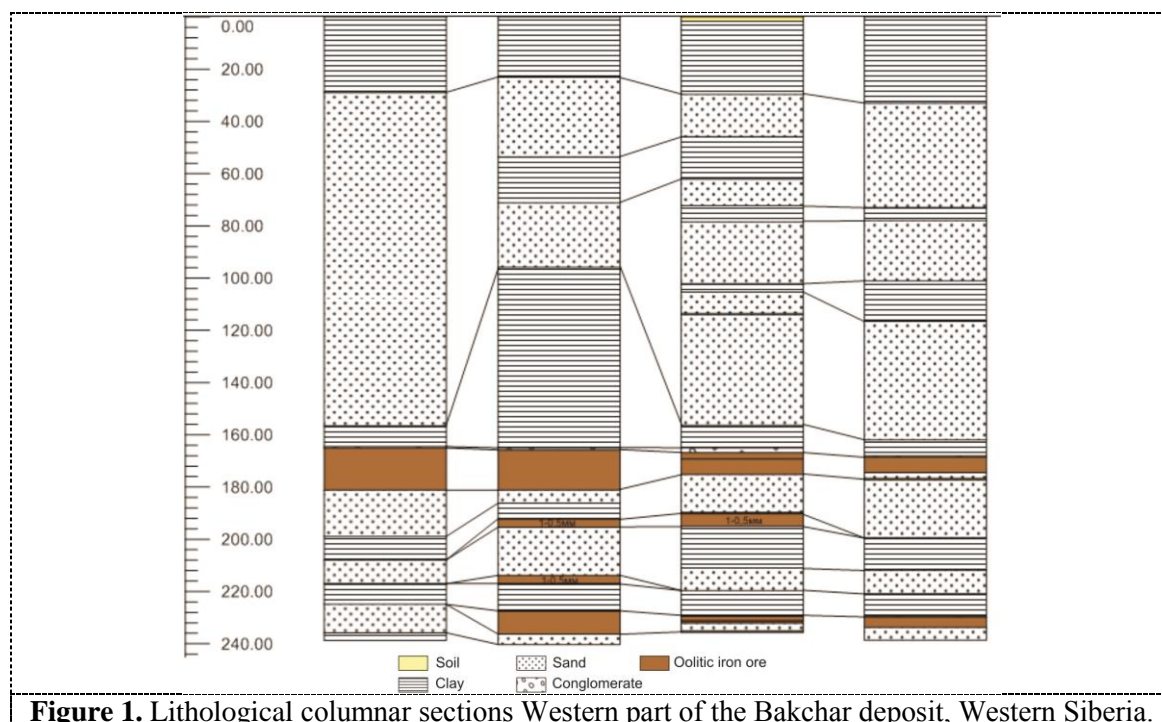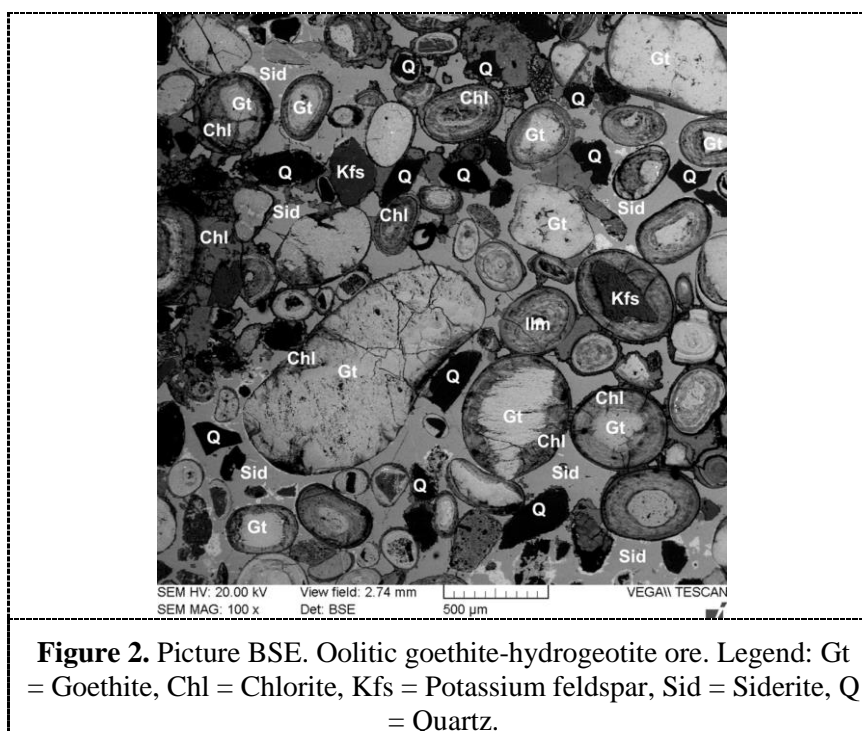

Figure 1. Lithological columnar sections Western part of the Bakchar deposit, Western Siberia.

All minerals composing ores are divided into two genetic groups: allotigenic, authigenic and polygenic (Figure 2) [8]. The allotigenic part of the ores is represented by quartz, feldspar, magnetite, ilmenite, zircon and rutile. Authigenic minerals include carbonates, clayey and hydromica minerals, glauconite, chlorite, the actual ore phases (goethite, hydrogoethite, lepidocrocite), as well as phosphates, sulfides and native silver [8]. The content of hydrogoethite in brown ores varies from 48% to 75%, in glauconite-chlorite from 19.6% to 61.2%, in transition types of ores from 22.2% to 65.1% . The sulfide association comprises microinclusions in the contact of fragmented minerals and concentres of goethite-hydrogoethite and leptochlorite composition. Pyrite is the essential sulfide mineral in oolitic iron ores. To polygenic minerals are referred kaolinite and illite, bearing signs of terrigenous and sedimentary origin.

Figure 2. Picture BSE. Oolitic goethite-hydrogeotite ore. Legend: Gt = Goethite, Chl = Chlorite, Kfs = Potassium feldspar, Sid = Siderite, Q = Quartz.

5. Geochemistry

To characterize the chemical composition of oolitic iron ore were used results of X-ray fluorescence analysis (Eastern part) and exploratory testing (Western part). The total sample includes more than 250 analyses (Table 1).

Oolitic iron ores are over Clarke content of Be, Sc, Ge, Y, Mo, W, Th, P and the iron group elements Cr, Co, Ni, V and chalcophilic Zn, Pb, Sb, Ag, As [10]. Recent elements in the oolitic ores are represented by sulfides, phosphorus − REE and calcium phosphates [8, 11]. The content and composition of the REE more properly reflect the characteristics that influence the formation of the overwhelming majority of sedimentary rocks. The most important factor controlling the REE content in the sediments is a competition between the two sources: the terrigenous component and seawater. It must be borne in mind that REE are more environment characterize the specificity of accumulation, and not the influence of drift sources [8].

Previous studies of the lithochemical features of oolitic iron ores have established that the types of ores that have been isolated are due to their different chemical composition [9, 10]. According to factor analysis, the first factor (F_1) 54% determines the distribution of components and is characterized by high values of SiO_2, K_2O, MgO, Al_2O_3, and significant negative loads Fe_2O_3tot, P_2O_5, LOI. The second factor (F_2) is not significant (Figure 3). Using a factor analysis, two main factors were defined, which took more than 70 % of dispersion over.

Table 1. Representative average chemical composition of iron ore-bearing strata's, Bakchar deposit, Western Siberia

	Eastern part[a]			Western part[b]		
	1[c]	2[d]	3[e]	4[c]	5[d]	6[e]
SiO_2,Wt%	43.09	21.72	43.40	45.10	21.30	59.41
TiO_2	0.13	0.21	0.09	0.34	0.27	0.35
Al_2O_3	3.96	2.97	4.68	6.81	5.39	6.74
Fe_2O_3tot	34.45	56.07	32.89	33.39	56.15	20.82
MnO	0.05	0.03	0.05	0.10	0.22	0.06
MgO	2.67	1.51	3.12	1.17	0.66	1.15
CaO	0.61	0.42	0.70	0.48	0.30	0.51
K_2O	1.31	0.38	1.49	2.18	0.97	2.39
P_2O_5	1.21	2.17	1.15	–	–	–
LOI	9.48	12.49	9.75	–	–	–
H_2O^-	–	–	–	3.70	2.75	3.59
Total	96.96	97.97	97.32	93.27	88.00	95.02
V, ppm	850.7	1379.7	901.9	900	1400	500
Cr	295.6	304.4	264.2	–	–	–
Co	31.5	39.3	43.1	–	–	–
Ni	78.9	92	81.3	–	–	–
Cu	11.1	11	9.9	–	–	–
Zn	178.3	189.4	159.5	–	–	–
Ga	11.87	10.39	13.14	–	–	–
Ge	0.76	0.91	0.94	–	–	–
Rb	110.82	73.32	117.89	–	–	–
Sr	66.75	60.8	70.5	–	–	–
Y	38.02	44.77	38.61	–	–	–
Zr	88.98	82.84	87.52	–	–	–
Nb	8.19	7.55	8.49	–	–	–
Mo	4.5	6.45	4.49	–	–	–
Cd	0.3	0.18	0.25	–	–	–
Sn	1.46	1.25	1.38	–	–	–
Sb	6.67	8.38	6.2	–	–	–
Cs	2.13	2.18	2.88	–	–	–
Ba	230.79	181.9	219.45	–	–	–
Hf	2.54	2.61	2.84	–	–	–

[a] XRF analyses were carried out at the National Research Tomsk State University (Tomsk)
[b] exploratory testing
[c] glauconite-chloritic ore
[d] goethite-hydrogoethitic ore
[e] transitional varieties rock/ore

The components of the clastic part (SiO_2, K_2O, MgO, Al_2O_3) and the ore part (Fe_2O_3tot, P_2O_5 and L.O.I.) influenced the variation of chemical composition of the oolite iron ores significantly. When typing lithochemical ore complex all three types of ore clearly became isolated in accordance with the difference in their chemical composition, which emphasizes the cyclic structure of the section.
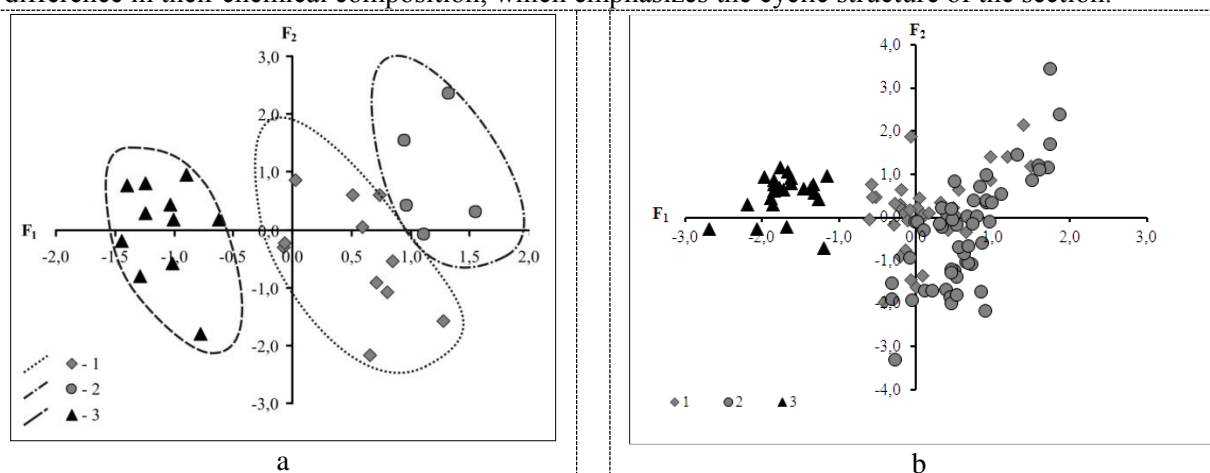

Figure 3. Factor diagram of oolitic iron ore of Eastern part (a) and Western part (b), Bakchar deposit, Western Siberia. 1 = glauconite-chloritic type ore; 2 = transitional type rock/ore; 3 = goethite-hydrogoethitic type ore.

These cycles are different, apparently, the general direction of the process of receipt of ferruginous sediments that control the speed and intensity of weathering on the paleowatersheds associated with tectonic and paleogeographic situation.

For sedimentary formations of humid climatic conditions, removal from feldspar Ca, Na and K is characteristic, which leads to an increase in the ratio of aluminum and alkalis in weathering products [3–5, 12–14]. The calculations of maturity indices of detrital material show that practically throughout the entire formation of the ore interval, the degree of maturity of the fine aluminosilicoclastics entering the basin was moderate. The magnitude of the chemical index of alteration (CIA) [12] in the ores of the entire ore formation does not exceed 70, which implies a dominance of the semi- arid-semihumid type climate throughout the Cretaceous and Early Paleocene in the paleo-watersheds (Figure 4).
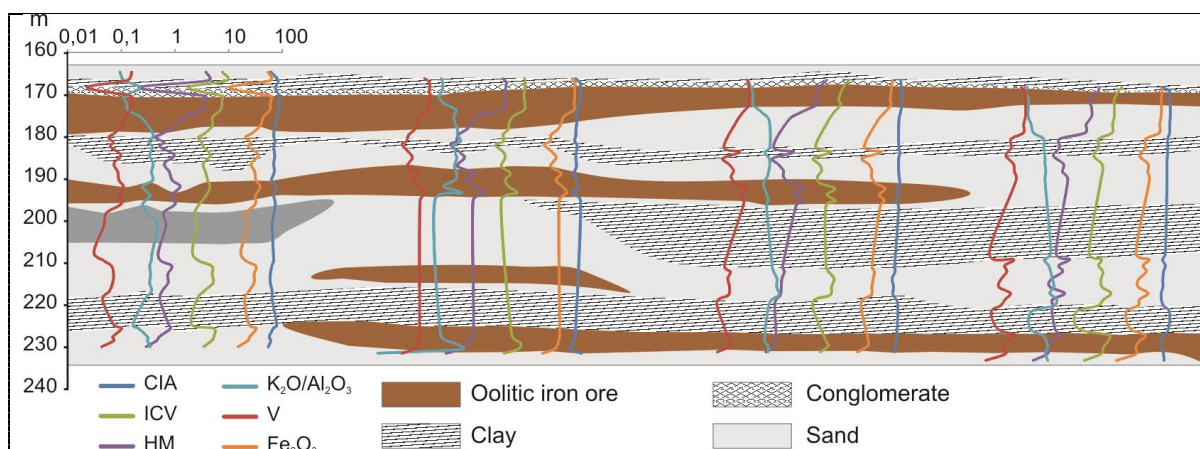

Figure 4. Geochemical correlations of columnar sections Western part of the Bakchar deposit, Western Siberia.

The index of compositional variability (ICV) [13] also reflects the degree of maturity of the fine aluminosilicoclastics entering the sedimentation area. For oolitic ores, it has values greater than 1, reflecting the presence of debris in them with a high content of non-clay silicate minerals, since more mature argillic rocks with a large number of clay minerals have lower ICV values. The values of the hydrolyzate module (HM) [14] in oolitic ores exceed 0.5, since they contain free iron oxides. The most pronounced increase in the values of HM is observed in the goethite-hydrogoethitic ores (HM to 5), in glauconite-chloritic ores it drops to 1.0. The ratio of K_2O/Al_2O_3 in oolitic ores varies from 0.09 to 0.82. The critical value is 0.30, separating according to [14] lithogenic and petrogenic formations.

Reverse correlation of CIA and K_2O / Al_2O_3 indices in the ores of the section. It indicates that the minimum values of K_2O / Al_2O_3 correspond to the epochs of the highest values of the chemical index of alteration and vice versa. The decrease in K_2O / Al_2O_3 values in the aluminasilicoclastic could be a consequence of the intensification of the processes of change in sedimentation caused either by a shift in climatic conditions to the region of more humid environments or by a change sea-level of the sedimentation basin.

6. Discussion

Within the complex of the tested ore allocated three types of sediments, the position which reflects its sectional cyclic structure of ore-bearing strata's. Clearly traced cycles, each of which consists of two ore types: brown goethite-hydrogoethitic and greenish-gray glauconite-chloritic oolitic iron ores. Transitional type ore/rocks (it may be simple sediments) fixes zone change in the conditions of sedimentation. These types have their own distinctive features, resulting in structural and textural features and variations of the mineral composition. Geochemical indexes are the elements which characterize the redox conditions and mode of formation of ore facies within the allocated cyclites [10].

According to [15] in the Cretaceous the territory of Western Siberia was a deep-sea epicontinental basin. Terrigenous material entered the marine sedimentary basin a little, and it often accumulated in the marginal parts. The biogenous sedimentation prevailed on the greater interior of the basin. The sedimentation regime was uncompensated. There was hydrogen sulfide contamination or oxygen deficiency in the waters of the basin and sediment [15]. The leading factor in the formation of the ore-bearing complex was a prolonged transgression of the sea, the maximum of which fell on the Maastricht. The appearance of stagnant depressions in the coastal part is associated with the breaking-up of the bottom of the sedimentation basin and the swamping of delta paleo-river and the formation of lacustrine-lagoon zones.

7. Conclusion

Studies have shown that the formation of oolitic iron ore is result clear staging, which is combined with the cyclical nature of mineral formation. At the heart of cycling is transgressive-regressive regime ore accumulation. Based on the authigenic composition, there are two contrasting groups of minerals in the ores, formed in reducing and oxidizing conditions. The reducing association characterizes glauconite-chloritic ores, the oxidizing composition determines the composition of brown goethite-hydrogoethite oolitic ores. These data also confirm the results of variation of geochemical parameters in the lithological section (CIA, ICV, HM, K_2O/Al_2O_3). Variations of geochemical indexes in the section are emphasized by the position and the change of different types of ores/rocks, which matched to a change in the conditions of sedimentation.

Acknowledgements

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