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Carboniferous Copper Sediment-Hosted Zhezkazgan deposit (Central Kazakhstan)

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Abstract: The ore-bearing strata of the Zhezkazgan ore district have a cyclic structure. Each cycle begins with layers of coarse-grained rocks and sandstone and ends with finely dispersed clastic rocks. Detailed petrographic studies of ore-bearing rock strata showed a composition of volcaniclastic sediments. The main parameters of the sedimentation conditions include physical conditions: the density and viscosity of the sediment-environment of underwater delta. The chemical sandstone conditions are redox, salinity and the temperature was of the medium range. Tectonic activity and climate are also important factors of the depositional area.

Keywords: *copper sediment-hosted, Zhezkazgan deposit, underwater delta, copper sandstones*.

1. Introduction

Stratiform Cu ore deposits account for a substantial proportion of the world's production of copper, in addition to significant amounts of silver, lead and zinc. Classic examples are the Permian Kupferschiefer (Germany and Poland), the Palaeoproterozoic Udokan deposit (Siberia), the Neoproterozoic central African Copperbelt (Zambia, Democratic Republic of Congo) and the Kalahari Copperbelt (Namibia and Botswana). Stratabound Cu-Ag and Cu-Co deposits are hosted in marine or continental (red beds) sandstone, shale and siltstone rocks; environmental associations with evaporites, basalts, conglomerates and breccias are common. Red beds are deposited in rift basins from fluvial, lacustrine and aeolian sediments, in arid to semi-arid oxidising environments, and for this reason they are commonly associated with evaporites [1].

As in other stratiform copper-bearing deposits in the world there is a direct link between the lithological and facies features of the host rocks and ore content. The immediate host rocks of the world's deposits are mainly organic-rich sediments (shale, sandstone, conglomerate, marl, and carbonate), and continental red beds constitute a characteristic component of the host rock sequence. In the case of Kupferschiefer-type deposits, the grey beds (reduced facies) represent shallow-marine to lagoonal or lacustrine sedimentation. In the case of red bed-type deposits, the grey beds are part of a continental fluvial sequence [2], euxinic sapropelic facies predominate, there are clay-rich bituminous shale and basinal facies in Lubin, Richelsdorf, Mansfeld, and the North German basin [3]. Copper sandstone Zheskazgan deposit is also one of the stratiform copper-bearing deposits.

The aim of this paper is to summarize available data on the Zhezkazgan copper deposit and provide new lithological descriptions of sandstones.

2. Geological Setting

Zhezkazgan deposits (the Kazakh name means "Copper Mine") are located in Central Kazakhstan (Figure 1) in the basin of the River Kara-Kengir

Figure 1: *Zhezkazgan polymetalic ore field location in Kazakhstan*

The Zhezkazgan copper region (Zheskazgan, Itauz, Saryoba deposits) is located in the northern part of the Zhezkazgan-Sarysu syncline (Figure 2), which is a Hercynian structure superimposed on the Early Caledonian folding base.

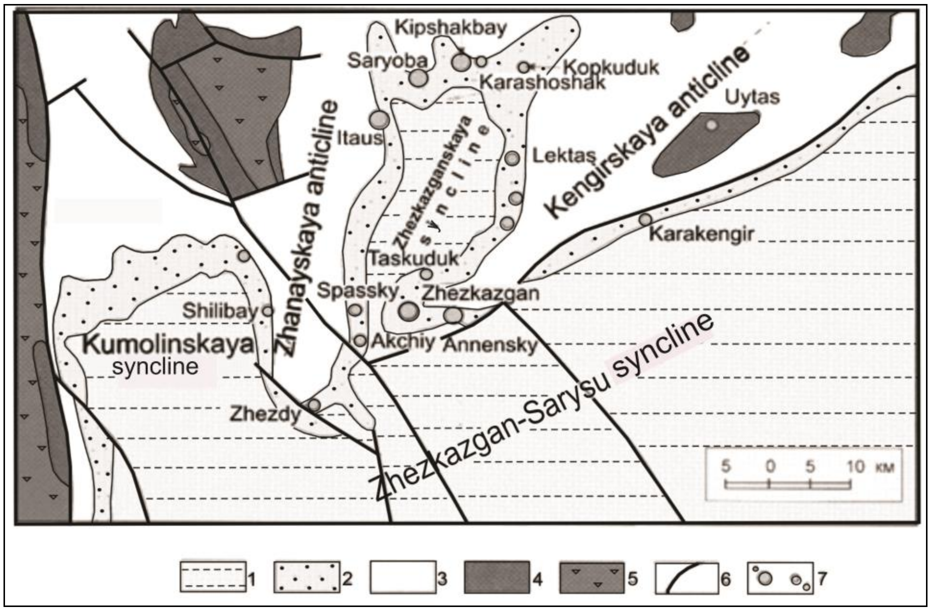

Figure 2: Zhezkazgan ore field (by S. Sh. Seyfullin and others, 1976 [4]):
1 – P multi-coloured sediments; 2 - C_{2-3} continental red and grey sediments; 3 - D_3fm-C_1 marine bituminous sediments; 4 – D red-coloured sediments; 5 – ledge of pre-Devonian basement, 6 - faults, 7 - copper deposits and occurrences

In the Zhezkazgan area are the following regional deep faults: Terektinsky, the north branch of the Terektinsky fault, the East Ulutausky meridional, Edygeysky and Zhezkazgan-Taskorinsky faults (Figure 3). All regional faults are ore-controlling.

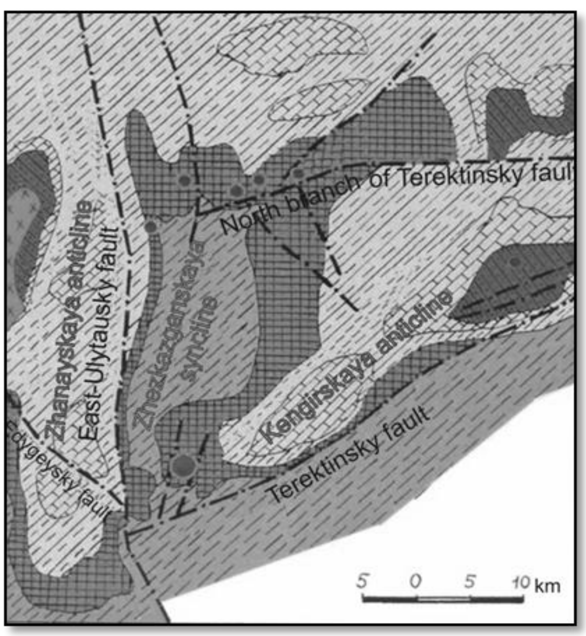

***Figure 3:** Faults in the tectonic schemes of the Zhezkazgan ore field (Seyfullin et al., 2004)*

Lower Devonian sediments are located at the bottom; and are represented by volcanic rocks of different composition, interbedded with red sandstones. Above these are only clastic and carbonate sediments: red-coloured sandstones and conglomerates of the Middle Devonian, silicified limestones, sandstone and marls of the Lower Carboniferous. The total thickness of these deposits is 1,500 m. The Zhezkazgan suite has a Middle-Upper Carboniferous age, and the thickness is about 700 m. This consists of regularly alternating grey-coloured and red-coloured sandstones and siltstones. Above this are crimson-red sandstones, mudstones, limestones and marls of Lower Permian age (Figure 4).

Zhezkazgan ore deposits are found exclusively in the grey-coloured rocks, regardless of lithology. Copper, lead and zinc is found in the grey-coloured rocks on average 4-5 times more often than in the red-coloured. Industrial mineralization of the deposit extends to a depth of about 600m. The poor copper mineralization occurs below.

The total number of mineralized grey-coloured strata in the field is 26, but commercial mineralization bears only 19 of them. These layers are combined into nine ore-bearing horizons, each of which includes several layers of ore-bearing rocks, separated from each other by red non-ore layers. There are Taskuduksky, Zlatoust, Pokrov, and Raymund (Lower, Middle, Upper) and Krestov, Pokro suites, and Transit zones.

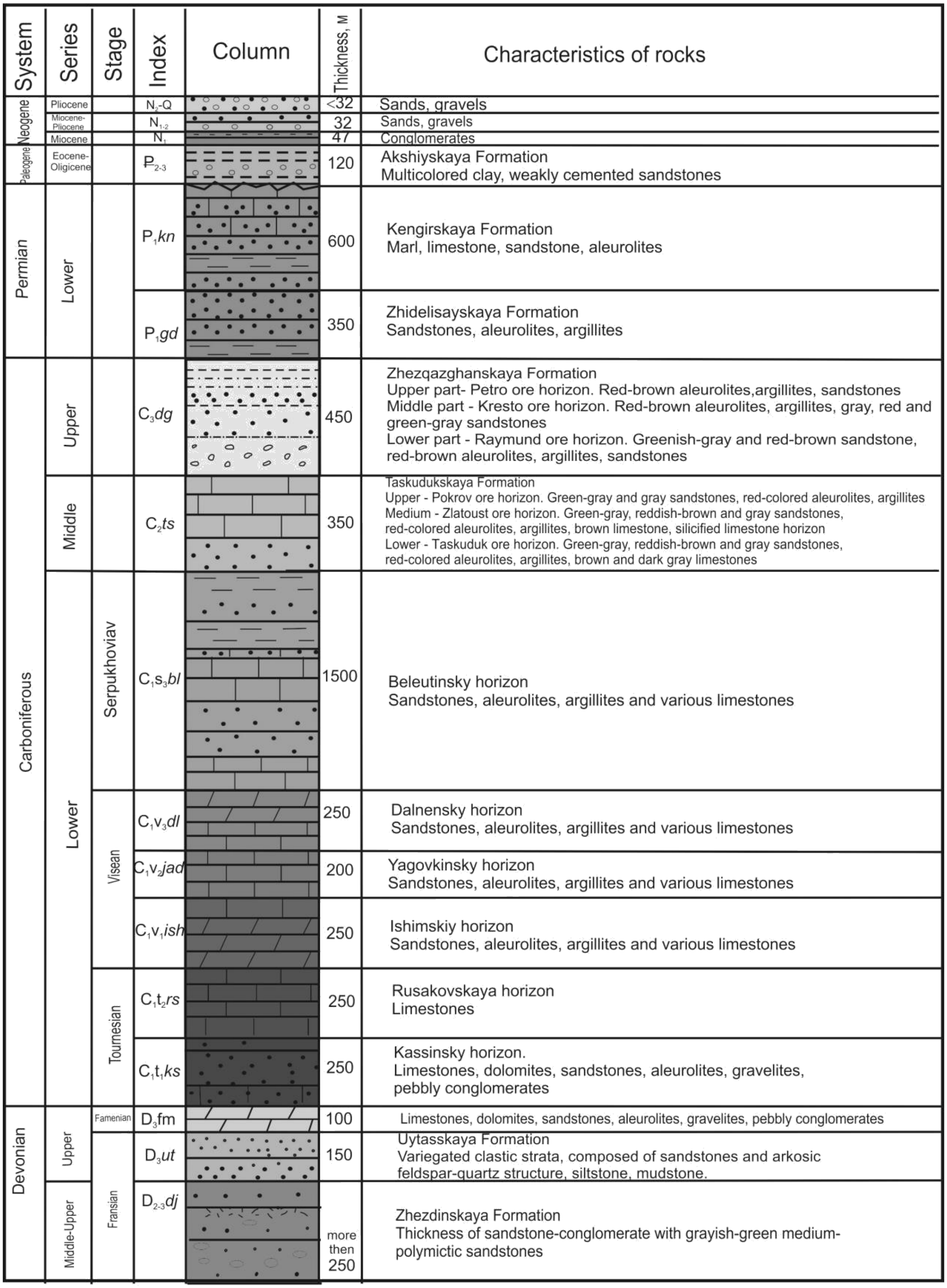

Figure 4: *Stratigraphic column of Zhezkazgan ore field*
(by Esenov Sh., Zaitsev Y., 1975 [6]; Satpayev K., 1999 [7])

The clastic rocks of Zhezkazgan deposits are continental, marine and transition facies in composition. Identification of some features of the sedimentary environments in the basin and provenance characteristics was made on indicators that were developed by Z.A. Yanochkina [5]. The ratio Fe_2O_3/Fe_2O_3 is a measure of oxidation (more than 1) or reduction (less than 1) conditions of sedimentation. When an Fe/Mn is of more than 13 it characterised that desalination pool is shallow, and when the value is less than 13 it can correspond to a deep-water marine environment. From the ratio of CaO/MgO it may be assumed to be a low (a value of ratio more than 1), or high (less than 1) mineralization pool. The ratio of Na_2O/K_2O is a sign of weakening (greater than 1) or increasing (less than 1) the intensity of the chemical weathering of rocks. Changing The ratio of Sr/Ba in the sedimentation basin area can show the transition from freshwater conditions (Sr/Ba less than 1) to the sea (more than 1).

3. Sedimentation environment

There series of studies of rocks from the Zhezkazgan deposit was done comprising a detailed analysis of the tectonic, climatic regime and palaeogeographic situation during weathering, transportation and accumulation (sedimentation) of the terrigenous material ore-bearing strata [6, 7]. There were also compiled geological documentation section deposits from core boreholes, outcrops and the preparatory treatment of mine workings [8].

Sedimentation in the study area occurred in the large river valley, controlled by a series of deep faults. It changed its direction from the meridional to the southeast (Zhezkazgan Sarysu-syncline) in the area of fields Taskora and Jaman-Aibat. This is confirmed by the typical association of fluvial sediments: alluvial fans (foothills) with the local bedrock erosion, floodplains, coastal plains, coastal and underwater deltas. River flow activity was seasonal, floods alternated with periods of drying. The existence of such a river artery and described mode of operation is confirmed by the study of modern depositional environments. Thus, according to G. E. Reynard and I.B. Singh [9], for example, the width of sand deposits in the valley of the Brahmaputra River was up to 30 km with thicknesses of 20-40 m, and the width of the alluvial plain of River Kosi was 500 km. In this case the active formation of sediments in the river depositional environment occurs only during high floods, for several days or one or two weeks in a year.

Sedimentation in the Zhezkazgan Depression sedimentary basin was of distinct rhythmic regular character called a cyclic tectonic regime in conjunction with original climatic conditions. The cycle begins with tectonic activity, creating a more or less dissected relief and the increasing humidity of the climate. Moderate intensity streams erode sandy material surrounding the river valley land areas.

Due to the significant potential geomorphological relief in the early periods of the cycle flood waters cause erosion, which is fixed in the form of layers and lenses of conglomerates and breccias composed of sand bodies. Relatively stable periods are expressed in the formation of aleurolite and argillite layers in the composition of the sand layer. Grey-coloured rocks are formed at the beginning of a regressive cycle as a result of the accumulation of the products of physical weathering (Na_2O/K_2O = 1.45) in the shallow water pool with underwater currents (Table 1).

Table 1: *Geochemical parameters for Zhezkazgan rock deposit*

Pair ratios / Sediments	$\frac{Fe_2O_3}{FeO}$	$\frac{Fe}{Mn}$	$\frac{CaO}{MgO}$	$\frac{Na_2O}{K_2O}$	$\frac{Sr}{Ba}$
Grey sandstones	0.91	27.82	2.52	1.45	0.33
Green siltstone	0.90	75.99	1.86	0.55	0.43
Brown sandstones	2.66	40.94	1.65	1.56	0.40
Red siltstones and mudstones	2.98	65.73	1.28	0.41	0.31

The source of clastic material was a sedimentary and igneous rock complex. In quiet areas fine-grained and aleurite-pelitic dispersed material was deposited; it was enriched to a green colour by chlorite. Sedimentation n of the transported material takes place in the subaqueous part of the delta, where the flow has sufficient strength, resulting in a large cross-bedded rock texture. The sedimented material was transferred into a muddy slurry dense mass that precluded the settlement within basins and rivers by fish, as well as other types of swimming animals.

In relatively quiet areas of the basin bottom sediments were exposed by rewashing and formed horizontal layering or poorly expressed stratified texture. The Fe_2O_3/FeO ratio of grey sandstones and green aleurolits was 0.97 and 0.90 respectively; it shows a quantity of reducing the environmental conditions of sedimentation (Table 1). As the Fe/Mn ratio has a value of 27.82 to 75.99, it can indicate shallow-water sedimentary basin (for deep-sea conditions Fe/Mn is less than 13). In such conditions the formation of chloritic material in cement of clastic sediment and in the whole clay rocks gives grey-green tone colours. Separate areas in the sedimentary basin were subjected to vertical movements. These areas were subject to filling sediments in continental conditions. This is marked by the appearance of layers of red aleurolites and argillites with different thicknesses in the grey-coloured sandstone. In the process of uplift of those areas, there was erosion of the hinterland and the red layers contain fragments of the coarse-grained rocks. There was probably a rich vegetation around a coastal zone and herbivorous quadrupeds appeared. This is evidenced by the paw prints and tailmarks of animals, printed in grey-coloured fine-grained sandstones of the coastal zone with ripple marks. In a further development of the cycle, the coastal areas turned into continental plains.

The sedimentation cycle completed stabilisation of the tectonic regime, and the medium sand section changed to a fine-grained material. A sedimentation environment moves underwater sections of the basin to its coastal areas. Further long periods of sedimentation occur in conditions of alluvial plains, and here the material accumulates predominantly due to chemical weathering from the source rocks. Small-amplitude oscillatory processes lead to the accumulation horizons of interbedded grey and red coloured rocks that are usually characteristic of coastal areas of sedimentary basins.

The accumulation of thick horizons of red siltstones and mudstones occurs in the final stage of the cycle. This may happen during continental environment with predominantly gently sloping topography of the surrounding area. The sedimentation took place where the measure of oxidative conditions of the environment was Fe_2O_3/FeO = 2.66-2.98 (Table 1). There is numerous mud cracks formed on the surface by precipitation during frequent drying of continental sedimentary basins. The distance between them and the opening width depends on the thickness of the layer. Sediments lose water and were rapidly compressed into compact sedimentary rocks. When these areas were submerged mud cracks appear to be filled with new sediment or soaked and deposited.

Material from chemical weathering of the provenance rocks accumulated in the alluvial plain (Na_2O/K_2O = 0.41) (Table 1). In such conditions floodplains with typical weak seasonal currents and shallow lakes deposited material with fine pinnate layered wavy alternating red argillites, siltstone, brown and brownish-grey aleurolite-sandstone and fine-grained sandstones. Vegetation that emerged during periods of humid climate may disappear with the onset of an arid climate in the region. The root system of vegetation invades the initial stratification of rocks, giving them a lumpy texture; sometimes the root residues develop carbonate pseudomorphs. The absence of halite and gypsum in the ore-bearing strata of the rocks indicates relatively freshwater sedimentation. This is also confirmed by the value of geochemical components CaO/MgO = 1.28-2.52 and Sr/Ba = 0.31-0.43 (Table 1).

Accumulation conditions in the ore-bearing strata of Zhezkazgan series identified 12 lithogenetic rock types [8]. We established that the mineralization was associated with sandstone facies of the underwater part of the delta, which has favourable reservoir properties to infiltrate solutions and for the ore formation.

The facies of sandy sediments in the underwater part of the delta PR was divided into two lithogenetic types [10].

Lithogeneous type PR-1 is the most common for this facies, and is represented by grey, greenish and brownish shades of average-to-fine-grained sandstone. The texture of the sandstone is large and cross-bedded, the interlayer thickness is 1-3 cm, and their series is 1-2 m. Crossed, slightly cut off, multidirectional and straightforward layering is rarely seen. Sorting of detrital material is average; no regularities of changes in the clastic components of the layer were established. A weak sort of material is related to the proximity of drift sources and to fast transportation of material without sufficient differentiation of debris by size.

Layers of sandstones of this type have a lenticular and stratum shape, their thickness varies from 1-2 to 30-40 m. Changes in the structural layers of rocks were caused by tectonic pulsations. Usually more coarse-grained material lies at the base of the sandstone. These sandstones are formed in the initial period of tectonic activity, when the erosion activity of the river flows was increased. Sometimes interlayers and lenses of intraformational conglomerates consist of sharp-edged and unsorted debris from bedrock, which are mostly red siltstones. Sometime within one layer of sandstone 1 - 4 layers of conglomerates can be found, their thickness varies from 0.1 to 2 m. Such a structure is due to tectonic uplift and subsidence that could cause activation of fluvial erosion or stabilisation [11].

The quantity, duration and intensity of inner cycles in a layer of sandstone can be determined by the interlayers of conglomerates, and the size and composition of sediments. Internal transitions in the layers are gradual, so their boundaries are weak and often arbitrary. On the other hand, the boundary layers of sandstones in this lithogenetic type are distinct. The lower boundary with the underlying red aleurolites and argillites of continental sediments is especially exposed by varying degrees of erosion of the river delta flows. The layering of underwater delta sediments is visible by the change of structure, and impure allogenic material distributed by layering, sometimes changing interlayer shades. The orientation of cross-bedding can be different depending on the direction of arrival of the clastic material. In some parts of layers that are stacked with apparently homogeneous material, layering is almost invisible, and rocks are characterised by streaky or massive (homogeneous) texture. Sandstones in the underwater part of the delta are laterally and facially replaced by lithogenetic different rock types. These replacements have certain regularity. At the bottom layer red-coloured and fine-clastic continental deposits are dispersed. The sediments of shallow coastal and continental coastal plains are located above. Laterally, usually outside of the field, they often change to brown medium-grained sandstones of continental alluvial sediments.

Lithological type PR-2 is sandstone with interbedded conglomerates, but with a smaller grain size of clastic material. In the layers of fine-medium-grained sandstones are aleurolites. Aleurolites interbed with green and dark green argillites at a thickness from 0.1-0.2 to 1-2 m can be found. Layering of sandstone varies from cross-bedded to a horizontally layered, and argillites and aleurolites are horizontally layered and non-oriented. The appearance of fine-grained and dispersed rocks in the layer indicates the relative stabilisation of tectonic activity, and the increased content of chlorite shows the depth of the water basin [12].

Depending on the tectonic and palaeogeographic situation, ore-bearing sandstones of the underwater part of the delta may overlap stratigraphically above the grey-coloured fine-grained shallow coastal sandstones, red-coloured sands and clay rocks of the coastal alluvial-lacustrine continental plains.

Intraformational conglomerates occupy various stratigraphic positions and have a different composition of clastic material. Often debris conglomerates consist of pieces of red argillites and siltstones that have already dried up and were compacted at the surface. Less common are fragments of brown fine-grained sandstone, and sometimes local green siltstones and sandstones. The distance the debris is transported is usually not far, so they do not have time to sort and become rounded, they immediately enter the sand mass, which becomes the cement of conglomerates. Such conglomerates, or rather their sand cement, are ore-bearing, as underwater delta sandstones are ore-bearing. Fine-grained and possibly dispersed particles are transferred to the deeper parts of the basin in a hydrodynamically active environment of fast currents and can be found in underwater deltas. Sandy sediment devoid of fine-grained components and tightly packed can be found, and has significant initial effective porosity and reservoir properties. These pores are filled with cementing ore and vein (siliceous-carbonate) material during the circulation of ore-forming solutions in sandstones which leads to a decrease in porosity and increases the strength of ore sandstones.

Within sandstones of Zhezkazgan suites there are so-called "Raymond" conglomerates consisting of well-rounded pebbles of older rocks from the neighbouring source regions.

4. Lithology

Rock samples for the study were taken from the mines and quarries of the Zhezkazgan field. We made double polished thin sections from these samples at Adam Mickiewicz University and Kazakh National Technical University. Ore and rock-forming minerals were studied using a polarizing microscope to reflect and transmit light at high resolution. The chemical composition of the minerals was studied by BSE and EDS methods in the Laboratory of Electron Microscopy in the Institute of Geochemistry, Mineralogy and Petrology of the Warsaw University on the electron probe microanalyser CAMECA-SX 100. Semi-quantitative analysis was carried out at the Laboratory of Microscopy and Microprobes in the Faculty of Geology and Geography at Adam Mickiewicz University (Poznan) on a scanning electron microscope Hitachi S-3700N (SEM) and energy dispersive X-ray spectrometer Noran SIX (EDS).

Specially selected samples were subjected to petrographic, chemical and physical research.

A number of geochemical parameters were used to identify features of the sedimentation of rocks (Table 1). The values of Fe_2O_3/FeO are important in grey sandstones and green siltstones and equal to 0.91 and 0.90, this ratio indicates reducing conditions of sedimentation. As the Fe/Mn ratio has a value from 27.82 to 75.99, it is determined that the sedimentary basin was not deep (for deep-sea conditions the value of Fe/Mn must be less than 13). Formation of chlorite material and cement in bulk sediments leads to a grey-green appearance under these conditions. Grey-coloured rocks are formed at the beginning of a regressive cycle as the result of sediments of physical weathering products (Na_2O/K_2O = 1.45). Interbedded grey-coloured and red rocks reflect a change in sedimentary environments. Red sandstone and siltstone have different ratios Fe_2O_3/FeO 2.66-2.98. An absence of salt and gypsum in the grey, green, brown and red rock compositions indicates the freshwater environment of sedimentation. This is also confirmed by the values of geochemical components CaO/MgO = 1.28-2.52 and Sr/Ba = 0.31-0.43.

The petrographic composition and the content of the clastic material in the grey-coloured and red-coloured rocks in the Zhezkazgan deposit are similar, indicating that they were formed from the same supplying sources. The grey sandstones show a greenish tint, which is caused by the chloritization of biotite and the content of greenish-grey fragments of minerals and rocks. The contents of detrital material vary in the sandstones between 75 and 95% (Figures 5, 6).

The sandstones can be divided into three groups according to grain-size: medium-grained (grain size 0.25-0.5 mm) and fine-grained (0.05-0.1 mm). Coarse-grained sandstones are very rare. The clastic material in the sandstones and aleurolites are mainly composed of quartz and feldspars, and fragments of various types of rocks (Figures 7, 8). The contents of quartz grains fluctuate between 20 and 30%. Feldspars include orthoclase, microcline and plagioclase grains; the latter contain up to 20-30% of anorthite content, which corresponds to oligoclase.

Feldspars are subjected to varying degrees of alteration; sericitization is the dominant process.. The carbonate content in the rocks is low, typically lower than 5-8%; carbonates are represented mainly by calcite, although small amounts of siderite have been also noted.

The rock fragments consist of pyroclastics, acid volcanic rocks, shales, and limestones (Figure 9, 10).

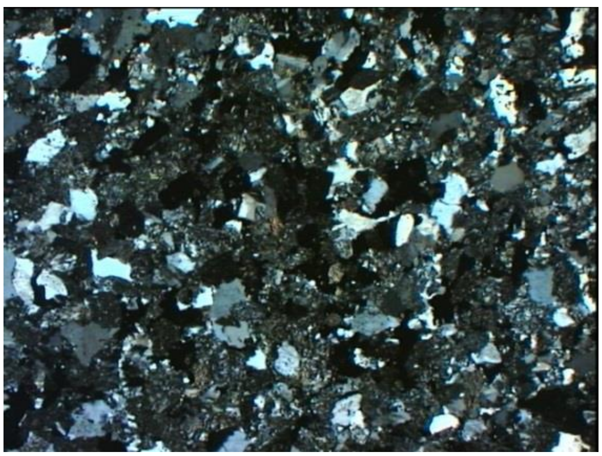

Figure 5: *Image of sandstone in the polarizing microscope in transmission light, power* 25^X*, with analyser*

Figure 6: *Image of sandstone in the polarizing microscope in transmission light, power* 20^X*, with analyser*

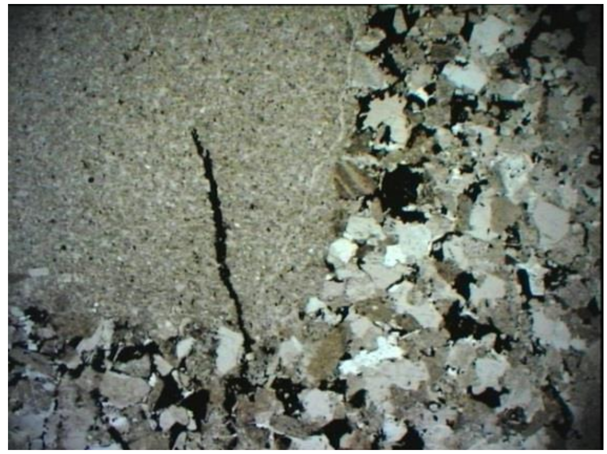

Figure 7: *Image of aleurolite included in sandstone in the polarizing microscope in transmission light, power* 25^X*, without analyser*

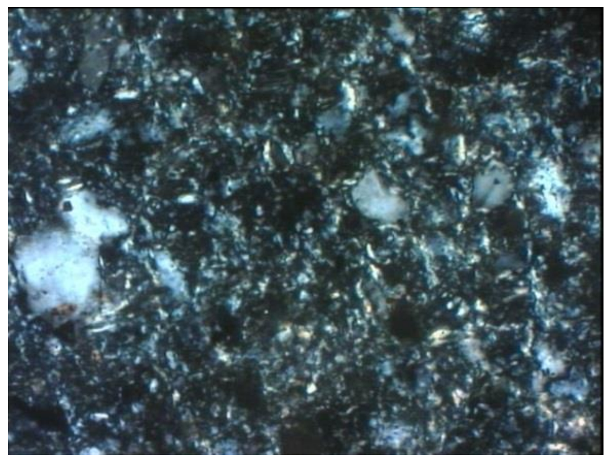

Figure 8: *Image of aleurolite in the polarizing microscope in transmission light, power* 50^X*, with analyser*

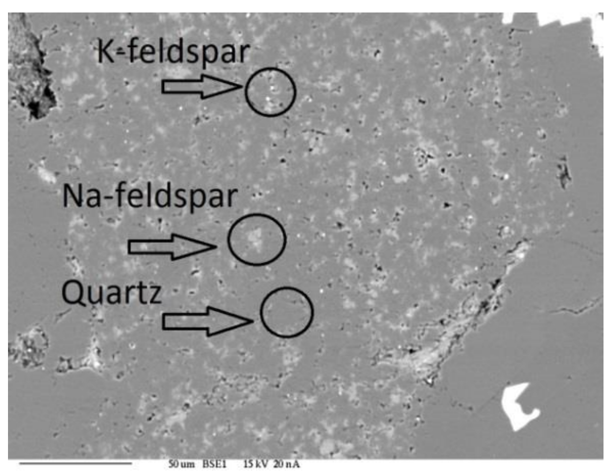

Figure 9: *Image of sand-grain in electron probe microanalyser CAMECA SX 100. Grain is the pyroclastic*

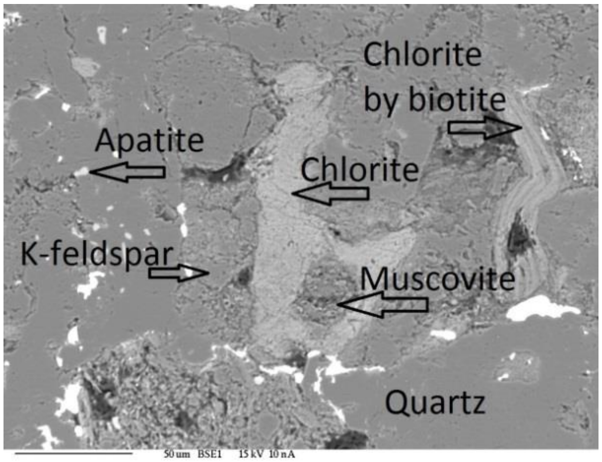

Figure 10: *Image of sand-grains and calcite cement in electron probe microanalyser CAMECA SX 100*

Angular and subrounded grains predominate rounded fragments are less common (their share does not exceed 25%) (Figure 11).

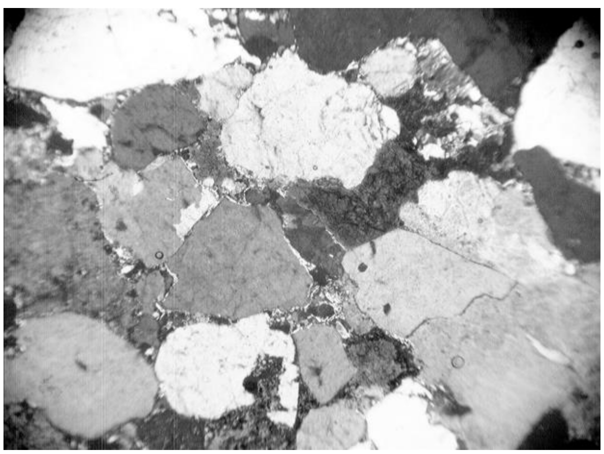

Figure 11*: Image of subrounded and angular grains in sandstone in the polarizing microscope in transmission light, power 4^X, with analyser*

The sandstones show a high degree of compaction, a result of diagenetic processes. The volume of cement is about 15-18% of total rock. The cements have various compositions: clay minerals, carbonate minerals, quartz, and ore minerals. They form pore fillings as well as grain coats, also patchy and basal types. The grey sandstones contain small amounts of iron-containing minerals, which are present in fragments of volcanic rocks and in altered biotite flakes (Figure 10).

Red beds are medium and fine-grained sandstones. The grain size varies from 0.25 to 0.5 mm of medium and 0.1 to 0.2 mm for the fine-grained types. Iron hydroxides associate clay mineral cement, and give the red sandstone a brown hue. Red sandstones occur in barren areas of the field. The detrital material of the red sandstones is polymictic, similar to that in the grey sandstones. Grains are composed of quartz, feldspar, and a variety of rocks (metamorphic and volcanic rock fragments). Feldspars are subjected to secondary changes: calcitization, sericitization and silification. Grains are mainly angular. The red sandstones contain different cements: clay minerals and carbonates. The cement volume is about 15-20% of the rock. Red beds structure is cross-bedded, in most cases lumpy. Primary layered texture of rocks stored in intervals of interbedded siltstones and sandstones, the layers are thin and have different morphology. Primary layering in siltstone and argillaceous intervals were broken by plant roots and structure became lumpy. Such formations distinguished as soil and subsoil layers. Thickness of red beds is variety.

5. Ore minerals

In the process of mineralization, ore solutions penetrated into the space between the grains, and ore minerals replaced clay and carbonate cement (Figure 12). All ore minerals are found in the cement and the cracks in the grains. Three most common Cu-bearing minerals are chalcopyrite, bornite and chalcocite. Lead occurs in galena and zinc in sphalerite. Silver is contained in other minerals (including native silver), as well as in sulfides. The silver content increases from galena - chalcopyrite - bornite – to chalcocite. Rhenium associated with the copper sulfides generally occurs in bornite.

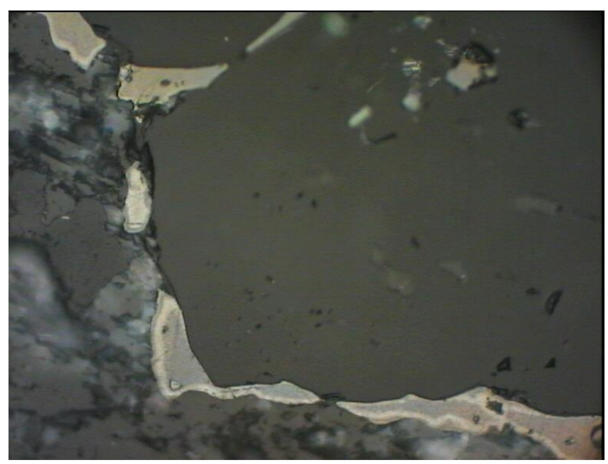

Figure 12*: Image of pore cementation, chalcocite around quartz, in the polarizing microscope in reflection light, power 50^X, without analyser*

The composition and the degree of secondary changes in the clastic material of the ore-bearing rock of deposits are thus identical. The different colours in the multi-coloured rock strata are caused by features of the geological conditions and sedimentation of sedimentary material. The initial colouring of rocks in post-sedimentary stages of transformation does not seem to undergo further changes. Features of the environment of sedimentation ore-bearing rock strata are characterised using the appropriate geochemical indicators

6. Summary

Sediment-hosted copper has a cyclic structure. Each cycle begins with layers of coarse-grained rocks, sandstones and ends with fine grained clastic rocks. Detailed petrographic study of ore-bearing rock strata showed a volcaniclastic composition.

Grey sandstone sediments were developed in reducing conditions and the sedimentary basin was not deep. They are formed at the beginning of a regressive cycle as a result of physical weathering; and the environment of sedimentation basin was freshwater.

General mineralization of copper deposits connects with the grey sandstone in the underwater part of the delta. Lithogenetic sandstones type PR-1 and PR-2 are ore-bearing. Copper-hosted sandstones from underwater facies in the Zhezkazgan deposit fit into the overall picture of sediment formation in the other major Cu hosted stratiform deposits of the world [13].

7. Acknowledgements

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References

[1] F. Pirajno, *Hydrothermal Processes and Mineral Systems*, Geological Survey of Western Australia, 2009.

[2] K. C. Misra, *Understanding mineral deposits*, Kluwer Academic Publisher, 2000.

[3] S. Sh. Seyfullin, *Stratiform copper deposits western part of Central Kazakhstan*, Alma-Ata, Science, 1976.

[4] D. J. Vaghan, M. Sweeney, G. Friedrich, R. Diedel, C. Haranczyk,“The Kupferschiefer: An Overview with an Appraisal of the Different Types of Mineralization”, *Economic Geology*, Vol. 84, PP. 1003-1027, 1989.

[5] E.A. Yanochkina, *Statistical methods for studying variegated layers*, Moscow, Nedra, 1966.

[6] Sh.E. Esenov, Y. Zaitsev, *Geology and minerals of the Dzhezkazgan ore district*, Moscow, Nedra, 1975.

[7] K.I. Satpayev, *Collected Works*, Vol. 3, Almaty, Gylym, 1999.

[8] A.B. Baybatsha, *Engineering geology of mineral deposits with the basics of geoinformatics*, Almaty, Gylym, 2000.

[9] G.E. Reynard, I.B. Singh, *Terrigenous of sedimentation environment*, Trans. from English, Moscow, Nedra, 1981.

[10] L.N. Botvinkina, Y.A. Zhemchuzhnikov, P.P. Timofeev, *Atlas of lithogenetic types Middle Carboniferous coal-bearing deposits of the Donets Basin*, Moscow, Academy of Sciences, 1956.

[11] A.B. Baibatsha, “A new look at the geological structure and geodynamic development in Kazakhstan”, *Materials of Republic Conference NAS*, Series Geol., V. 2, PP. 66-74, 2008.

[12] B.K. Proshlyakov, V.G. Kuznetsov, *Lithology and lithofacies analysis*, Moscow, Nedra, 1981.

[13] Peter Laznicka, *Giant Metallic Deposits*, Springer Berlin Heidelberg, 2010.