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ORE FORMATION DURING PRE-GREENSCHIST ALTERATION OF SEDIMENTARY AND VOLCANOGENIC ROCKS

(Tabs. 2)

Abstract: Alterations of sedimentary and volcanogenic rocks reach a considerable degree and intensity as soon as in the period between diagenesis and metamorphism in the greenschist facies, i.e. in the conditions of temperature from ca. 50 up to 300—350 °C and pressures up to 3—5 Kbar. The authors designate these alterations as deep-seated epigenesis.

Temperatures of epigenetic alterations varying between 100—280 °C and temperatures of mineral origin in secretory veinlets between 150—350°C have been determined by means of the method of homogenization of inclusions in minerals of various rocks (Tab. 1).

Experimental study of mobilization of ore elements of rocks by thermal solutions (in autoclaves at the temperature of 300° C and the pressure of 300 bars) proved that a considerable part of ore elements — Cu, Ni, Co, Pb, Zn, Cr representing ca. 20—50 % of original content in the acid medium substracted to solutions from the rocks (Tab. 2).

From the studies of several ore regions and results of experiments it comes out that mobilization and migration of ore components of rocks during the processes of deep -seated epigenesis reach a considerable degree and may lead to formation of important telethermal ore deposits in sedimentary-volcanogenic complexes.

Резюме: Изменения осадочных и вулканогенных пород достигают значительной степени и интенсивности уже в этапе между диагенезом и метаморфизмом фации зеленых сланцев, т. е. в условиях температуры колеблющейся приблизительно от 50 до 300—350 °C и давления до 3—5 килобар. Авторы называют эти изменения глубинным эпигенезом.

Температуры эпигенетических изменений, варьирующие в пределах от 100 до 280 °C и температуры образования минералов в секреционных прожилках от 150 до 350 °C были определены с помощью метода гомогенизации включений в минералах разных пород (таб. 1).

Экспериментальное изучение мобилизации разных элеменитов пород при помощи термальных растворов (в автоклавах при температуре 300 °C и давлении 300 бар) показало, что значительная часть рудных элементов — Cu, Ni, Co, Pb, Zn, Cr представляющая в кислой среде около 20—50 % первоначального содержания перешла в растворы из пород (таб. 2).

Из исследования многочисленных рудных районов и результатов экспериментов вытекает, что мобилизация и миграция рудных компонентов пород достигает значительной степени во время процессов глубинного эпигенеза и это может приводить к образованию значительных телетермальных рудных месторождений в осадочно-вулканогенных комплексах.

Alteration of sedimentary and volcanogenic rocks in Pre—greenschist facies resulted from the influence of chemically active solutions at the temperature range from 50 to 300—350°C and the pressure not exceeding 3—5 kilobars.

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Rock alteration is so considerable and from the point of view of useful material so important that further work on this problem is badly needed.

The best widespread alterations are as follows: 1. neogenesis of zeolites, montmorillonites, quartz, chlorite, epidote alongside with plagioclase albitization in pyroclastic rocks, rich in fragments of volcanic glass; the alteration occured at the depth of 7—10 km, pressure of 2—3 kilobars, whereas temperatures seemed not to exceed 200—300°C; 2. neogenesis of dickite, quartz, albite, hydromica, epidote, chlorite and progress of mosaic-metasomatic texture of limonite, pumpellite, prehnite, clinozoisite in quartz-kaolinite rocks, clays, quartz-feldspar sandstones and other sedimentary rocks; 3. alterations of coals (for instance, in coal beds of the Donetsk basin) from lignite to antracite and acompanying transformations of host quartz-argillaceous and carbonaceous rocks, which turned to schists, quartzite-sandstones and crystalline limestones. Through the present -day data antracite formation ocurred at the temperature of 180—250°C; 4. wide distribution of veins, veinlets and other accumulations compositionally peculiar to host rocks; quartz ones - in silicate rocks, carbonaceous - in carbonates, quartz-jaspilites - in jaspilites; they often contain ore components.

Lack of equiponderant parageneses of minerals, high dependence of final products both upon the composition and state of primary rocks, alongside with particular role of metasomatic alterations prevent these rocks to be referred to low temperature fascia of regional metamorphism according to Escola (1915).

At present, secondary alterations of sedimentary rocks, from sediment diagenesis to their metamorphism, refer to epigenetic ones. *Abyssal epigenesis is considered to be secondary alteration and neogenesis of minerals, resulted from the factors peculiar only to abyssal processes.* Fascia of regional epigenesis are assumed to be distinguished like associations of rocks of close mineral composition, characterized by combination of newly formed structural and mineral signs, characteristic of certain stages of epigenetic progress of rocks.

The fascia (stages) of regional epigenesis are as follows: *starting epigenesis and the abyssal one.* Some autors cite metagenesis, which through some data is characteristic of low-temperature subfacies of greenschist facies, and through another ones is intermediate between epigenesis and metamorphism.

Factors of various epigenetic fascia formation are as follows: a) depth of rock plunge or PT-conditions; b) starting mineral composition; c) chemical activity of solutions, defining metasomatic alterations.

Ore deposits formed due to thermal solutions at 100—300°C are of widespread occurence among sedimentary and volcanogenic rocks subjected to epigenetic alterations. The above deposits most commonly have nothing to do with magmatic chambers, although in some classifications they are referred to low-temperature stages of magmatic ore formations. In Russian and foreign literature such deposits are called telethermal, i.e. remote from its source or, by some authors, from magmatic chamber.

Telethermal deposits are of widespread occurence the world continents. They need further study and genetical reestimation. They are as follows: multiple sheet and crosscutting deposits of lead and zink in carbonaceous rocks of river vallies of Mississippi and Missouri in the USA, Upper Silesia in Poland, in Canada, Australia, Africa, USSR - Kazakhstan and Kirgizia; uranium deposits in sandstones of Colorado plateau; copper-lead-zink in slate rocks of Mansfeld - GDR, in Poland etc.; antimonite and cinnabar deposits among clastogene rocks in Nikitovka (Ukraine), Khaydarkan (Middle Asia) and Altay; bornite--chalkopyrite deposits of copper in sandstones of Dzhezkazgan (Kazakhstan), in many regions of South Africa, the Donetsk basin (cuprous sandstones) etc. Among them there are unique deposits as to their content and reserves of metals (Dzhezkazgan, Mansfeld, Nikitovka etc.).

Telethermal deposits by Park — Mak-dormid (1966) resulted from hydrothermal solutions, removed from magmatic chamber at a great distance. During their migration these solutions lost heat and chemical activity. The above deposits are usually simple as to their mineral composition, have no near-by-ore alterations and are presented by stratiform and veined bodies.

Telethermal deposits by Smirnov (1969) are peculiar to rocks of sedimentary formations free of active igneous rocks. A majority of them are characterized by bedded ore bodies peculiar to certain stratigraphic horizons and multibedded and widespread occurrence of ore bodies. Telethermal deposits have been established to be formed at final stages of geosyncline progress during transition to platform period.

By Fedorchuk's opinion (1977) telethermal mercury deposits formed at the temperature of 50—250°C and the pressure reaching several thousand of kilobars. Structurally and morphologically they can be devided into: 1. veined and cross-cutting bodies peculiar to steeply dipping zones of crush among terrigenous, effusive and metamorphic rocks, where ore minerals both fill cavities and replace them; 2. bedded concordant-stratiform deposits.

By Zhukova (1978) telethermal deposits ("mississippi type") are characterized by: their widespread occurrence, covering certain stratigraphic beds or horizons; lack of spatial association with igneous rocks; low or complete lack of near-by-ore alteration; simple mineral composition - sphalerite, galenite, pyrite, calcite; wide distribution of colloform structures; presence of rare and scattered elements; reference to the regions of intensively folded structures and pre-ore disturbances.

Turchenko (1978) cites data on low temperature (up to 350°C) alteration of tufogene-sedimentary sulphidebearing ultrabasites with formation of mineral associations, peculiar to prehnite-pumpellite and greenschist fascia of metamorphism responsible for sulphide copper-nickel mineralization of the Pechenga region in Kola peninsula.

In many cases telethermal deposits show signs of both epigenetic hydrothermal and sedimentary deposits, that's why the question of their genesis is far from being settled.

Presently, there are several points of view as to the genesis of telethermal deposits, they are as follows:

Magmatogene-hydrothermal genesis (Volfson, 1970, 1971; Zakharov, 1960; Knyzev, 1959; Smirnov, 1952, 1966; Zhukova et al., 1978). This group deposits are associated with deepseated igneous rocks. The authors' conclusion results from: a) presence of crosscutting bodies alongside with bedded ones; b) alteration of wall rocks, resulted in silicification, sericitization and kaolinization; c) stages of ore formation presented sometimes by various paragenses; d) relatively high temperatures of mineral formation, through the data on gazeous-liquid inclusions - from 50 to 100 and 200°C.

Sedimentary syngenetic genesis (Rutie, 1960; Konstantinov, 1963; Popov, 1970). This is confirmed by widespread occurrence, stratigraphic sequence, stratified ore beds, lack of igneous rocks and lack of tectonic control of mineralization.

Sedimentary-metamorphic genesis (Domarev, 1967; Shneiderkhen, 1957, 1958; Gorzhevsky — Kozerenko, 1971 et al.) is confirmed by primary-sedimentary bedded syngenetic accumulation of ore material and its migration during diagenesis, epigenesis and metamorphism.

Epigenetic formation due to chemically active subsurface water of abyssal circulation (Germanov, 1953, et al). This viewpoint results from the following: a) low temperatures of mineral formation, corresponding to heated waters of abyssal circulation; b) composition of mineral neogeneses, peculiar to that of host rock; synroot character of the occurrence of ore deposits and veined zones, that makes impossible to recognise ways for ore material supply from outside.

We studied ore manifestations of polymetals of Nagolny range, Nikitovka deposit in Donetsk basin, some deposits in GDR, those of black shales in Uzbekistan and other regions, alongside with rocks of tavrichevsky suite, limestones of Balaklavsky deposits in Krimea, sandstones, aleurolites and argillites of carbonaceous series of Carboniferous period in the Donetsk basin. All the above rocks apply to the sedimentary ones, however they altered significantly during abyssal epigenesis. The latter conclusion results from their full crystallization, desection by veins and veinlets, structured by quartz, calcite and other minerals.

Temperatures of formation for minerals of rocks and veinlets have been determined through method of homogenization of gaseous-liquid inclusions in minerals (Tab. 1). Maximum temperatures in rocks are lower than 300°C that testifies to their transformations during premetamorphic stage, i.e. during abyssal epigenesis. Some areas of balaklavsky marmorized limestones and slates of black shales formation are clarified, there are more veinlets here, moreover maximum clarification is characteristic of veinlet gouges. Above mentioned transformations appear to result from local, somewhat higher temperature metamorphism, that is testified by increased temperatures of homogenization in comparison with non-clarified rocks (1—3, Tab. 1). The same high temperatures are peculiar to crystallization of veinlet minerals. So far as ore zones of telethermal deposits occur in fractured rocks with great many veinlets, temperatures for mineral formation here are somewhat higher as well (6—8, Tab. 1).

Data cited in the Table 1 and analogous values from other regions testify to rather high temperatures responsible for alteration of primary mineral composition of rocks, formation of veinlets and accumulation of ore minerals both in cross-cutting and leaf-by-leaf cavities of rocks.

The results of fluid inclusions study show that mobilization and migration of ore components during abyssal epigenesis are due to aqueous-saline solutions, carbon dioxide and organic matter (Kuznetsova's data). The above mentioned phenomenon and capillary-filmy state of solutions explain mobilization and accumulation of a considerable body of metals even by comparatively small bulk of water, which liberated during epigenetic rock transformation.

Table 1

Temperature of formation for minerals in rocks and veinlets*

No.	Rock	Temperature of homogenization, °C	
		minerals of groundmass of rocks	minerals of veinlets
1.	Marbled limestone from Balaklavsky quarry, Krimea	Calcite, 120—140	Calcite, 210
2.	Marbled limestone from tavrichesky suite with veinlets of calcite, Balaklavsky region, Krimea	Non-clarified grondmass of rock, calcite, 80—200 Clarified areas of rock in gouges of veinlets, up to 300	 Calcite, 240
3.	Coaly-micaceous silicificated schist, black shale formation, Uzbekistan	Quartz, 140—160 Clarified areas af schist in gouges of veinlets, quartz, 180—215	Quartz, 180
4.	Long-flame coals and their host rocks in the Donetsk basin	70—90**	Quartz, 150—350
5.	Anthracites, semi-anthracites and their host rocks in the Donetsk basin	170—240**	Quartz, 150—350
6.	Chlorite-sericite schist outside the ore zone, GDR	Quartz, 190—235	
7.	Chlorite-muscovite schist within the ore zone, GDR	Quartz, 190—280	
8.	Amphibole-carbonate-epidote schist within the ore zone, GDR	Quartz, 260—290	Quartz, 270—380

* Measurements by Kuznetsova

** Crytical temperatures for metamorphism of coals by Levenshtein (1962)

We studied experimentally mobilization of ore elements by thermal solutions. The experiments were carried out in autoclaves at the temperature of 300°C and the pressure of 300 bars in acid, neutral and alkaline medium supplied with chlorides and carbonates of sodium. We studied behaviour of copper, nickel, cobalt, lead, zink, chromium and in some cases iron, manganese and silver.

Active substraction of metals to solutions from various rocks, subjected to abyssal epigenesis have been recognized to take place. Characteristic peculiarities here are as follows: 1. total content of ore components is higher and substration is lower in non-clarified groundmass of rock - limestones and slates of black shale formation, than that in clarified sites of corresponding rocks (1—4, Tab. 2); 2. total content of ore components outside the ore zones is higher and their mobilization by thermal waters is lower than in the corresponding rocks inside the ore zones (5—8, Tab. 2). Thus, owing to local higher temperature metamorphism components became more mobile and participated in the formation of ores and ore manifestations of streaky type; 3. experiments with sandstones, aleurolites and argillites show, that the higher is the tempe-

Table 2

Mobilization of ore components by thermal solutions (in % to starting content)

Medium	1	2	3	4	5	6	7	8	9	10	11
acid	20.8	25.5	43.5	51.2	41.3	50.3	25.0	47.2	51.9	46.0	21.6
neutral	12.1	18.3	3.0	11.5	3.8	6.8	6.5	6.6	15.3	8.8	3.0
alkaline	13.5	21.1	9.7	8.6	6.6	6.7	4.8	5.7	19.5	12.1	5.4
start. cont	0.0134	0.0130	0.0329	0.0244	0.0383	0.0258	0.0458	0.0414	0.0729	0.0433	0.0287

Explanations: 1 — Limestones of tavrichesky suite, non-clarified groundmass of rock, Krimea. 2 — The same limestones, clarified sites in gouges of calcite veins. 3 — Coaly-micaceous schists of black shale formation, non-clarified groundmass of rocks, Uzbekistan. 4 — The same schists, clarified sites in gouges of quartz veins. 5 — Schists of black shale formation outside the ore zone, Uzbekistan. 6 — The same schists within the ore zone. 7 — Chlorite-micaceous schists outside the ore zone, GDR. 8 — The same schists within the ore zone. 9 — Sandstones, aleurolites and argillites, host long-flame coals, the Donetsk basin. 10 — The same rocks, containing anthracites. 11 — Metamorphic rocks-gneiss, Priasovie.

rature of epigenetic transformation of these rocks, from long-flame coals (70—90°C) to anthracites (170—240°C), the lower is subtraction of metals into solution, though it remains to be rather important (9—10, Tab. 2). In contrast to the above mentioned we show data on deeply-metamorphosed rocks - gneiss, metal subtraction of which is well below, than from the sedimentary rocks (11, Tab. 2). The latter phenomenon results from the fact that the increase of rock metamorphism leads to the increase of content of more stable forms of metals.

Thus, rock alteration during abyssal epigenesis is rather important and associates with considerable migration of disseminated metals in rocks. Formation of telethermal deposits can be genetically associated with epigenetic (pregreenschist) transformation of volcanogenic-sedimentary rocks. The latter ones had increased content of ore components, which became mobile under the action of thermal solutions, resulted from epigenetic alteration of rocks that in turn is testified by stratigraphic arrangement of many deposits to the certain type of rocks, proximity of isotopic data of many elements in host rocks and ore deposits, their chemical composition and mineral parageneses of neogenesis.

On the grounds of various data on telethermal deposits, analytical and experimental values we arrived at a conclusion, that: a) mineral structure of veins in epigenetically altered rocks, as a rule, resembles that of host rocks; b) origin of vein minerals and perivein alterations took place at the temperatures close to those of epigenetic rock transformations; c) mobilization and migration of ore components in rocks under the action of telethermal solutions were rather important that in turn could lead to the concentration of metals and ore deposit formation.

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