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OXYGEN ISOTOPES IN SOLUTION OF THEORETICAL PROBLEMS AND APPLIED TASKS OF ORE GEOLOGY

(Figs. 5)

Abstract: The results of the original investigations of application of the oxygen-isotope method for the solution of the theoretical problems and practical tasks of the ore geology are considered in this paper. For the first time the isotope-oxygen investigation of a wide scope of ore minerals from hydrothermal deposits of Sn, W, B, Be, U, Ta, Fe, Nb, Mo, Hg, Au, etc. from different regions of the USSR as well as of other countries has been carried out. The isotope-oxygen proofs that carbonate and bicarbonate complexes are the main chemical form of the transfer of many ore elements are obtained. Prospects of the usage of oxygen-isotopic criteria for solving a number of prognosis-evaluation and geological prospecting tasks are shown for the first time.

Резюме: В статье рассматриваются результаты оригинальных исследований автора по использованию изотопно-кислородного метода для решения теоретических проблем и прикладных задач рудной геологии. Впервые проведено изотопно-кислородное исследование широкого круга рудных минералов из гидротермальных месторождений Sn, W, B, Be, U, Ta, Fe, Nb, Mo, Hg, Au и др. из различных регионов СССР и ряда зарубежных стран. Получены изотопно-кислородные доказательства того, что карбонатные и бикарбонатные комплексы являются основной химической формой переноса многих рудных элементов. Впервые показаны перспективы использования изотопно-кислородных критериев для решения целого ряда прогнозно-оценочных и геолого-разведочных задач.

As is known, stable isotopes, and primarily oxygen isotopes, brought into geology not only a powerful means of scientific investigations, but also new ideas and notions, made it possible to solve important theoretical and applied tasks of ore geology on the radically new isotopic basis.

It is precisely oxygen-isotopic method that, to a large extent, determined the progress achieved in studying principal relationships of hydrothermal ore formation.

A galaxy of such scientists as H. Craig, H. Taylor, S. Epstein, I. Friedman, J. O'Neil, S. Sheppard, R. Rye and others, made a great contribution to development of the present model of hydrothermal ore deposits formation. The model is based upon the fundamental notion implying that paleohydrothermal ore-forming systems are long-lived convection-circulation hydrodynamically semi-closed systems which are set to motion by the heat energy of intrusions. At different stages of evolution of mobile belts, depending on geologo-tectonic environment, the systems involved magmatic, marine, formation and meteoric waters.

Owing to oxygen-isotopic studies, such important parameter, as integral water mass, circulating in paleohydrothermal ore-forming system, was quanti-

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tatively assessed for the first time. It was found that "water/rock" ratio of hydrothermalite varies from 0.1 to 10.0 and even more. This means that hundreds and thousands cubic kilometres of water, mostly exogenic in nature, are involved in ore-forming system to give rise to ore deposits and wallrock alterations of host rocks (Борщевский, 1980).

Results of oxygen-isotopic studies of uranium-bearing alkaline metasomatites from regional fault zones of a Precambrian shield (Борщевский и др., 1976), as well as generalization of world evidence on the evolution of isotopic composition of oxygen from regionally metamorphosed rocks, enabled us, together with Academician A. V. Sidorenko, to make a well-grounded conclusion that even deep zones of regional metamorphism, regional alkaline metasomatosis and granitization, maintain a geologically active relation with the main planetary water reservoir, i. e. world ocean, thereby providing material circulation of matter and energy between hydrosphere and lithosphere (Сидоренко — Борщевский, 1975).

Therefore, it would be justified to conclude that not only formation of hydrothermal ore deposits but also metamorphogenic and magmatogenic ore formation, in the end, are determined by water-fluid regime of the Earth crust which is, as it now becomes obvious, an open system for hydrosphere waters.

So, oxygen isotopy made a great contribution to the modern theory of hydrothermal ore formation.

There is a new, very promising trend in isotopic studies of ore deposits: oxygen-isotopic study of ore minerals proper. Isotopic characteristics yield valuable information necessary for solving important genetic problems of hydrothermal ore formation, such as the nature of ore-bearing fluids, the chemical form of ore element transportation, the ore formation temperature, etc.

Investigation carried out by us in 1973—1983 were the first experience in studies of a wide scope of such ore minerals as cassiterite, wolframite, scheelite, magnetite, borate and borosilicate, beryl, titano-niobo-tantalite, etc. from hydrothermal ore deposits of practically all major industrial regions of the Soviet Union as well as of other countries (Борщевский и др., 1977; Борщевский — Борисова и др., 1978; Борщевский — Покалов, 1978; Борщевский — Борисова — Лисицын и др., 1978; Борщевский — Медведовская и др., 1978; Борщевский — Подольский и др., 1978; Борщевский — Апельцин и др., 1979; Борщевский — Доломанова и др., 1979; Борщевский, 1980; Борщевский — Апельцин и др., 1980; Борщевский — Гинзбург и др., 1980; Борщевский — Борисова и др., 1982; Борщевский — Лугов и др., 1982).

Fig. 1 shows oxygen-isotopic histograms for a large group of oxygen ore minerals. In addition, however, it was necessary to determine constants of oxygen isotope fractionation in "ore mineral-water" systems so as to interpret valuable genetic information incorporated in oxygen isotopic composition of these ore minerals. For this purpose, using the original theoretical model, β-factors for water, quartz, cassiterite, scheelite, uraninite and other ore minerals were computed. The obtained values were employed for plotting oxygen-isotope fractionation temperature dependence curves (OIF) in systems: quartz — water, scheelite — water, cassiterite — water, etc. (Fig. 2).

We can see that oxygen ^{18}O heavy isotope under isotopic equilibrium is predominantly concentrated in water rather than in ore minerals. $\delta\ ^{18}O$ ore mineral values as well as computed β-factors were used to solve some important theoretical and applied problems.

First, taking as an example hydrothermal deposits of tin, tungsten, iron, manganese, boron, beryllium, niobium etc., the important role of isotopically

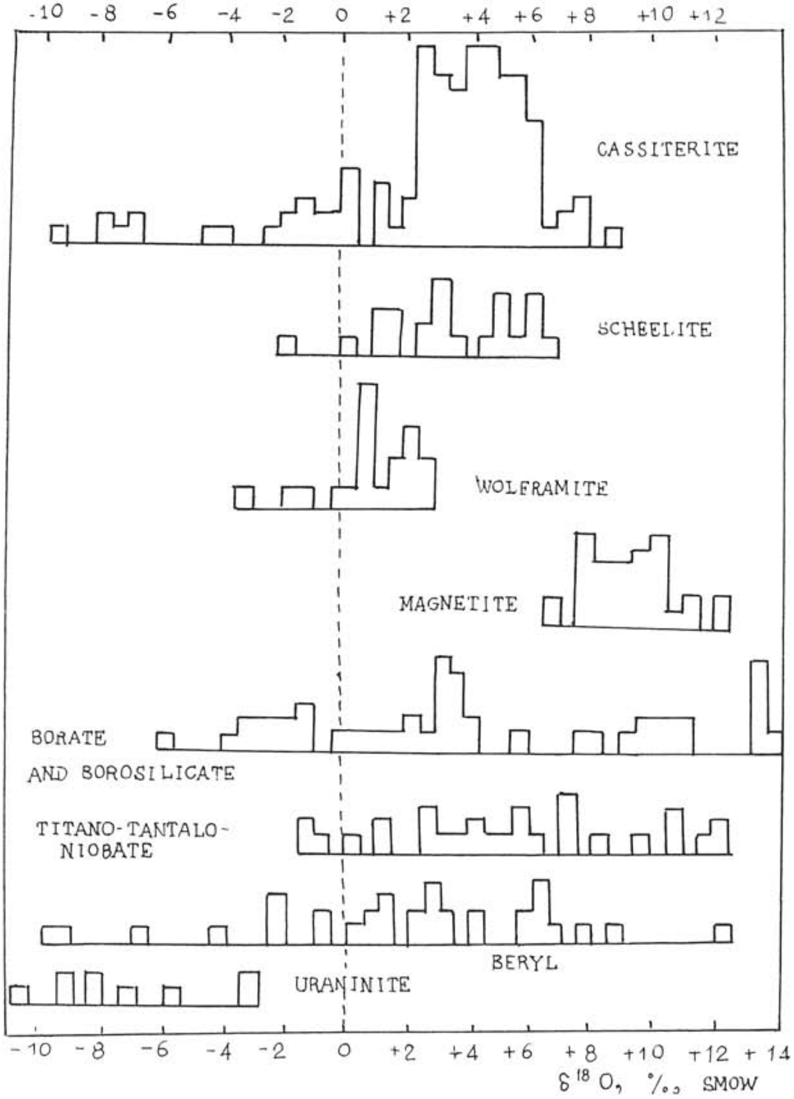


Fig. 1. Oxygen isotopic composition of ore minerals from hydrothermal deposits of the Soviet Union and some other countries.

light, formational and meteoric waters in endogenic hydrothermal ore formation was confirmed (Борщевский, 1980).

Second, appropriate oxygen-isotopic geothermometers were designed for mineral paragenetic assemblages: quartz-cassiterite, quartz-scheelite, quartz-wolframite, quartz-beryl, quartz-datolite (Борщевский — Борисова и др., 1978; Борщевский — Медведовская и др., 1978; Борщевский — Хитаров и др., 1978; Борщевский — Апельцин и др., 1979; Борщевский — Доломанова и др., 1979; Борщевский, 1980; Борщевский — Апельцин и др., 1980; Борщевский — Борисова и др.,

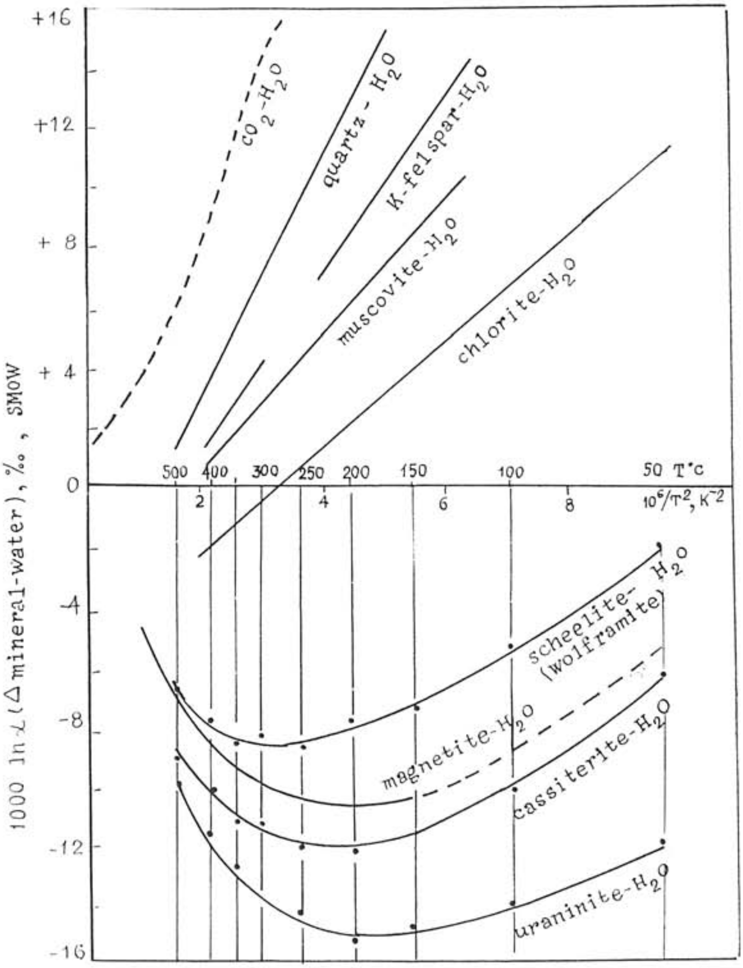


Fig. 2. Curves showing oxygen isotope equilibrium fractionation (OIF) in "mineral — water" system.

1932). The temperatures obtained for the formation of ore assembleges from a number of hydrothermal tin, tungsten, beryllium, boron deposits, well agreed with thermobar-geochemical evidence (Fig. 3).

Third, $\delta\ ^{18}O$ values for ore minerals combined with β-factor values clearly point to carbonated water composition of ore-bearing fluids, thus independently confirming the important role of CO_2 in hydrothermal ore formation,

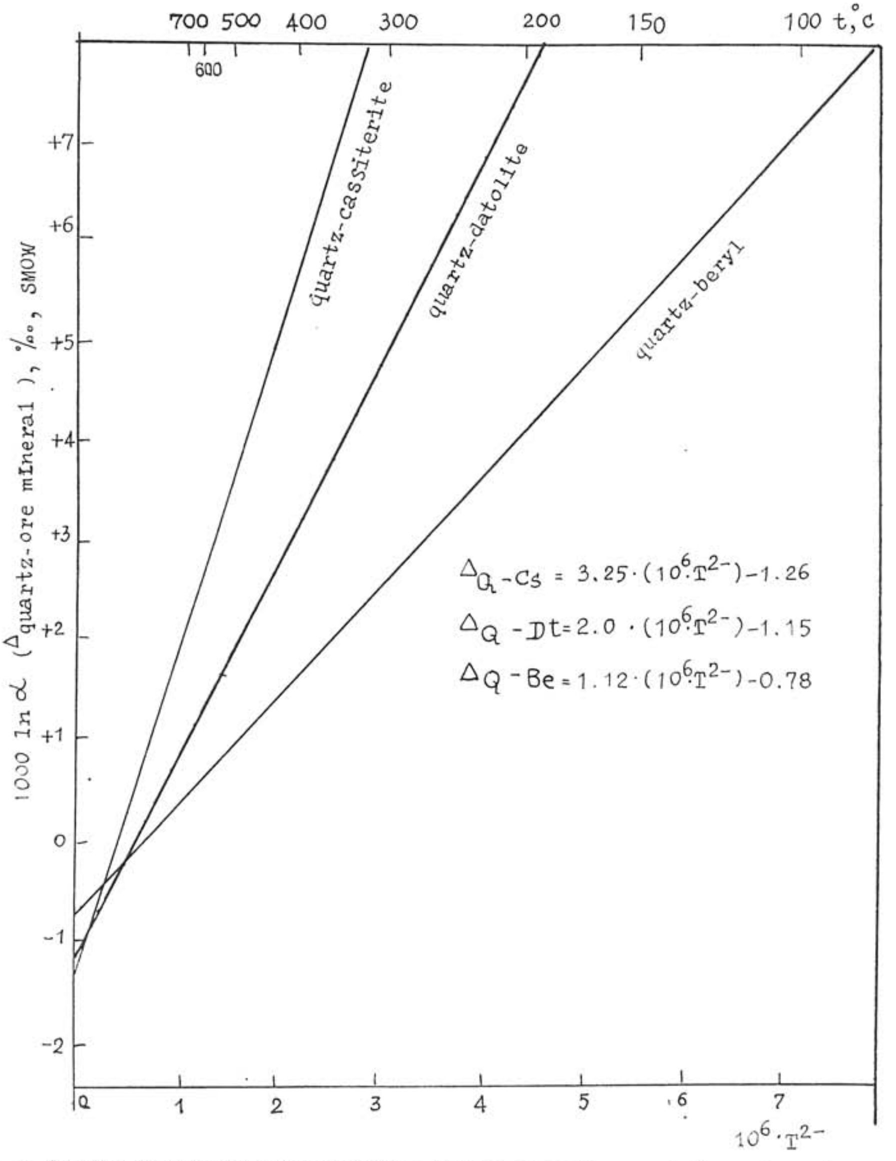


Fig. 3. Oxygen isotopic geothermometers for paragenetic associations "quartz — ore mineral".

which is well known from results of numerous investigations of fluid inclusions in minerals.

Moreover, we obtained oxygen-isotopic evidence of participation of carbonate complexes in tin, tungsten, iron and other mineral element transportation (Борщевский, 1980).

The systematic increase of oxygen-isotopic concentration that is found by us for wolframite, cassiterite, scheelite, magnetite and tantalo-niobate (Fig. 4) indicates that most important in the formation of the above-mentioned minerals were carbonate, and probably, bicarbonate complexes which are the only concentrators of ^{18}O isotope in ore-bearing fluid and which determine, in the end, isotopic composition of these ore minerals. Therefore, we can speak for example with certainty of the possible existence of hydrocarbonate-oxitungsten anion complex compounds in hydrothermal ore-forming solutions.

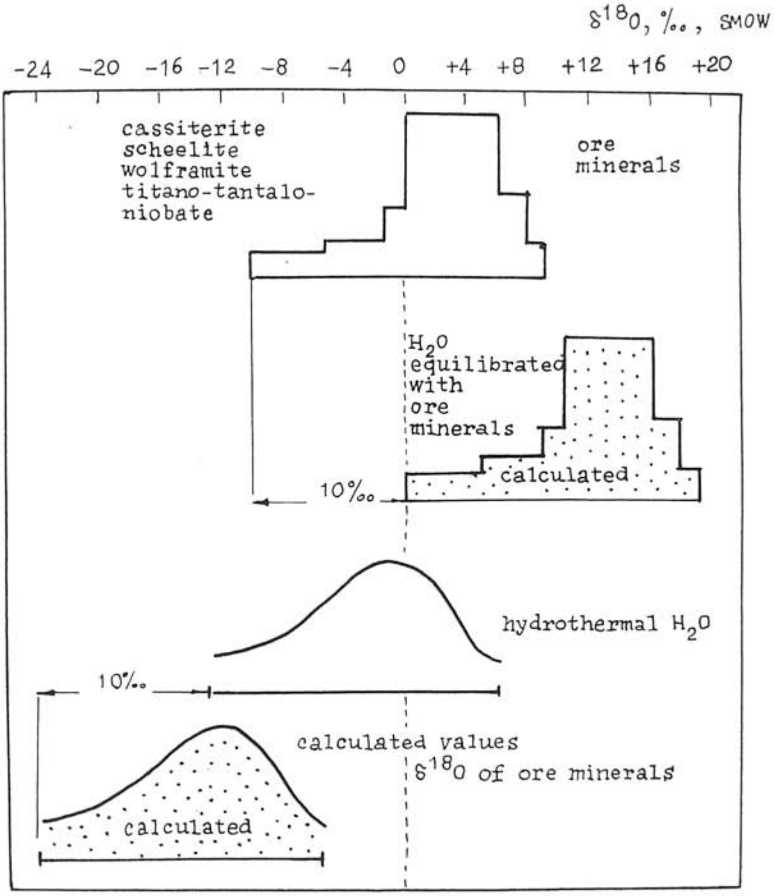
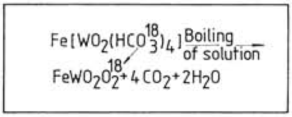


Fig. 4. Oxygen isotopic composition of ore minerals and equilibrated water.

As is shown in Fig. 5, when these complex compounds are decayed and wolframile-ion is transformed into wolframate-ion, two-oxygen atoms are bound to be borrowed from heavy isotopic bicarbonate-ion, which means that ferberite will be enriched in heavy isotope ^{18}O even in the process of its formation. At the same time, tungsten-bicarbonate complexes contribute to the transport of bivalent ions of iron, manganese and calcium that can migrate either together with tungsten in the form of dissolved bicarbonates, or together with bicarbonate-tungsten anion complex.



$$Fe[WO_2(HCO_3^{18})_4] \xrightarrow[\text{of solution}]{\text{Boiling}} FeWO_2O_2^{18} + 4CO_2 + 2H_2O$$

Fig. 5. Mechanism of ferberite formation with participating carbonate complexes.

So, carbonate and bicarbonate anions play a specific chemical role in the transportation of ore elements, while bar regime of CO_2 in ore-bearing solutions is one of the most important factors not only for transportation of ore elements but also for ore emplacement.

We believe that the modern model of hydrothermal ore-bearing system ensures a well-grounded approach to the problem of ore elements source.

As prolonged convection circulation of huge masses of carbonated water solutions brings about powerful hydrothermal rock alteration and thereby intense mobilization of ore elements disseminated in ore-forming minerals, there are all grounds to assume that not only intrusive massifs but also sedimentary and metamorphic rocks serve as sources for ore elements.

Hydrothermal rock alteration and mobilization of ore elements, in turn, are commonly accompanied by oxygen-isotopic rock alteration, the value of which can be taken, in the first approximation, as a measure of mobilization of ore element out of rocks and its concentration at geochemical barriers.

It should be emphasized that the proposed model of hydrothermal ore formation furnishes great possibilities for application of the concept of geochemical barriers as it determines with enough accuracy the integral mass of ore-bearing water solutions which passed through some geochemical barriers.

In our opinion, this model of ore process brings together conflicting notions of "productive" horizons of sediments, on the one hand, and "source" granitoids, on the other. For example, if within some large hydrothermal convective system there is a "productive" horizon of sedimentary rocks, it will inevitably produce a real genetic link between mineralization and host rocks, and mineralization and intrusive rocks, because fluid moves from host rocks through igneous rocks to an ore deposit, thereby genetically the whole geological triad: host rocks — igneous rocks — ore deposit.

The oxygen-isotopic studies of hydrothermal ore deposits of various genetic types brought out interesting patterns of relations that depend both on geochemistry of oxygen isotopes, and distinguished features of hydrothermal ore-bearing systems.

These patterns of relations enabled us, taking boron, tin molybdenum and rare metal hydrothermal deposits as an example, to show prospects of the usage of oxygen-isotopic criteria for solving a number of prognosis-evaluation and geological prospecting tasks, including:

— evalution of the size of boric mineralization and outlining promising economic ore occurrences (Борщевский — Борисова — Лисицын и др., 1978; Борщевский — Апельцин и др., 1980);

— reconstruction of paleorelief of tin ore district by erosional level and establishment of the depth of tin deposits (Борщевский — Подольский и др., 1978; Борщевский — Доломанова и др., 1979);

— establishment of association of tin deposits with different ore formation epochs (Борщевский — Борисова и др., 1978);

— bringing out productive stages of ore mineralization at molybdenum deposits (Борщевский — Покалов, 1978);

— prognostication of mineralization at depth, using as the basis oxygen-isotopic vertical zoning of rare metal deposits (Борщевский и др., 1983).

In conclusion it should be noted that as far back as 1964 Academician A. V. Sidorenko in his book "Geology is the science of the future" pointed out that modern geology acutely needs isotopic, i. e. real genetic classification of rocks and ores (Сидоренко, 1964). In this context the oxygen-isotopic systematics of tin ore deposits of the Soviet North-East, based on oxygen-isotopic properties of cassiterites and geologo-tectonic setting of ore deposits, was the first attempt that turned out to be successful (Борщевский — Лугов и др., 1982).

There are all grounds to believe that further modification of isotopic geology will help us to create isotopic classification of hydrothermal ore deposits in the nearest future.

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