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GEOLOGY

Satellites of Giant Ore Deposits

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Large and superlarge (giant) deposits are commonly accompanied by a halo of veined satellite deposits (hereafter, satellites) showing a strong mineralogical–geochemical link with ores of the deposits. Mineralogical–geochemical associations of the satellites are commonly more differentiated than those of ore deposits, although the associations are closely linked with paragenetic ore associations of giant deposits.

One can identify at least three types of satellites: (1) deposits closely related to the giant deposit in terms of structure (they are formed simultaneously with the deposit from a single hydrothermal system); (2) deposits formed in conjugate independent structures from common sources of mineral substance under different physicochemical conditions; and (3) deposits formed at a later stage due to the remobilization (regeneration) of ore material of the giant deposit and its older satellites.

Satellites of type 1 are developed at large porphyry copper deposits of the Bingham (United States) and Peschanka (Chukotka) types. They are represented by

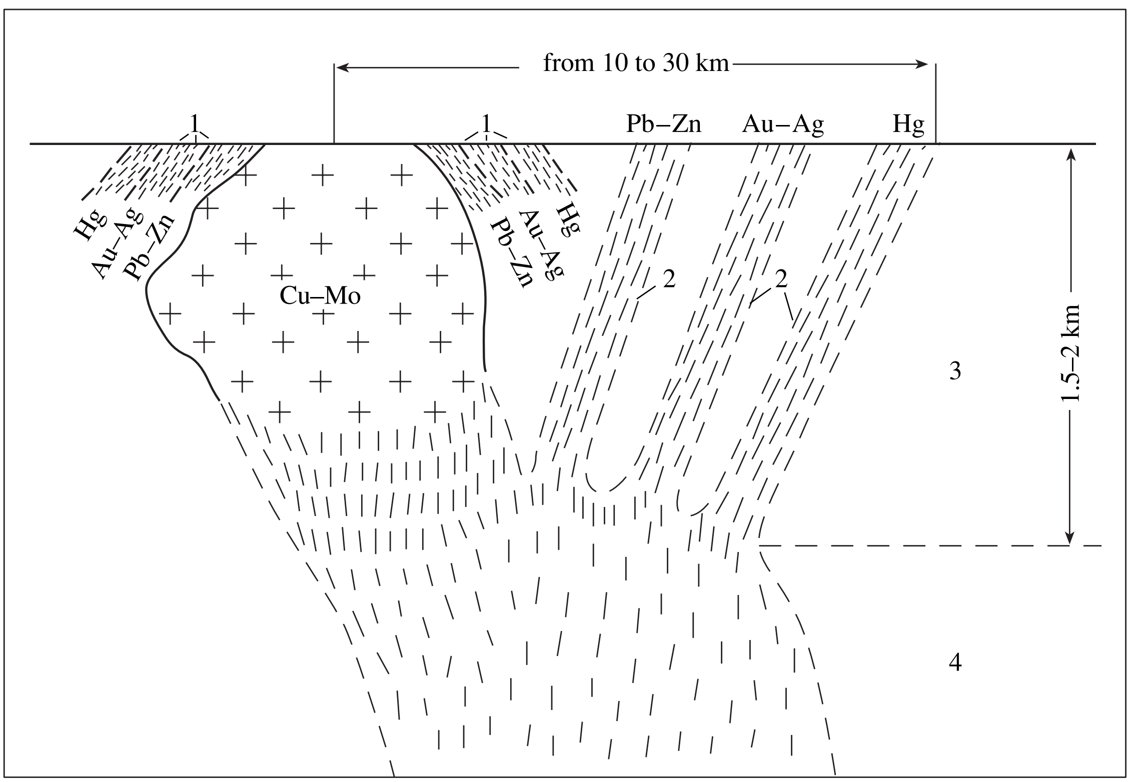

Fig. 1. Formation scheme of satellite deposits (hereafter, satellites) in structures of porphyry copper deposits (Bingham, United States; Peschanka, Chukotka). Ore formation zones: (1) nonporphyry ore zones; (2) satellites, (3) differentiation of ore-bearing fluids, (4) deep-seated undifferentiated fluid.

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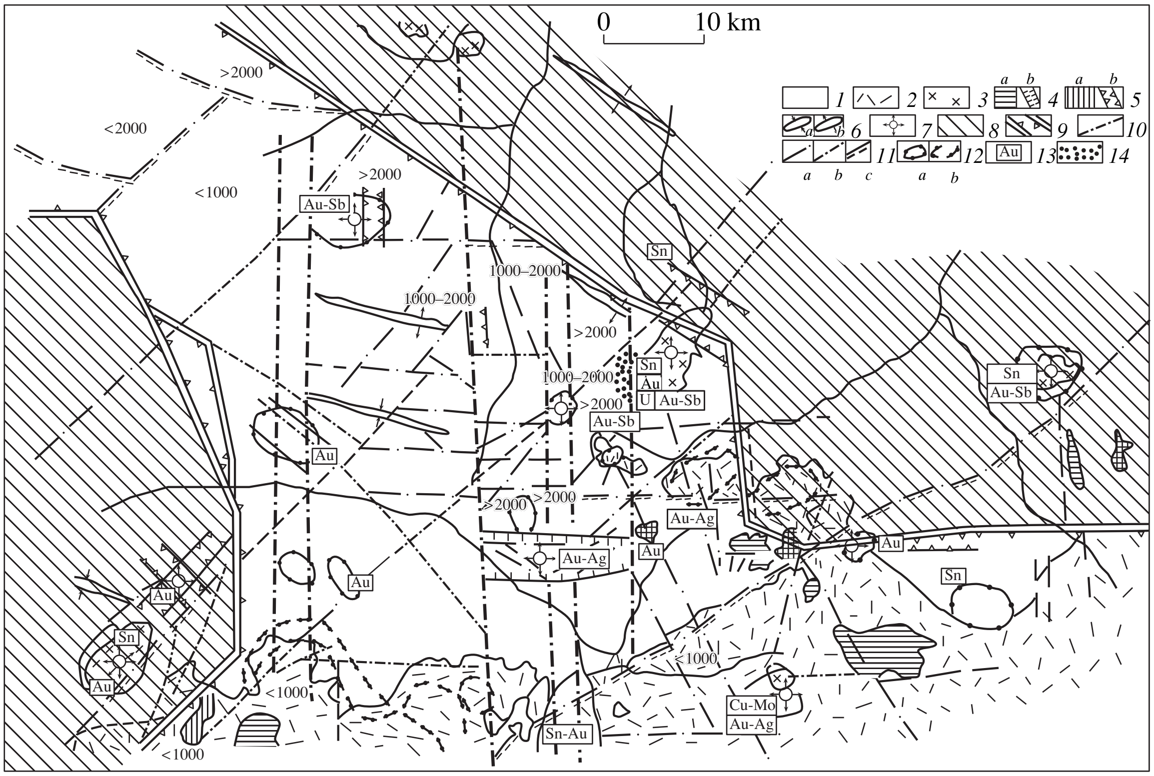

Fig. 2. Schematic structure of the Maisk ore district. (*1*) Lower structural stage (Triassic silty–shaly sequence); (*2*) upper structural stage (volcanogenic sequences of the OCVB); (*3*) granitoid plutons; (*4*) intermediate and basic magmatic bodies: (*a*) subvolcanic massifs, (*b*) dike fields; (*5*) rhyolitic magmatic bodies: (*a*) subvolcanic massifs, (*b*) dike swarms; (*6*) brachyfold axes: (a) synclinal, (*b*) anticlinal; (*7*) ore-bearing domes; (*8*) blocks with the inferred location of weakly granitized basement at a depth of >3000 m; (*9*) boundaries of blocks with an uplifted weakly granitized basement (numbers designate depths of the basement location); (*10*) ore-localizing fractures and fold zones (fragments of hidden faults); (*11*) other fractures: (*a, b*) based on geological data (proven and inferred, respectively), (*c*) based on gravimetry; (*12*) magnetic anomalies: (*a*) related to rock mineralization, (*b*) related to magmatic rocks; (*13*) ore deposits and occurrences; (*14*) gold–sulfide zone of vein–disseminated ores in the giant deposit.

veined (nonporphyry) base metal, gold–silver, and antimony–mercury ores. Analogues of the veined ores are widespread as satellites of the ore fields of porphyry deposits (Fig. 1). The diversity of satellites depends on specific features of the erosion of rocks in ore districts. The satellites are often referred to as the upper structural stage of the giant deposit. In such cases, only the excavation and investigation of lower levels of the ore field can solve the problem.

Let us illustrate satellites of type 2 based on the case study of the Maisk ore district (Chukotka) [1], which is typical of superlarge auriferous provinces in the Pacific belt. First, gold–quartz orebodies were discovered. Epithermal gold–silver, antimony, and mercury orebodies were found at the second stage of geological prospecting. The large Maisk gold–sulfide deposit was discovered only at the late stage of detailed geological prospecting (Fig. 2). Mineral–geochemical associations of all orebodies mentioned above are reflected in orebodies of the Maisk deposit (Fig. 3). The formation of auriferous sulfide zones is related to the activity of the postaccretionary Late Mesozoic Okhotsk–Chukotka volcanogenic belt (OCVB). Ore potential of the OCVB was inherited from the metallogenic specialization of terranes at the base [2].

Satellites of type 3 are described in geological literature as regenerated deposits [3], such as Miocene gold–silver ores of the Precambrian Homestake deposit and epithermal veins of the Omchak ore district [2].

Giant deposits typically develop as inherited structures at the center of ancient (often, Precambrian) large ferruginous–quartzite, uranium–polymetal, massive sulfide, disseminated sulfide, chromite, and copper–nickel (basic–ultrabasic) anomalies [4]. Fine sulfidization and nanomineralization zones accompanying giant deposits are of particular significance among the anomalies. In contrast to massive and stringer-disseminated ores accompanying the giant deposits, the disseminated material is very suitable for the mobilization and subsequent concentration in veined satellites.

Boundaries of ore districts are commonly outlined by haloes of satellites. Despite the diversity of physiochemical constraints and ore-forming solutions, satellites of all types show a common trend. Relative to ores of the giant deposit, ores of satellites are more differentiated. Their mineralogical–geochemical associations

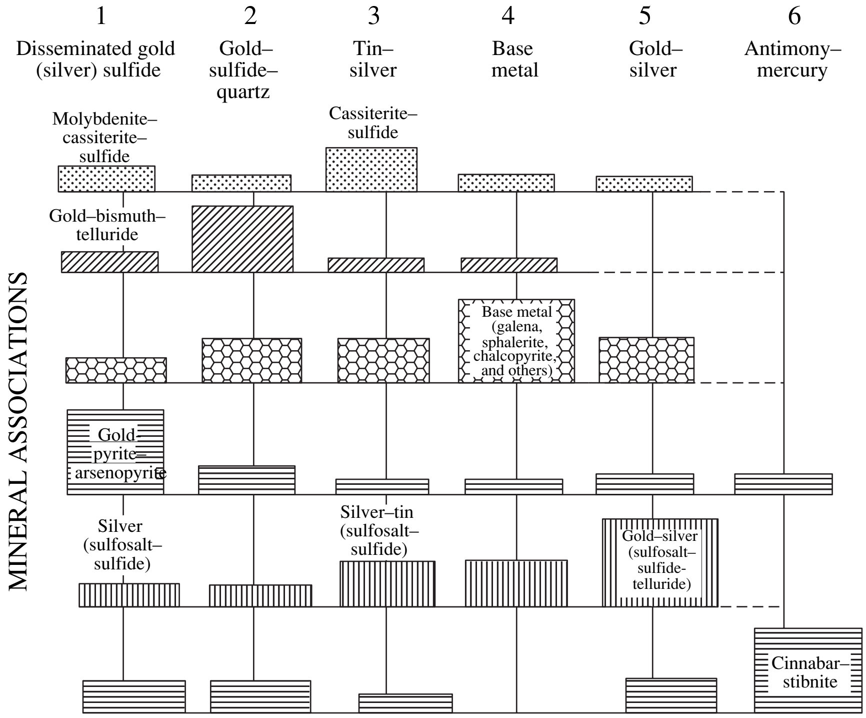

Fig. 3. Mineral assemblages of the Maisk ore district. Multistage mineralization in (1) the large (Maisk) deposit and (2–6) its satellites.

are less numerous and sophisticated (up to the point of monomineral associations). They can generally be considered multistage fragments of giant deposits. The fragments (satellites) become independent only when they lose structural–temporal links with the giant deposit. In terms of the diversity of mineralogical–geochemical associations, giant deposits of the adjacent structures usually lead the hierarchic series of satellites of various mineral types even in the scenario described above. Therefore, it is very important to identify the hierarchic series based on the mineralogical–geochemical link of satellites with the giant deposit. However, sources of ore material are uncertain, and the satellites are almost always characterized by a high degree of convergence owing to similar physicochemical constraints of ore formation. The genetic uncertainty drastically decreases after the identification of the hierarchic series of a certain giant deposit. The giant

Series of giant deposits and their satellites

Giant deposits	Examples	Satellite deposits
Ferruginous quartzites	Isua (Greenland) and Hill (Western Australia) types	Massive sulfide (pyritic), magnetite skarns, gold–quartz, gold–silver, and rare earth element
Uranium–polymetal	Olympic Dam, Witwatersrand, and Central European ore province	Skarn rare metal and rare earth element, five element, base metal, tin–tungsten, tin–silver, gold, gold–silver, and antimony
Massive sulfide base metal	Noranda (Canada) and Kuroko (Japan) types	Base metal (skarn, vein, and metasomatic), gold–silver, silver, and antimony
Gold–sulfide disseminated ore	Maisk (Chukotka), Bakyrchik (Kazakhstan), and Carlin (United States) types	Porphyry, skarn, vein, and metasomatic (auriferous, gold–sulfide, gold–silver, gold–sulfide–quartz, and gold–quartz)
Porphyry copper (molybdenum)	Bingham and Peschanka (Chukotka) types	Skarn, metasomatic, and vein (quartz–sulfide base metal, gold–silver, gold–sulfide–quartz, antimony–mercury, and mercury)
Siver–sulfide and porphyry tin (silver)	Bolivian and Dukat types	Greisen and vein (rare metal, cassiterite–silicate–sulfide, tin–silver, gold–silver, and antimony)
Copper–nickel, chromite, and platinum group metal	Bushveld (South Africa) and Norilsk (Russia) types	Porphyry copper, massive sulfide, base metal, gold–analcime, gold–telluride, and tungsten–mercury

deposits are always better studied than other deposits. Therefore, it is not difficult to decipher mineral assemblages of satellites based on analysis of the mineral composition of ores of the giant deposit. Thus, one can understand the dynamics of the evolution of satellites.

The table presents a classification of satellite deposits based on mineralogical–geochemical analysis of giant deposits [4]. One can see that similar mineral types are widespread among the satellites of different series, although they are certainly heterogeneous in terms of genesis (source of ore material). For example, gold and gold–silver satellite deposits have been discovered in the vicinity of giant deposits of virtually all mineral types. This is primarily explained by low-quality requirements on the economic grade of mineralization. However, gold deposits of the same mineral type in various ore formation series drastically differ with respect to ore grade. Satellites of the uranium–polymetal series have the highest grades, whereas satellites of the silver–sulfide and porphyry tin series have lower grades. Complete series with well-developed antimony, antimony–mercury, and fluorite satellites are typically associated with Au-rich giant deposits. Hence, stable low-temperature conditions of ore deposition promote the concentration of Au-rich mineral associations, all other things being equal [2].

Study of the phenomenon of giant deposits revealed that mineralogical–geochemical associations of their ores define the mineralogical types of satellite deposits. Therefore, the inverse problem—prediction of giant deposits on the basis of small ore occurrences—is of great applied interest, particularly, for insufficiently investigated regions.

The number of mineral types of satellites usually does not exceed the number of multistage mineral assemblages of giant deposits. The geochemical spectrum (including the trace element composition) of ores of satellites is a proxy of the mineral composition of ores of the respective giant deposit.

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