Morphology, composition, and zoning in primary geochemical halos around gold-antimony mineralization

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Geochemical methods are of considerable practical importance in locating and surveying antimony mineralization, so we examined primary halos in a gold-antimony deposit that was surveyed in detail to a considerable depth. The primary halos were examined in 1972-4 in order to define geochemical prospecting features for gold-antimony mineralization and to predict the occurrence of similar mineralization in adjacent areas with similar geological, structural, and lithologic features. Particular attention was given to the following: the halo compositions, the indicator elements for a particular type of mineralization, halo zoning, criteria for erosion and cutdown level, and prospects for mineralization at depth.

This deposit lies at the center of a Mesozoic folded system at the junction between a megaanticlinorium and a megasynclinorium. The deposit is associated with an ore-bearing fault line lying 300-350 m to the northeast of a major tectonic junction lying along a deep fault line. The mineralized fault line lies on the southwest flank of an anticline forming one of a series of fifth-order small folds, and it is of northwest strike and steep northeast dip. This fault line itself has transverse associated joints preceding the mineralization, giving the area a block structure, which has influenced the morphology of the orebody. The fault line is also bounded by a fairly large transverse fault line at the southeast flank of the gold-antimony deposit, which has played a major part in localizing the mineralization. Three distinct areas in the deposit can be defined on the morphology: the northwest, central, and southeast blocks (fig. 1).

The orebody is of vein type, and within it the ore columns are largely associated with the transverse fault lines. These columns are tilted to the southeast toward the major transverse fault at 65-75°.

The country rocks are mainly sandstones with some siltstones, and near the quartz-antimonite veins they are silicified, pyritized, sericitized, and carbonatized. The transverse metasomatic zoning is clearly symmetrical.

The mineral composition of the primary ores is fairly simple, the principal components being quartz and antimonite, with frequent traces of pyrite, arsenopyrite, berthierite, and occasionally sphalerite, chalcopyrite, boulangerite, and certain other sulfosalts. The principal mineral association in the economic ores is gold-quartz-antimonite; the pyrite-arsenopyrite association (the earliest) is of subordinate importance and occurs in the extensively silicified parts throughout the mineralized zone, as well as in minor jointed zones. The quartz-carbonate-polysulfide association is of very limited occurrence and forms veinlets in the country rocks near the quartz-antimonite vein.

Systematic geochemical sampling was performed on cores from 49 survey boreholes from 200 to 600 m deep along 9 lines covering all three blocks of the orebody and extending for more than 1000 m. Some 1300 samples were taken from the space around the orebody.

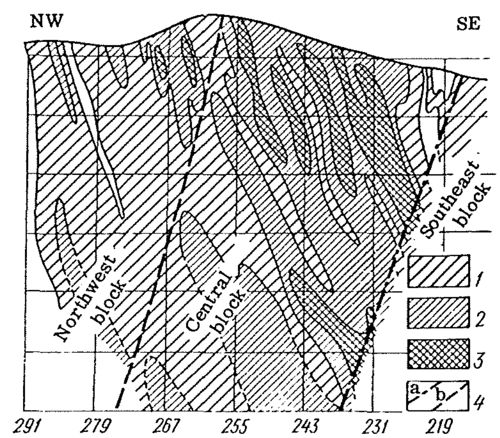

FIGURE 1. Projection of mineralized zone and thickness variation in a vertical plane for a quartz-antimonite vein.

Vein thickness (arbitrary units): 1 - 0-1, 2 - 1-2; 3 - 2-3; 4 - fault lines: a) known, b) supposed.

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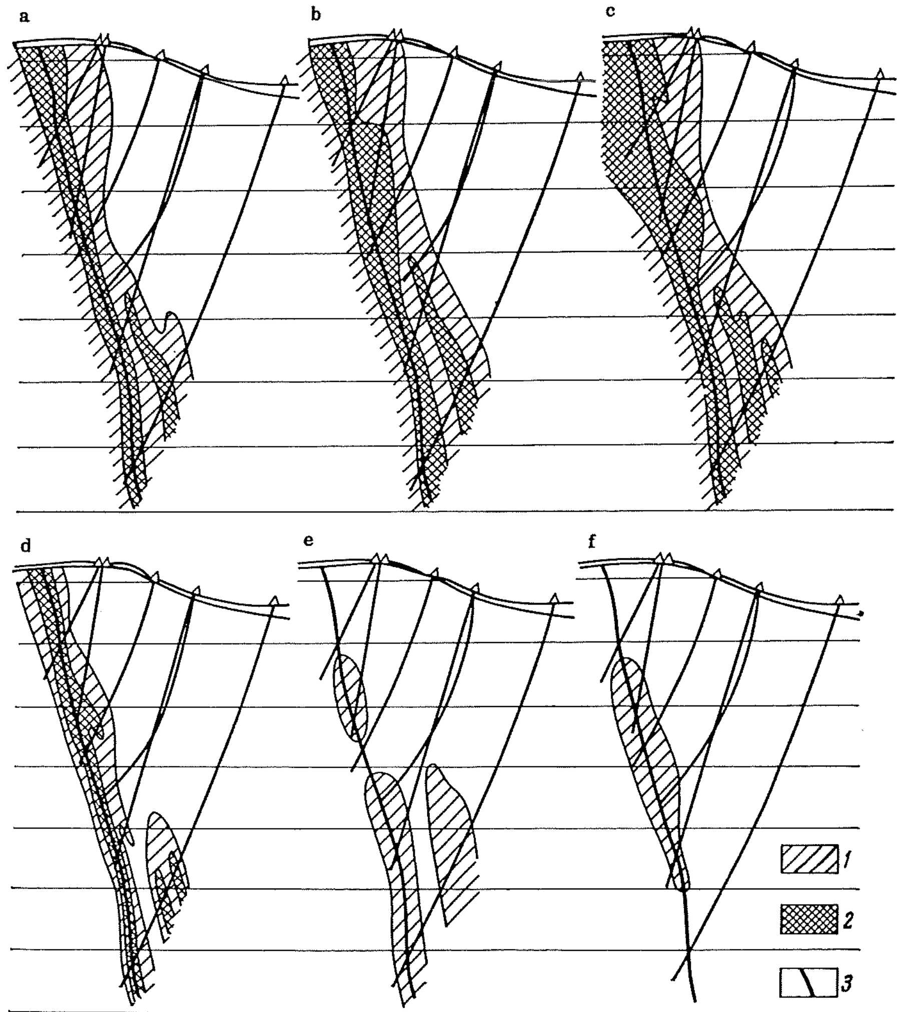

FIGURE 2. Primary geochemical halos, line 243.

Element contents (%) in halos: a - Au: 1) $5\cdot10^{-7}$–$1\cdot10^{-5}$, 2) $1\cdot10^{-5}$–$1\cdot10^{-3}$; b - Sb: 1) $1\cdot10^{-3}$–$1\cdot10^{-2}$, 2) $1\cdot10^{-2}$–$1\cdot10^{1}$; c - As: 1) $1\cdot10^{-3}$–$1\cdot10^{-2}$, 2) $1\cdot10^{-2}$–$1\cdot10^{1}$; d - W: 1) $5\cdot10^{-5}$–$1\cdot10^{-4}$, 2) $1\cdot10^{-4}$–$1\cdot10^{-2}$; e - Ag: 1) $5\cdot10^{-6}$–$1\cdot10^{-4}$; f - Hg: 1) $4\cdot10^{-8}$–$1\cdot10^{-7}$; 3 - orebody.

Semiquantitative analyses for 31 elements were performed on all geochemical specimens. These were burned in a high-current arc by a powder technique. The mercury level was determined by high-sensitivity atomic absorption (limit of detection $1\cdot10^{-8}$%), gold was determined spectrochemically ($3\cdot10^{-7}$%), and antimony, arsenic, and germanium were determined by quantitative spectral analysis (relevant levels from $3\cdot10^{-4}$ to $1\cdot10^{-4}$%). The spectral analyses were checked in accordance with the generally accepted instructions (6) (σ_{av} did not exceed 1.5 for all elements). The geochemical sampling data were interpreted in terms of the geological structure (P.M. Polyanskiy and I.M. Koshik), using data currently available from geological surveys on the deposit.

We determined the background and minimally anomalous levels, together with the linear productivities for all elements. The parameters of the background distribution were based on batches of samples taken outside the possible geochemical anomalies, where there were no signs of hydrothermal alteration. The primary halos were delineated by reference to the minimal anomalous contents, which themselves were calculated at the 5% significance level.

TABLE 1. Elemental compositions of primary geochemical halos.

Ore column, mineralization type	Majority series
I	W—Sb—As—Au—Be—Cu—Hg—Sn—Ba—Ga—Ag—Co—Ni—Ge—Pb—Mo—Zn—Li
II	As—Sb—Au—W—Be—Hg—Ba—Co—Cu—Sn—Ni—Ge—Ag—Ga—Li—Pb—Mo—Zn
III	Au—Co—Ni—Pb—Ba—Li—Sb—Ga—Mo—As—Cu—W—Ge—Sn—Be—Ag—Hg—Zn
IV	Au—W—As—Mo—Co—Ni—Sb—Pb—Ba—Ga—Sn—Ge—Cu—Li—Zn—Ag—Hg—Be
V	Au—W—Li—Sn—Cu—Sb—Ni—Ge—Be—Ga—Mo—Ba—Pb—As—Hg—Co—Zn—Ag
Au—Sb	Sb—As—Au—W—Hg—Be—Ba—Cu—Sn—Co—Ni—Ga—Pb—Ag—Li—Mo—Zn—Ge
Sb—Au	Au—Ni—Pb—W—Mo—Li—Co—As—Ga—Ba—Cu—Sb—Sn—Ag—Ge—Be—Zn—Hg

Note: The main halo-forming elements are shown in bold type.

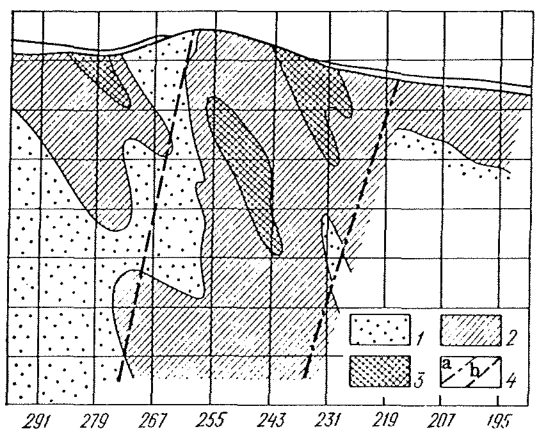

FIGURE 3. Antimony distribution in a longitudinal vertical section of the mineralized zone.

Relative accumulation levels (%): 1 - $3 \cdot 10^{-5}$-$1 \cdot 10^{-2}$, 2 - $1 \cdot 10^{-2}$-$1 \cdot 10^{-1}$, 3 - $1 \cdot 10^{-5}$-$2 \cdot 10^{-1}$; 4 - fault lines: a) known, b) supposed.

The method was based on identifying and evaluating the principal data-bearing elements, which define the geochemical pattern in this gold-antimony formation. This method involves ranking the elements in terms of their contribution to the sum of all elements. This parameter has been called the relative element-accumulation factor (3). The elements are ranked in decreasing sequence, which enables one to evaluate the representativeness of a particular halo section and thus to define the principal elements. The resulting majority series (5) are used in comparing geochemical halos for the various blocks and for various horizons.

The zoning in the primary halos was also based on the relative element-accumulation factors, which were calculated along with the majority series at this institute by means of Simplex, Stepan, and Ryadel computer programs (Ye. N. Posnyakov). The features of the primary halos at various levels within the range were examined; the spectral data showed that the main group of elements accumulating around the ore produces primary influx halos, namely gold, antimony, arsenic, tungsten, tin, lead, silver, zinc, copper, barium, nickel, cobalt, molybdenum, lanthanum, thallium, and germanium. Another group of elements (titanium, zirconium, scandium, and manganese) forms efflux halos, and a third group (yttrium, ytterbium, chromium, phosphorus, and vanadium) shows no tendency to migrate in either sense.

These delineated primary halos are of fairly low level for most of the elements, and are also of comparatively small width. Only antimony, arsenic, tungsten, and mercury (fig. 2), zinc, copper, gallium, phosphorus, chromium, and yttrium form halos of width up to 140-160 m and contrast up to 100 times the background. Here we present data only for transverse section 243 (central block), in which the structure of the anomalous fields is best represented; not all the elements give a contrast picture on all occasions in the other lines.

The primary halos reproduce the shape of the orebody and reflect the variability in the vein thickness, as is clear also from geological surveys on the ore columns. This tendency is most prominent in the longitudinal vertical section, especially for antimony (fig. 3). The maximum levels occur in a group of ore columns in the central and northwestern blocks. The

TABLE 2. Zoning in primary geochemical halos.

Mineralization type	Level	Relative accumulation levels (arbitrary units)								
		Ba	Be	Au	W	Ga	Sb	As	Co	Cu
Gold-antimony	I (borehole 133, 62)	**0.082**	0.035	0.086	0.104	0.026	0.105	0.167	0.044	0.042
	II (borehole 138, 139)	0.052	0.063	0.089	**0.107**	0.036	**0.122**	0.116	**0.048**	**0.072**
	III (borehole 30, 135)	0.054	**0.068**	**0.121**	0.099	**0.058**	0.114	0.105	**0.059**	0.060
	IV (borehole 9, 94)	0.024	0.056	0.110	0.057	0.019	0.103	**0.190**	0.026	0.056
Antimony-gold	I (borehole 16, 17)	**0.069**	0.030	0.181	0.079	0.035	0.038	**0.061**	0.053	0.045
	II, III (borehole 80, 100)	0.054	0.038	**0.218**	**0.117**	**0.060**	**0.046**	0.060	**0.092**	0.058
	IV (borehole 132, 63)	0.056	**0.055**	0.142	0.083	0.049	0.020	0.044	0.018	**0.063**

Mineralization type	Level	Relative accumulation levels (arbitrary units)									
		Mo	Ni	Sn	Pb	Ag	Hg	Zn	Ge	Li	Bi
Gold-antimony	I (borehole 133, 62)	0.012	0.054	0.051	0.056	0.067	**0.065**	0.007	—	**0.027**	—
	II (borehole 138, 139)	0.028	0.023	**0.064**	**0.075**	**0.084**	0.064	**0.008**	—	0.002	—
	III (borehole 30, 135)	**0.059**	**0.061**	0.053	0.023	0.045	0.049	—	—	0.015	—
	IV (borehole 9, 94)	0.025	0.033	0.037	—	—	0.025	0.006	—	—	—
Antimony-gold	I (borehole 16, 17)	0.015	0.053	**0.053**	0.060	**0.057**	**0.066**	0.056	—	0.030	—
	II, III (borehole 80, 100)	0.071	**0.073**	0.038	**0.075**	0.030	—	0.004	—	**0.030**	—
	IV (borehole 132, 63)	**0.080**	0.046	0.047	0.041	—	0.014	0.006	**0.020**	0.008	—

Note. Maximal accumulation levels for halo-forming elements are in bold type.

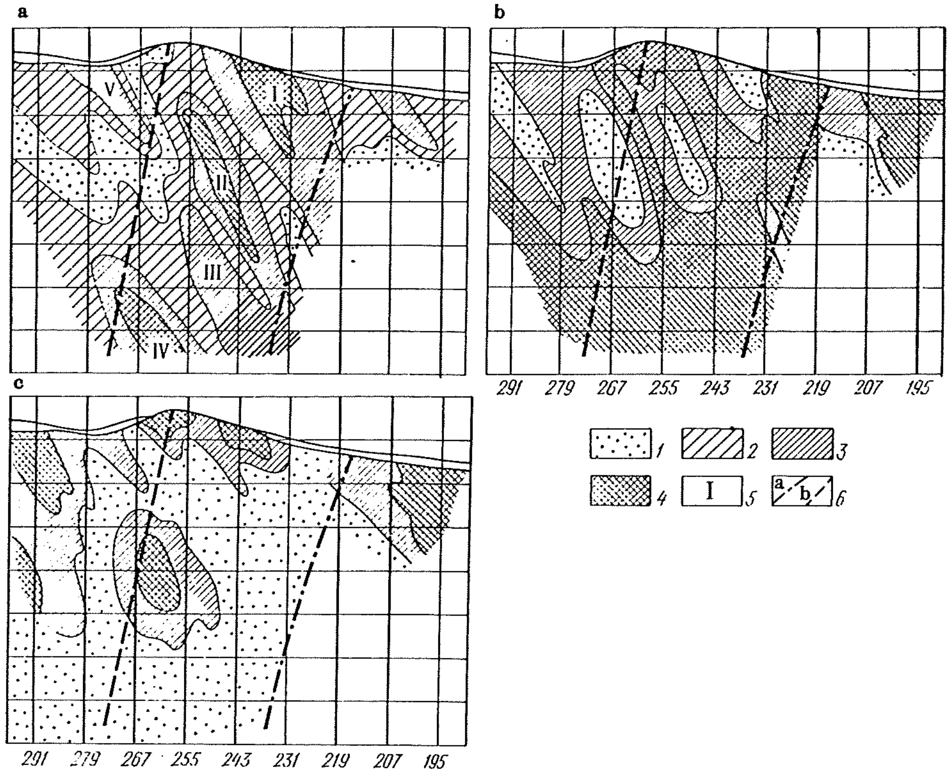

FIGURE 4. Primary multiplicative halos in a longitudinal vertical section of the mineralized zone.

Products of element contents: a – Au·Sb·As·W: 1) $1\cdot10^{-5}$–$1\cdot10^{1}$, 2) $2\cdot10^{1}$–$1\cdot10^{3}$, 3) $1\cdot10^{3}$–$1\cdot10^{5}$, 4) $1\cdot10^{5}$–$1\cdot10^{7}$; b – Ti·Zr·Sc·Mn: 1) $1\cdot10^{0}$–$1\cdot10^{3}$, 3) $1\cdot10^{3}$–$1\cdot10^{5}$, 4) $1\cdot10^{5}$–$1\cdot10^{7}$; c) Hg·Ag·Pb·Zn: 1) $1\cdot10^{-5}$–$1\cdot10^{-2}$, 3) $1\cdot10^{-2}$–$1\cdot10^{0}$, 4) $1\cdot10^{0}$–$1\cdot10^{1}$; 5 – number of ore column (tables 1–3); 6 – fault lines: a) known, b) supposed.

highest antimony levels occur in the upper horizons.

The shape of the halos in the longitudinal-section plane may be best seen from multiplicative halos for various element groups; the group of elements showing highest contrast (antimony, arsenic, and tungsten) indicates five ore columns in the longitudinal vertical section, four of these lying in the central block and one in the northwestern one (fig. 4). Columns I, II, and V are also indicated by fairly contrasting dips in the efflux elements Ti, Zr, Sc, and Mn (fig. 4b).

These ore columns differ substantially in the element compositions of the primary halos (table 1); the principal halo components (relative-accumulation parameters 0.1 or more) in columns I and II are antimony, arsenic, and tungsten; columns III, IV, and V have only gold as the principal element. There are no principal components in the halos in the southeast block (table 1).

The element accumulation in the primary halos allows one to distinguish two groups of geochemically different ore columns: the gold-antimony I and II, and the antimony-gold III, IV, and V (fig. 4a and table 1). The primary halos of the gold-antimony columns contain not only antimony, arsenic, and gold together with tungsten but also some mercury and barium. The halos of the antimony-gold columns contain gold along with nickel, lead, cobalt, tungsten, and molybdenum. These differences in composition can serve as criteria for rejecting geochemical anomalies associated with orebodies of various mineral types.

The structural features of the mineralization have influenced the zoning in the primary geochemical halos considerably. The morphology of the orebodies is also related to the vertical zoning for columns of both types (table 2).

The vertical zoning in the halos associated with the gold-antimony mineralization (I) and those in the antimony-gold form 2 may be

TABLE 3. Majority element series at various levels in primary geochemical halos.

Mineralization type	Level	Majority series
Au—Sb	I (borehole 133, 62)	As—Sb—W—Au—**Ba**—**Hg**—**Ag**—**Pb**—Ni—Sn—Co—Cu—Be—Li—Ga—Mo—Zn—Ge
	II (borehole 138, 139)	Sb—As—W—Au—**Ag**—**Pb**—**Cu**—**Sn**—Hg—Be—Ba—Co—Ga—Mo—Zn—Li—Ge
	III (borehole 30, 135)	Au—Sb—As—W—**Be**—**Cu**—**Ni**—**Co**—Mo—Ga—Ba—Sn—Hg—Ag—Pb—Li—Zn—Ge
	IV (borehole 9, 94)	As—Au—Sb—W—**Be**—**Cu**—**Sn**—**Ni**—Co—Mo—Hg—Ba—Ga—Zn—Pb—Ag—Li—Ge
Sb—Au	I (borehole 16, 17)	Au—W—**Ba**—**Hg**—As—**Pb**—**Ag**—**Zn**—**Ni**—Co—Sn—Cu—Sb—Ga—Be—Li—Mo—Ge
	II-III (borehole 80, 100)	Au—W—**Co**—**Ni**—**Pb**—**Mo**—As—**Ga**—**Cu**—Ba—Sb—Be—Sn—Li—Ag—Zn—Hg—Ge
	IV (borehole 132, 63)	Au—W—**Mo**—**Cu**—**Ba**—**Be**—**Ga**—**Sn**—**Ni**—As—Pb—Sb—Ge—Co—Hg—Li—Zn—Ag

Note: Indicator elements for levels are shown in bold type.

represented via the following series: 1) Ba-Li-Hg-As_2-Sn-Ag-Pb-Zn-Sb-W-Au-Cu-Ni-Co-Ga-Mo-Be-As_1; 2) Ba-Hg-As-Sn-Ag-Zn-Li-Sb-Pb-Au-W-Ni-Co-Cu-Ga-Ge-Mo-Be.

The elements in the upper ore levels are followed by those in the middle ore ones and then in the lower ones in these zoning series from left to right.

This zoning is similar in its general lines to that found in other gold-ore deposits, and on the whole it constitutes a unique vertical-zoning series for such primary halos (4, 7). A minor difference is a shift at the middle of the series toward gold, antimony, and tungsten, which occurs because antimony is the main component of the ores at this deposit, whereas tungsten is the most abundant element after the economic ones, and auxiliary elements in the zoning series always occupy the middle position (2).

We have used the zoning in the primary geochemical halos also in order to evaluate the position of the geochemical anomalies with respect to the mineralization; the majority series here provide a reliable basis, since they reflect the extents of accumulation in the anomalous sections, i. e., the zoning proper. The precise position of the anomaly with respect to the mineralization causes the principal elements in the majority series to be followed by elements whose associations characterize the zoning at the corresponding level. The anomaly arising from accumulation of the major elements (antimony, gold, arsenic, and tungsten) may be treated as an upper ore level for these types of mineralization, as can the anomaly associated with barium, mercury, and lead (table 3, level I), which goes with suppression of mercury, molybdenum, and gallium. On the other hand, the anomaly in which copper, nickel, cobalt, gallium, and molybdenum predominate over barium, mercury, and lead (table 3, level IV) is a lower ore one.

These trends in the zoning were used in evaluating the erosion-cutdown level for each ore column (table 1). The above sections were supplemented with a multiplicative section for the minor elements Hg·Ag·Pb·Zn (fig. 4c). The distribution of peaks for the main halo-forming elements and those above the ore show that ore columns I and V have the deepest levels of erosion cutdown, while column II is less eroded, and columns III and IV are completely covered and therefore are worth tracing to some depth.

The following major conclusions are drawn from the primary geochemical halos at this gold-antimony deposit:

1. Primary geochemical halos are formed by a wide range of elements, which can be divided into two major groups in terms of the concentrations in the halos: 1) elements forming influx halos (gold, antimony, arsenic, tungsten, lead, silver, zinc, copper, barium, mercury, nickel, cobalt, molybdenum, and lanthanum) and elements that form efflux halos (titanium, zirconium, scandium, and manganese). These primary halos reproduce the shape of the orebodies and clearly indicate the maxima and minima associated with the ore columns. In addition, columns I, II, and V show the fields

representing maximum influx element levels coincident with the areas of extensive efflux.

2. There is a distinct geochemical difference in the element compositions of the halos accompanying the various ore columns; columns I and II are geochemically of gold-antimony type (antimony important), the principal elements in the halos being antimony, gold, arsenic, and tungsten. The antimony-gold columns III, IV, and V (dominated by gold) have only gold as the principal element. In general, the antimony-gold type tends to predominate as the depth increases.

3. The primary geochemical halos show contrast vertical zoning due to relative accumulation in the various parts of the space around the ore. This zoning corresponds to the zoning in the primary halos at sulfide-type ore deposits (7).

4. The details of the spatial distribution and the zoning allow one to evaluate the prospects of various parts of the deposit. The most promising area for antimony mineralization is provided by the deep horizons in the central block, where some boreholes have reached the upper parts of the antimony-gold mineralization. The lower horizons of the northwest block are also promising for antimony-gold mineralization. The prospects of the southeast block can be evaluated only when deeper boreholes have been drilled.

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