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DESCRIPTIVE, AND GRADE AND TONNAGE MODEL FOR GOLD-ANTIMONY DEPOSITS

by

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FOREWORD

This report is an initial effort to establish a series of models for different types of antimony deposits. Gold-antimony deposits are associated with low-sulfide gold-quartz vein deposits that occur in deformed metamorphic belts. Dr. Dennis P. Cox encouraged this work, thereby a continuation of investigations I started in the former USSR. Until recently, gold-antimony deposits were not recognized as an individual type differing from traditional simple epithermal antimony vein deposits. This model proposes a new model for these deposits that may be useful for geologists interested in gold and antimony deposits.

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ABSTRACT

Gold-stibnite-quartz vein deposits and stratiform disseminated-veined deposits in low-grade metamorphic belts are one of the major economic types of antimony deposits. From 1860 to 1990, mined antimony tonnage produced from them was about 1.6 million tons (i.e., almost 40 percent of the world antimony output), and as much as 83 tons of gold. This new model is based on specific features of these deposits that occur in gold-bearing compressive shear zones in Archean greenstone belts, and Late Proterozoic and Phanerozoic folded troughs of pelitic turbidites. The deposits occur mainly in the outer fringes of low-grade, greenschist facies metamorphic belts. The main ore-controlling structures are strike-slip and high-angle reverse faults. Common characteristics include: the paragenesis of high purity gold (940-1,000 fineness) with stibnite and berthierite; ductile deformation of ore veins; and metamorphogenic granoblastic foliated textures of the massive stibnite ore. A combination of local geochemical aureoles of gold, antimony, and arsenic is an indicator of gold-antimony deposits. The proposed model should contribute substantially to exploration for this type of gold-antimony deposits.

INTRODUCTION

Gold-antimony deposits occur in gold-bearing regional zones in many countries and continents. Major antimony producers of this type of deposit are Republic of South Africa, Bolivia, Russia, China, and France. These gold-antimony deposits are less common in other gold provinces. From 1860 (start of precise records) to 1990, about 1.6 million tons of antimony was mined from these deposits, i.e., almost 40 percent of the common world mined antimony. About one-third of metal mined can be credited to deposits within a 20 km long zone in Murchison Range, South Africa. As much as 83 tons of gold were recovered as a byproduct from gold-antimony deposits world wide. This quantity is a minimum because the information about gold recovery is not complete. Thus, general gold:antimony ratio is at least 1:20,000 and increases up to 1:1,000 in some deposits.

This model contains some important conditions: (1) The model has to be adequate to present information on the structure, composition, and distribution of gold-antimony deposits; (2) The deposit information has to be complete for entry into a data-base; and (3) The model has to correspond to general requirements adopted previously for other deposit models by Cox and Singer (1986).

For condition one, older data were analyzed previously in a monograph in Russian (Berger, 1978). New data were incorporated from a series of papers and books on South African, Australian, Yakutian gold-antimony deposits that were published through 1992. The data base for grade and tonnage includes 49 deposits. The second condition could not be entirely fulfilled because of the incompleteness of geological and mining data for many deposits. The model is based on the most studied deposits. The information on the others, however, appears to confirm the main features of the model proposed herein. For condition three, the book, "Mineral Deposits Models" (Cox and Singer, 1986) was used as a guide.

ACKNOWLEDGMENTS

I found warm support for my studies among U.S. Geological Survey geologists at Menlo Park, California, and I felt myself well received in an atmosphere of state-of-the-art geological investigations. Dennis P. Cox, Arthur Grantz and Theodore G. Theodore helped me arrange this work. Helpful data was provided by James Bliss. Dan Mosier spent time preparing plots of tonnage and grades of gold-antimony deposits and was indulgent of my slips. Susan García typed this report and other materials.

Keith Weston and Avi Olshina from the Geological Survey of Victoria showed me the Costerfield and Nagambie gold-antimony deposits near Melbourne, Australia.

DESCRIPTIVE MODEL OF GOLD-ANTIMONY Deposits
by Vladimir I. Berger

MODEL NUMBER 36C

APPROXIMATE SYNONYM Mesothermal auriferous fissure veins antimony deposits (C.Y. Wang, 1952)

DESCRIPTION Stibnite, berthierite, gold (940-1000 fineness), aurostibite in metamorphosed quartz-carbonate vein in compressive shear zones in low-grade greenschist facies of regionally metamorphosed rocks; includes strata-bound veined-disseminated gold-antimony mineralized rocks hosted by carbonaceous (graphitic) schist, quartzite, and metamorphosed tuff. Confined to syntectonic (collision-type) gold belts. The veins are similar to low sulfide gold-quartz veins but are very rich in sulfides, especially in stibnite (Model 36a of B.R. Berger, 1986).

GENERAL REFERENCES L.N. Indolev (1975), V.I. Berger (1978), T.N. Pearton and M.L. Viljoen (1986).

GEOLOGICAL ENVIRONMENT

Rock Types Three types of host rocks: (1) Archean greenschist (talc-, chlorite-, carbonate-, and mica-bearing) formed from mafic and ultramafic lava, and volcanoclastic rocks; (2) Late Proterozoic or Phanerozoic turbidite black shale, siltstone, sandstone, carbonate rocks; and (3) retrograde metamorphic greenschist that replaces high-grade crystalline rocks (gneiss, migmatite, biotite-schists). All three types of host rocks have two common features: Low grade greenschist facies of progressive or retrograde (in the third case) metamorphism precedes vein mineralization; and an original enrichment in the protolith of antimony, gold, and arsenic of as much as tens to hundreds times crustal abundance.

Age Range Archean to Mesozoic; strata-bound and stratiform ore bodies probably are pre-metamorphic, and the associated veins are late-stage metamorphic and pre- or syn-granitic.

Depositional Environment Generally, two stages of depositional environment are developed: (1) Intracratonic rift troughs, in particular Archean greenstone belts, and Late Proterozoic or Phanerozoic turbidite troughs along collapsed passive continental margins. Ore elements (Sb, Au, As, Fe, S, W) accumulated in the basinal rocks, in both disseminated and concentrated forms. (2) Strongly deformed fold belts formed under compression associated with the collision process. The belts are bordered by multiple granitoids with variable chemical compositions. Rocks within belts metamorphosed to low-grade greenschist facies. Gold-antimony deposits occur mainly in the outer parts of zonal metamorphic belts. Typical favorable metamorphic assemblages are: in ultramafic and mafic original rocks, talc-chlorite, talc-carbonate, quartz-chlorite-carbonate schists, and slate; in quartz-feldspathic rocks, mainly graywackes, quartz-chlorite-carbonate, quartz-mica-carbonate, sericite-chlorite-graphite schist, phyllite; in pelitic rocks, quartz-sericite-chloritoid, quartz-mica-chloritoid-graphite schist.

Tectonic Setting Regionally extensive strike-slip and high-angle reverse (thrust) faults and conformable major fold belts adjoining microcratons.

Associated Deposit Types Placer gold deposits form from weathering and erosion of gold-antimony deposits. Low sulfide gold-quartz veins result from similar mineralizing processes and, in some districts, a zonal pattern from low sulfide gold-quartz to gold antimony deposits corresponds to decreasing grade of regional metamorphism. Algoma type iron deposits and volcanogenic massive sulfides occur in the same environment but result from different mineralizing processes.

DEPOSIT DESCRIPTION

Mineralogy Early first phase (mainly disseminated mineralization in wall rocks): pyrite+arsenopyrite+ gold+(locally) pyrrhotite+chalcopyrite+ferberite+scheelite; second phase (weak): sphalerite+tetrahedrite+
boulangerite+jamesonite+bournonite+chalcostibite ($CuSbS_2$);
third phase: stibnite+berthierite ($FeSb_2S_4$)+gold+aurostibite ($AuSb_2$); rare native antimony+gudmundite (FeSbS)+ullmannite (NiSbS)+corynite (Ni(As, Sb)S)+gersdorffite (NiAsS).

Two types of gold distribution occur: (a) Invisible and submicroscopic gold of 800 to 930 fineness, mostly in arsenopyrite and less commonly in pyrite distributed in altered wall rocks of first phase mineral assemblage. Gold and arsenic are correlated positively; average gold contents are apparently limited to about 10 g/t. And (b) gold of various grain sizes from 0.01 mm to 0.5 mm distributed in stibnite, berthierite and quartz in veins of the third phase mineral assemblage. High purity gold (940 to 1,000 fineness) is quite typical. Average gold contents are as much as 70 g/t; strong correlation of gold with antimony occurs in the richest vein deposits. Gold of high fineness in alluvium around such deposits is an effective prospecting guide.

Texture/Structure Deformed ductile fabrics and, in some places, folded lenticular veins, saddle reefs, and stratiform bodies. Tectonically recrystallized fine-grained granoblastic stibnite with foliated (phyllonitic) structure. Rare relics of original open-space filling textures occur with sharply bent and twinned stibnite crystals in quartz veins. Replacement textures are common in mineralized and sheared wall rocks.

Alteration In clastic and argillaceous host rocks: carbonate minerals (ankerite, siderite)+ quartz+white mica (sericite, paragonite, pyrophyllite)+(near ore bodies) pyrite+ arsenopyrite+(rare) albite+epidote; in mafic and ultramafic host rocks: carbonate minerals (dolomite, magnesite)+quartz+fuchsite+sericite+sulfides.

Ore Controls Shear zones, drag folds, and a compressive-type deformation either precedes or follows introduction of metals. Individual ore shoots are related commonly to sigmoidal structures.

Weathering Oxidized zone up to tens meters in depth; including valentinite (Sb_2O_3), kermesite (Sb_2S_2O), stibiconite ($Sb_3O_6(OH)$), cervantite (Sb_2O_4).

Geochemical signature: Au, Sb, As, W, (rare Hg). A combination of the local geochemical aureoles of gold (0.01 to 0.1 g/t), antimony and arsenic (both 0.01 to 0.1%) is an indicator of gold-antimony deposits.

EXAMPLES

Alpha-Gravelotte, SAFR	(Abbot and others, 1986; Pearton and Viljoen, 1986)
Costerfield, AUVA	(Stillwell, 1953; Roberts and Knight 1976)
Sarilakh, RUSA	(Berger, 1978, 1990; Indolev and others, 1980)

COMMENTS

Some additional features of the composition and of prospecting guides for these gold-antimony deposits are noted:

(1) As a rule, gold-antimony ores are ductilly deformed. Original coarse crystalline aggregates of stibnite are locally transformed during deformation into micro-grained banded sulfide mylonite. The ore deformation separates, paragenetically, the initial mineral assemblages from superimposed post-deformation sulfide mineralization of lead, zinc, and mercury.

Gold-antimony ore is characterized by low grades of silver (up to 10 g/t, Ag/Au = 1 to 0.07) and mercury (up to .00001 percent). Mercury halos around ore bodies are usually weakly developed.

Barite, cinnabar, realgar, orpiment, chalcedony, and hydrothermal argillization of wall rocks, i.e., components of the typical epithermal antimony deposits, do not occur. They are superimposed in some deposits.

Some gold-antimony deposits are characterized by thermal metamorphism related to post-mineral granites or dikes. The main mineralogical transformation is replacement of stibnite, berthierite, and pyrite by native antimony, gudmundite, and pyrrhotite.

(2) Exploration for gold-antimony prospects within regional gold-bearing compressive folded zones usually requires a series of successive steps:

(a) Determination of intersections of strike-slip faults and associated extensive shear zones with transverse lineaments established by geological, petrological, structural, geomorphological and geophysical heterogeneities in the region.

(b) Selection of potential ore-bearing structural intersections that coincide with low-grade greenschist facies of regional metamorphism and with local anomalies of high purity gold in alluvium.

(c) Site-specific prospects for physical exploration outlined by a combination of gold, antimony, and arsenic soil and (or) rock anomalies.

GRADE AND TONNAGE MODEL OF GOLD-ANTIMONY DEPOSITS

A list of 49 main gold-antimony deposits for which grade and tonnage data was available or could be estimated is shown in Table 1. The cumulative distributions tonnage and grades of antimony and gold are shown on the Figures 1-3.

COMMENTS

(1) For most gold-antimony deposits, exact data on tonnage, and on antimony and gold grades are not available. The author made his own estimates for 28 deposits as a result of first-hand experience in gold-antimony deposits exploration. These include twelve Russian deposits that were studied in detail along with one deposit in Czechoslovakia and two in Australia (Figure 1). Fragmentary figures for individual deposits and general mined metal and reserves data of different countries were used as a control. In spite of the approximate nature of some estimations, they provide a somewhat uniform comparison among the cited deposits.

All gold-antimony deposits may be divided into four classes according to a mined antimony and reserves:

(a) greater than 300,000 t of antimony - 3 deposits,

(b) from 100,000 to 200,000 t - 5 deposits,

(c) from 30,000 to 100,000 t - 13 deposits,

(d) less than 30,000 t - 29 deposits

(2) The data are somewhat heterogeneous. When considering the cumulative plots of tonnage and grades (Figures 1-3) it is necessary to consider:

(a) Some deposits consist of the one or two leader-veins (Sarilakh, Alpha-Gravelotte), while others are ore fields containing tens of veins (Brioude-Massiac, Hillgrove).

(b) Among the deposits, both compact veins of massive stibnite ore, and very economically different disseminated-veined ore bodies are present.

(c) Some deposits are well explored but not mined (Uderey, Sentachan and many other Russian deposits) whereas others are almost exhausted (South African deposits).

(d) The deposits are mined by different methods depending on economical conditions: the ore vein was mined only, or the ore vein and adjoining low-grade mineralized rocks both were mined, etc. Negative correlation of the antimony grades with tonnage ($r = -0.41$, $n = 49$) reflects not only geological differences, but also the various mining conditions.

(3) The antimony grades correlate with gold grades ($r = 0.45$, $n = 43$). Dots on the correlation graph (Figure 4) may be divided in two fields approximately corresponding to two mineralogical subtypes of gold-antimony deposits:

(a) Field I - antimony subtype; gold related to the stibnite-berthierite paragenesis. That is typical for very rich and large deposits.

(b) Field II - arsenian subtype with a predominance of negative correlation of antimony grades with gold grades; gold associates mainly with arsenopyrite and pyrite. This subtype is common for stratiform and small vein gold-antimony deposits.

Some relations in rich, large deposits indicate that at depth (somewhere up to 1.5 km) mineralization of subtype I may be replaced by mineralization of subtype II.

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Table 1.--List of gold-antimony deposits
[(e), Author's estimations of data]

	Deposit	Country	Province/Other	Total Ore (thousands of metric tons)	Sb%	Au (g/t)	References
1	Alpha-Gravelotte	South Africa	Transvaal, Murchison Range	(e) 9,000	3.5	0.9	Abbot a.o., 1986; Pearton and Viljoen, 1986
2	Amo	South Africa	Transvaal, Barberton Range	10	5		Viljoen a.o., 1986
3	BI	South Africa	Transvaal, Murchison Range	(e) 150	3	0.8	Pearton, and Viljoen, 1986; Muff, 1978
4	Billyakh	Russia	Yakutia, Verkhoyansk-Kolyma province	(e) 350	3	2.5	Indolev a.o., 1980; Shur, 1985; Berger, 1978
5	Blue Spec	Australia	West Australia	154	1.1	15.5	Gifford, 1990; McKeown, 1953
6	Bonanza Lode (Refton)	New Zealand	Southern Island	(e) 20	25	16	Williams, 1965; Sher, 1972
7	Brioude-Massiac	France	Haute Loire, central French massif	330	10		Perichaud, 1972; Roger, 1972
8	Caracota	Bolivia	Potosi	(e) 120	25	5	Ahlfeld, 1974; Ahlfeld and Schneider-Scherbina, 1964
9	Cevennes	France	Avdèche	(e) 60	7		Roger, 1972; Sher, 1974

Table 1.--List of gold-antimony deposits.--Continued

	Deposit	Country	Province/Other	Total Ore (thousands of metric tons)	Sb%	Au (g/t)	References
10	Chilcobija	Bolivia	Southern flank of the country	(e) 850	11	5	Ahlfeld, 1974; Ahlfeld and Schneider-Scherbina, 1964
11	Coimdai	Australia	Victoria	8	9.9	6.5	Fisher, 1953
12	Costerfield	Australia	Victoria	65	54	60	Stillwell, 1953; Roberts and Knight, 1976
13	Dubrava	Czechoslovakia	Slovakia, Low Tatry	(e) 1,800	5	3	Hak, 1966; Berger, 1978
14	Dúrico-Beirão	Portugal	Porto	33	37	8	Conto a.o., 1990
15	Gothic	Zimbabwe	Lower Gwelo district	53	1e	19.9	Amm, 1946
16	Hillgrove	Australia	New South Wales	880	1.81	7.93	Boyle, 1990; Harrison, 1953
17	Indarama	Zimbabwe	Que Que district	500	1e	9.4	Mehliss, 1968, Foster a.o., 1986
18	Kim	Russia	Yakutia, Verkhoyansk -Kolyma province	(e) 700	5	4	Indolev a.o., 1980; Shur, 1985
19	Kinyas	Russia	Yakutia, Verkhoyansk -Kolyma province	(e) 1,000	10	15	Indolev a.o., 1980
20	Krasna Gora	Czechoslovakia	Bohemian massif	16	6.5	1	Odehnal, 1972; Quiring, 1945

Table 1.--List of gold-antimony deposits.--Continued

	Deposit	Country	Province/Other	Total Ore (thousands of metric tons)	Sb%	Au (g/t)	References
21	Krohalinoe	Russia	Magadan region, Verkhoyansk-Kolyma province	(e) 30	5	1	Panichev, Fedotov, 1973; Berger, 1978
22	La Biards	France	Saint Yrieix distr.	(e) 30	5		Bouladon, 1989; Sher, 1974
23	La Lucette	France	Mayenne, Armorican massif	840	5	10	Serment, 1978; Bouladon, 1989
24	Maltan	Russia	Yakutia, Verkhoyansk -Kolyma province	(e) 800	5	18	Indolev a.o., 1980; Berger, 1978
25	Marichal	France	Creuse, central French massif	(e) 18	5		Bouladon, 1989
26	Markovskoe	Russia	Yakutia, Verkhoyansk -Kolyma province	(e) 800	2	3	Berger a.o., 1984
27	Monarch-Cinnabar	South Africa	Transvaal, Murchison Range	(e) 150	2.9	0.7	Wilson, 1945; Pearton, 1986
28	Monarch-Free State	South Africa	Transvaal, Murchison Range	(e) 5,000	3.1	0.7	Pearton and Viljoen, 1986, Pearton, 1979
29	Moonlight (Wiluna)	Australia	West Australia	640	0.6	10	Hagewann a.o., 1992; McLeod, 1965

Table 1.--List of gold-antimony deposits.--Continued

	Deposit	Country	Province/Other	Total Ore (thousands of metric tons)	Sb%	Au (g/t)	References
30	Mulati	South Africa	Transvaal, Murchison Range	(e) 250	2.8	0.6	Pearton and Viljoen, 1986, Sahli, 1961
31	Nagambie	Australia	Victoria	7,000	<1e	1.2	Gilles, 1990
32	Olympiada	Russia	Krasnoyarsk region, Yenisei Upland	(e) 10,000	1	4	Li, Shokhina, 1974; Berger, 1981, 1990
33	Pan Hsi	China	Hunan	1,100	16	6	Tien a.o., 1928; Quiring, 1945; Wang, 1952
34	Pezinok	Czechoslovakia	Slovakia, Male Karpaty	(e) 100	2.5	1.7	Polak, Hanas, 1981; Quiring, 1945
35	Razdolninskoe	Russia	Krasnoyarsk region, Yenisei Upland	(e) 800	5	3	Alexandrolv a.o., 1966; Berger, 1981
36	Ringwood	Australia	Victoria	4	44	62.5	Wilkinson, 1971
37	San Luis	Bolivia	Central part of the ore belt	(e) 35	20		Ahlfeld, 1974; Ahlfeld and Schnider-Scherbina, 1964
38	Sarilakh	Russia	Yakutia, Verkhoyansk-Kolyma province	(e) 10,600	6	6	Anasenko and Bichok, 1970; Berger, 1978; Indolev a.o., 1980; Zharikov, 1978
39	Scrafford	United States	Alaska	6	15	3	Robinson and Bundtzen, 1982; Nokleberg a.o., 1991

Table 1.--List of gold-antimony deposits.--Continued

	Deposit	Country	Province/Other	Total Ore (thousands of metric tons)	Sb%	Au (g/t)	References
40	Seinäjoki	Finland		500	0.9	1.7	Pääkkönen, 1966; Mozgova a.o., 1977
41	Sentachan	Russia	Yakutia, Verkhoyansk-Kolyma province	(e) 1,500	30	50	Indolev a.o., 1980; Berger, 1978
42	Shabari	South Africa	Transvaal, Murchison Range	(e) 65	3	3.87	Pearton and Viljoen, 1986
43	Sliscovitch	United States	Alaska	(e) 1,5	35	10	Brooks, 1916; Anderson, 1947; Nokleberg a.o., 1991
44	Tan	Russia	Yakutia, Verkhoyansk-Kolyma province	(e) 400	4	2.5	Indolev a.o., 1980; Kudryavtsev, 1979
45	Uderey	Russia	Krasnoyarsk region, Yenisei Upland	(e) 700	7	3	Berger, 1981; Vlasov a.o., 1986; Zharikov, 1978
46	United Jack	South Africa	Transvaal, Murchison Range	(e) 2,200	3	0.8	Pearton and Viljoen, 1986; Muff, 1978; Sahli, 1961
47	Weigel-Athens	South Africa	Transvaal, Murchison Range	(e) 5,500	3	0.7	Wilson and Viljoen, 1986; Van Eeden a.o., 1939
48	West Gore	Canada	Nova Scotia	32	1.4	2	Can. Deparment Energy, Mines and Resources, 1980

Table 1.--List of gold-antimony deposits.--Continued

	Deposit	Country	Province/Other	Total Ore (thousands of metric tons)	Sb%	Au (g/t)	References
49	Wuhsi	China	Hunan	320	28	10	Tien and Wang, 1934; Fedorchuk, 1985

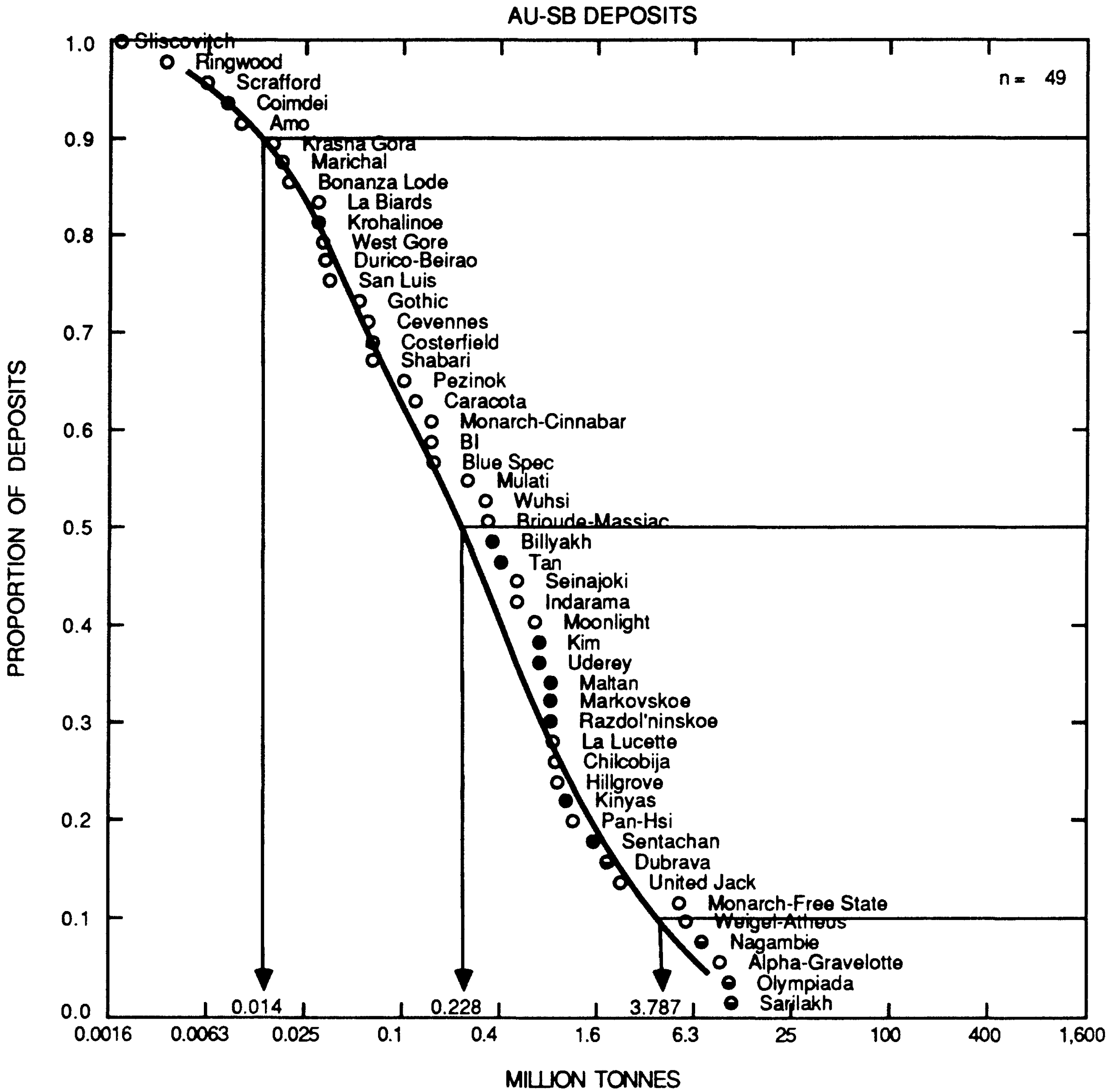

Figure 1. Tonnages of gold-antimony deposits

- • Deposits were studied by author.
- ◉ Deposits were visited by author.
- o Other deposits.

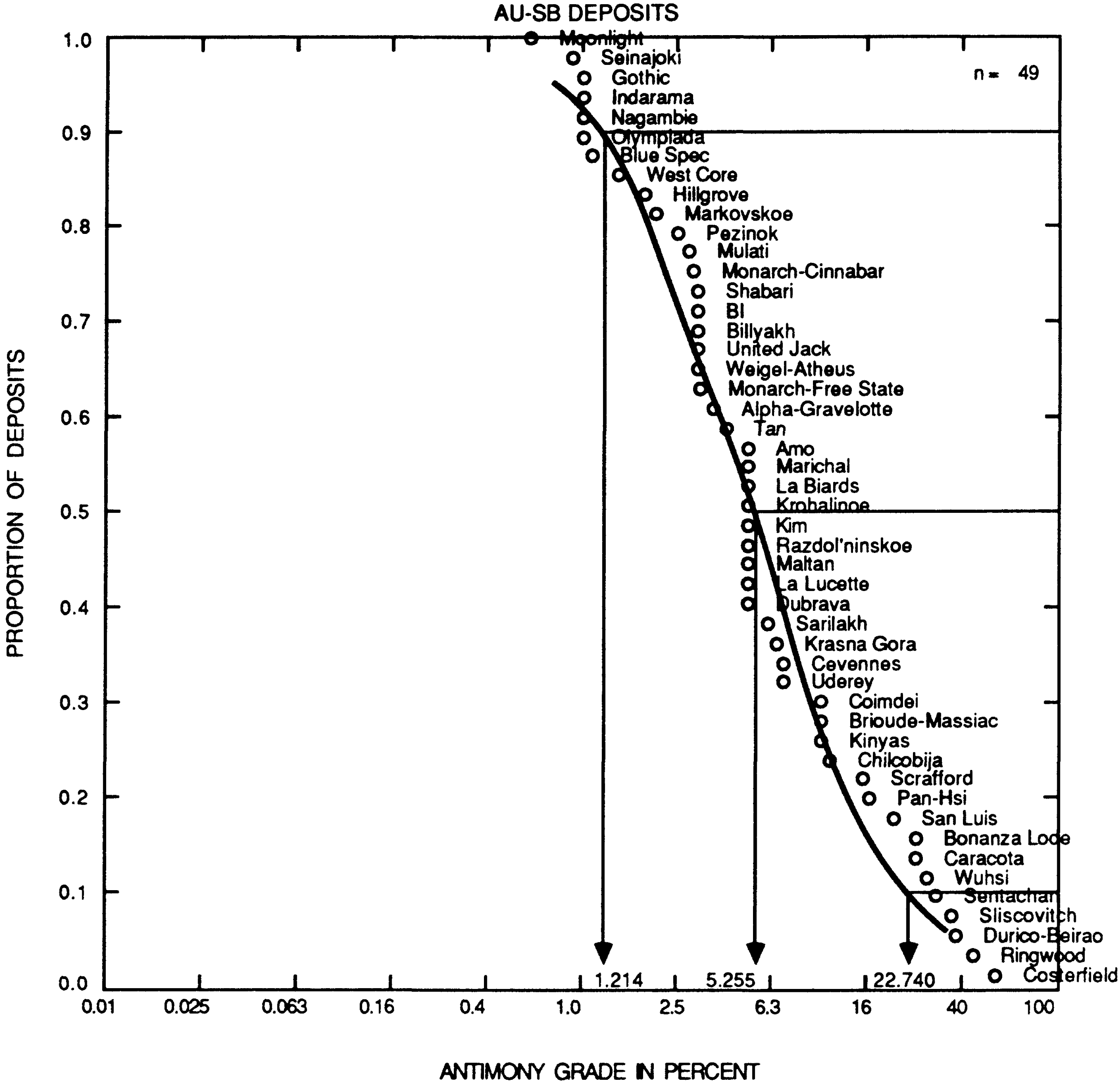

Figure 2. Antimony grades of gold-antimony deposits.

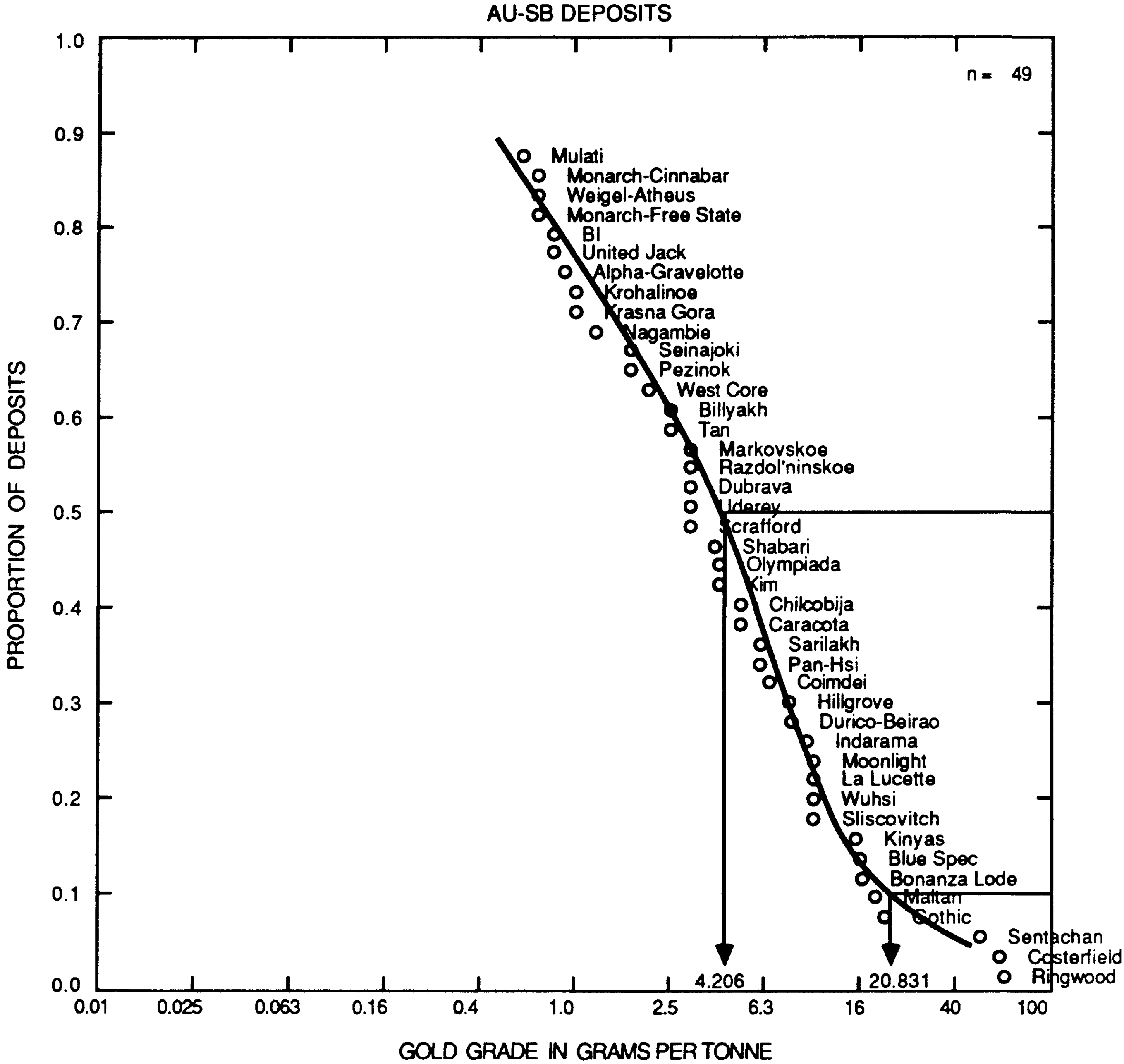

Figure 3. Gold grades of gold-antimony deposits.

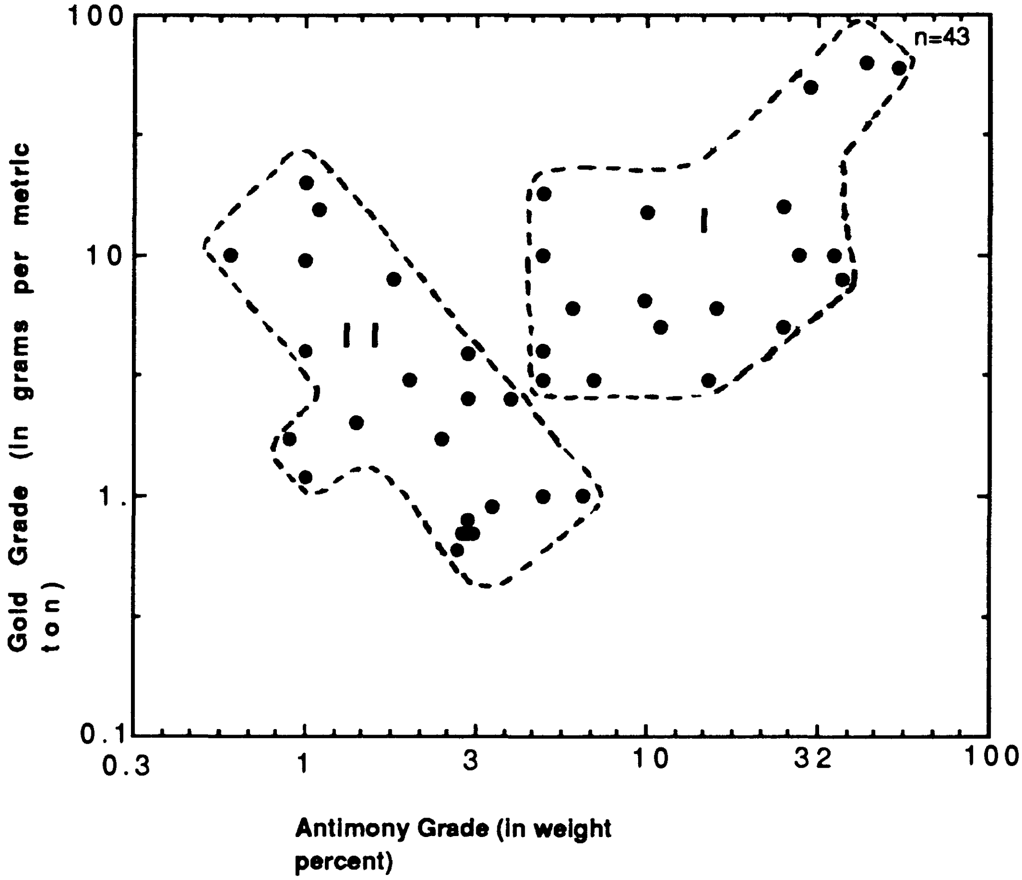

Figure 4. Plot showing correlation of antimony in weight percent and gold in grams per metric ton. I, antimony subtype; II, arsenian subtype.