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Grade-tonnage and target-area models of Au-Ag-Te veins associated with alkalic rocks

by

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PREFACE

This report presents preliminary models of Au-Ag-Te veins associated with alkalic rocks which are needed for quantitative mineral resource assessments. The models have not been reviewed for conformity with U.S. Geological Survey modeling standards currently being drafted by the Mineral Deposits Modeling Review Board. These models are an initial attempt to characterize the size, gold and silver grades and target areas of Au-Ag-Te veins. Revisions can be expected. Additions, corrections, and comments are welcome and should by directed to Jim Bliss, U.S. Geological Survey, 210 E. 7th St., Tucson, AZ 85705-8454.

INTRODUCTION

These models apply to deposits matching the descriptive model of Au-Ag-Te veins, number 22b, by Cox and Bagby (1986). The deposit type, simply stated, by Cox and Bagby (1986) is "gold telluride minerals and fluorite in veins and breccia bodies related to hypabyssal or extrusive alkalic rocks." Thorpe and Franklin (1984) have prepared a similar descriptive model for alkalic subtype mineral deposit type as part of the their general intrusion-associated gold class (No. 15b). They identify Kirkland Lake camp and Young-Davidson at Matachewan, Ontario, Canada as member deposits.

Essential features of these deposits are (1) veins hosting gold, silver, and telluride minerals, and (2) associated hypabyssal or extrusive alkalic rocks. In addition to veins, deposits modeled here also include breccia, replacement, and disseminated mineralization. Current exploration and deposit exploitation are focused on bulk minable mineralization. Gold in unoxidized mineralization is usually sulfide- or telluride-hosted, or extremely fine-grained. Consequently, derivative gold bearing placers from these deposits may be absent or poorly developed.

Recognition of deposits that fall into this deposit type is confounded by several factors. Whereas silver is noted in the deposit-type name, gold is the primary commodity for deposits included in these grade, tonnage, and target areas models. A related deposit type with silver as the primary commodity has been recognized (e.g. Flathead, Montana) and remains to be modeled separately. The presence of telluride minerals has not been specifically described in some deposits, but these deposits were included in the model due to similarity in deposit geology to adjacent Au-Ag-Te deposits or other Au-Ag-Te deposits identified using the descriptive model. Telluride minerals may easily go unrecognized and deposits are often oxidized and primary sulfide/telluride mineralization may not be preserved.

The association of igneous rocks to mineralization may be ambiguous. Although the deposits are hydrothermal in origin, they are at least in-part genetically related to magmatic fluids (Saunders, 1986). The alkalic igneous rocks associated with them are believed to be derived by partial melting of metasomatized lower crust or mantle possibly as a result of subduction (Westra and Keith, 1981; Mutschler and others, 1985; Birmingham, 1987; Eriksson, 1987; Musselman, 1987; Maynard and others 1990; Allen and Foord, 1991). In this model we have included deposits that are either hosted by appropriate igneous rocks or show some spatial, temporal, or geochemical relation to the nearby alkalic rocks. Also, due to the complexity of the nomenclature for alkalic igneous rocks, classification of related igneous rocks may be difficult. For a given deposit, the literature describing the igneous rocks present often include many classification schemes. The definition of "alkalic" that we use is from Shand (1922) in which a rock is classed as alkalic if it contains total alkalis in excess of that necessary to combine with silica and alumina to form feldspar. Four subtypes of alkalic rocks are therefore possible. Thus, any rock bearing a feldspathoid or alkali amphibole or pyroxene is alkalic. If chemical data exists for igneous rocks, the classification schemes of Irvine and Baragar (1971) or De la Roche and others (1979) were employed.

EXPLANATION OF MODELS USED

The definition of a mineral deposit model as given by Cox and Singer (1986, p. 2) is

> "the systematically arranged information describing the essential attributes (properties) of a class of mineral deposits. A model may be empirical (descriptive), in which instance, the various attributes are recognized as essential even though their relationship are unknown; or it may be theoretical (genetic), in which instance, the attributes are interrelated through some fundamental concepts."

With a descriptive model available (in this case one for Au-Ag-Te veins by Cox and Bagby (1986)), member deposits can be sought and perhaps recognized. When found, data about their grades, tonnages, and target areas can be used for modeling. Ideally, the data should represent the estimated pre-mining tonnages, and grades. Estimates should be made of tonnage at the lowest given cut-off grades. The grade, tonnage, and target area models are presented in a graphical format (plots) to make it easy to display the data and to compare with others (Cox and Singer, 1986; Bliss, 1992). The plots show grade, tonnage or target area on the horizontal axis, and the cumulative proportion of deposits on the vertical axis. The units are metric, and a logarithmic scale is used for tonnage, grade, and target area. Each point on a plot represents a deposit. The deposits are cumulated in ascending grade, tonnage, or target area. Smoothed curves, representing percentiles of a lognormal distribution that has the same mean and standard deviation as the observed data are plotted through the points. Intercepts for the 90th, 50th, and 10th percentiles of the lognormal distributions are identified. A detailed description of how these plots are generated has been published (Singer and Bliss, 1990).

GRADE AND TONNAGE MODELS

Several grade and tonnage models have been proposed for epithermal vein deposits of which the Au-Ag-Te type is an addition. They include Comstock epithermal veins (Mosier and others, 1986b), Creede epithermal veins (Mosier and others, 1986a), Sado epithermal veins (Mosier and Sato, 1986), epithermal quartz-alunite gold (Mosier and Menzie, 1986) and polymetallic veins (Bliss and Cox, 1986). Other types of epithermal deposits with precious and base metals include hot-springs Au-Ag (Berger and Singer, 1992), sediment-hosted Au (Mosier and others, 1992) and distal disseminated Ag-Au (Cox and Singer, 1992). The latter two models are a refinement of carbonate-hosted Au-Ag (Bagby and others, 1986).

Model preparation is easier for mineral deposit types with distinctive characteristics. Those mineral deposits which belong to these deposit types can be clearly recognized. As the efforts in mineral deposit modeling have evolved, more deposit types now under consideration are not well described and (or) understood. Modeling these remaining deposit types is difficult. This model of Au-Ag-Te veins is an attempt to improve this situation.

The definition of Au-Ag-Te veins is subject to several complications. Defining what is a deposit in a spatial sense is difficult because mineralization and mines working these veins are found at various distances from one another. Mining properties with a spacing of one mile (1.6 km) or less were treated as parts of the same deposit. For example, application of the rule for mining properties in the Bald Mountain district, South Dakota, resulted in a deposit with 35 mines aggregated in an area of 16.4 square kilometers (6.3 square miles). In a few cases, data from districts with mines of unknown spacing are represented as single deposits. The Zortman-Landusky deposit, Montana, has mineralization in two zones separated by a distance greater than 1.6 km but are reported together and are treated in this model as a single deposit.

A variety of gold cut-off grades are likely since a few deposits were worked using small-scale methods while others were worked using large open pits. As a general rule, data are selected so that the model better reflects the economic and technological situation of the 1980s. This has resulted in the exclusion of three smaller, high gold grade deposits (Ragged Top and Whitewood, Black Hills, South Dakota; and Boulder, Montana).

Several types of complications have been identified during the preparation and review of the Au-Ag-Te veins models. No claim is made that all issues raised have been resolved and continued discussion is needed for final resolution. Some issues include:

(1) Some Comstock-type deposits contain conspicuous telluride mineralization and occur in the same tectonic setting as Au-Ag-Te veins. High potassium, calc-alkalic rocks associated with Comstock deposits also overlap with true alkalic rocks. Misclassification of deposits is easy.

(2) Two deposits (Kirkland Lake, Young-Davidson), found in the Canadian Shield and included in this model, have also been included in the Homestake model Au (Mosier, 1986). The Kirkland Lake district meets the requirements of this model. Cross-cutting relationship noted at Kirkland Lake suggests that the mineralization is related to the alkalic rocks found in the district. Young-Davidson is in an area which is an extension of the geologic setting of Kirkland Lake. As noted earilier, Thorpe and Franklin (1984) also give both deposits as examples of intrusion-associated gold where the intrusive rocks are alkalic.

(3) It is suggested that the Allard Stock which also contains PGE in addition to Au and is found in the La Plata District, Colorado, be treated as (a) the only part of the district which the Au-Ag-Te veins model is applicable or (b) is not applicable since the PGE mineralization in this case is a product of magmatic segregation and not of hydrothermal processes. The Allard Stock may be a member of a small group of deposits (e.g., Goose Lake, Montana) of a type using the criteria of PGE associated with chalcopyrites in alkalic rocks and formed by magmatic segregation (Zeintek, verbal commun., 1991). It has also been suggested that chalcopyrite are parts of veins of a hydrothermal affiliation. Whether the Allard Stock should be treated as part of general mineralization of the La Plata district is not resolved. However, alkalic rocks and Au-Te mineralization are features of the district as a whole and, therefore, the entire district is treated as a Au-Ag-Te vein deposit. The mineralization at Allard Stock may be a separate mineralization event, but is insignificant in terms of total tonnage and has no impact on the deposit size or gold grade of the district.

(4) Thirty percent of the data are for deposits in the Northern Black Hills, South Dakota, and this may bias the model in ways not recognized. A special attempt was made in that area to capture data on the smaller-sized deposits which resulted in greater frequency of smaller deposits on the tonnage curve. However, the South Dakota deposits are not statistically different from the rest of the data set in terms of deposit tonnage, gold and silver grades, or target area sizes (Mann-Whitney U test).

Four other commodities have been either recovered or reported in sufficient detail to allow an estimate of grades to be made but too few values are available to justify modeling. They include the following:

- WO_3--grades are estimated for 2 deposits at 0.007 and 0.066 percent,
- Cu--2 deposits with grades less than 0.07 percent,
- Pb--3 deposits with grades less than 0.45 percent, and
- Zn--2 deposits with grades less than 0.024 percent.

Other commodities noted are V and PGE which are recognized in mineralization in the Allard Stock of the La Plata district, Colorado (see discussion above) and Ortiz deposit, New Mexico. The PGE associated at Ortiz is unverified. While telluride mineralization is a key component in this model, no grades or production was found for this metal with the exception of the Emperor deposit, Fiji. In that case, Te is reported to have been recovered, but the amount was not given nor the tonnage of ore processed. Fluorite veins are intimately associated with Au-Ag-Te veins in the Jamestown district, Colorado where 63,000 mt of CaF_2 was reported to have been recovered (Lovering and Goddard, 1950). However, these veins should be treated as a separate mineral deposit type as it is the result of a seperate mineralization event although possibly a related one.

The grade and tonnage model based on 24 deposits are shown in figures 1-3. No correlation was found among the variables. Tonnage, Au grade, and target areas were found to be not significantly different then lognormal (at the 1 percent level) using the skewness and kurtosis goodness-of-fit tests (Rock, 1988).

GOLD PLACERS

The ratio of Au-Ag-Te veins with gold placers to those without gold placers is about 6:1 as determined from reports on deposits used in our model. Deposits found in the Black Hills, South Dakota were not used since they are adjacent to the large Homestake deposit which is a member of the Homestake Au deposit type (Berger, 1986). In this case the contribution from Au-Ag-Te vein deposits to gold placers cannot be easily determined. The two Canadian deposits were glaciated and placers can not be expected. The estimate is also plagued by lack of reporting about placers since most papers available are focused on vein deposits, not placer deposits.

While most Au-Ag-Te vein deposits have associated placers, they are all small and are worked using small-volume methods under the classification scheme developed by Bliss and others (1987). This type of placer has volumes between 1,000 and 240,000 m^3, and gold grades between 0.58 and 17 g/m^3. Maximum contained gold is on the order of 4,000 kg. Evaluation of associated placer activity was made for the six Au-Ag-Te vein deposits in Boulder County, Colorado ((Koschmann and Bergenhahl, 1968), Cripple Creek (Lovering and Goddard, 1950), La Plata (Eckel, 1949), Zortman-Landusky (Hastings, 1987), Golden Sunlight (Koschmann and Bergenhahl, 1968; Ageton and others, 1969), Kendall-Muleshoe (Blixt, 1933), Ortiz (Johnson, 1972; Koschmann and Bergenhahl, 1968), White Oaks (Koschmann and Bergenhahl, 1968), and Emperor (Colley and Greenbaum, 1980). The median amount of gold expected from placering is about 200 kg based on data on placers associated with these deposits. The maximum contained gold from placering was 3,000 kg which is comparable to 4,000 kg, the maximum contained gold produced from small-volume mining.

TARGET AREA MODEL

A target area model, based on data from 21 deposits, helps to give an idea of the size of area of an undiscovered Au-Ag-Te vein deposit (fig. 4) as defined here. The model is crude because data on two or more mining properties at a spacing less than or equal to one mile (1.6 km) were aggregated to form single deposits for modeling purposes. Workings can be linked over a considerable area where properties are grouped using this spacing rule. The area defined in this way is certainly not a projection of mineralization to the surface or outcrop area because the aggregate area also includes substantial areas without mineralization. The target model so computed is partly an artifact of the procedure used, but it still gives an idea of the regional target areas that Au-Ag-Te vein deposits present.

DEPOSITS

A list of deposits and locations used in this preliminary model follows. The locality abbreviations are: CNON--Canada, Ontario; FIJI--Fiji, USCO--United States, Colorado; USMT--United States, Montana; USNM--United States, New Mexico; and USSD--United States, South Dakota.

Bald Mountain	USSD	Magnolia	USCO
Carbonate	USSD	New York-Spotted Horse	USMT
Carlson	USMT	Ortiz	USNM
Cripple Creek	USCO	Richmond Hill-Turnaround	USSD
Emperor	FIJI	Ruby-Ward Rose	USCO
Garden-Maitland	USSD	Smuggler	USCO
Gilt Edge-Annie Creek	USSD	South Ragged Top	USSD
Gold Hill	USCO	Two Bit	USSD
Golden Sunlight	USMT	Ward	USCO
Jamestown	USCO	White Oaks	USNM
Kendall-Muleshoe	USMT	Young-Davidson	CNON
Kirkland Lake	CNON	Zortman-Landusky	USMT
La Plata	USCO		

REFERENCES CITED

Ageton, R.W., Krempasky, G.T., and Rice, W.L., 1969, A systems approach to recovering gold resources in Jefferson county, Montana: U.S. Bureau of Mines Report of Investigations 7305, 16 p.

Allen, M.S., and Foord, E.E., 1991, Geochemical and isotopic characteristics of the Lincoln County porphyry belt, New Mexico; implication for regional tectonics and mineral deposits: New Mexico Geological Society, 42nd Field Conference Guidebook, p. 97-113.

Bagby, W.C., Menzie, W.D., Mosier, D.L., and Singer, D.A., 1986, Grade and tonnage model of carbonated-hosted Au, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 175-177.

Berger, B.R, 1986, Descriptive model of Homestake Au, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 244.

Berger, B.R., and Singer, D.A., 1992, Grade and tonnage model of hot-spring Au-Ag, in Bliss, J.D., ed., Developments in mineral deposit modeling: U.S. Geological Survey Bulletin 2004.

Bliss, J.D., Orris, G.J., and Menzie, W.D., 1987, Changes in grade, volume, and contained gold during the mining life-cycle of gold placer deposits: Canadian Mining and Metallurgical Bulletin, v. 80, no. 903, p. 75-80.

Birmingham, S.D., 1987, The Cripple Creek volcanic field, central Colorado: Austin, Texas, University of Texas, M. A. thesis, 295 p.

Bliss, J.D., ed., 1992, Developments in mineral deposits modeling: U.S. Geological Survey Bulletin 2004, [in press].

Bliss, J.D., and Cox, D.P., 1986, Grade and tonnage model of polymetallic veins, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 125-129.

Colley, Howard, and Greenbaum, David, 1980, The mineral deposits and metallogenesis of the Fiji Platform: Economic Geology, v. 75, no. 6, p. 807-829.

Cox, D.P., and Bagby, W.C., 1986, Descriptive model of Au-Ag-Te veins, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 124.

Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, 379 p.

-----1992, Grade and tonnage model of distal disseminated Ag-Au, in Bliss, J.D., ed., Developments in mineral deposit modeling: U.S. Geological Survey Bulletin 2004 [in press].

De la Roche, H., Leterrier, J., Grandclaude, P., and Marchal, M., 1980, A classification of volcanic and plutonic rocks using R_1R_2-diagram and major-element analyses--its relationship with current nomenclature: Chemical Geology, v. 29, p. 183-210.

Eckel, E.B., 1949, Geology and ore deposits of the La Plata District, Colorado: U.S. Geological Survey Bulletin 219, 179 p.

Eriksson, C.L., 1987, Petrology of the alkalic hypabyssal and volcanic rocks at Cripple Creek, Colorado: Golden, Colorado, Colorado School of Mines, M. S. thesis, 114 p.

Hastings, J.S., 1987, Ore deposits of the Little Rocky Mountains, Montana: Society of Mining Engineers Annual Meeting, Denver, Colorado, February 24-27, 1987, Preprint no. 87-22, 25 p.

Irvine, T.N., and Baragar, W.R.A., 1971, A guide to the chemical classification of the common volcanic rocks: Canadian Journal of Earth Sciences, no. 8, p. 523-548.

Johnson, M.G., 1972, Placer gold deposits of New Mexico: U.S. Geological Survey Bulletin 1348, 46 p.

Koshchmann, A.H., and Bergendahl, M.H., 1968, Principal gold-producing districts of the United States: U.S. Geological Survey Professional Paper 610, 283 p.

Lovering, T.S., and Goddard, E.N., 1950, Geology and ore deposits of the Front Range, Colorado; U.S. Geological Survey Professional Paper 223, 319 p.

Maynard, S.R., Nelson, C.J., Martin, K.W., and Schultz, J.L., 1990, Geology and gold mineralization of the Ortiz Mountains, Santa Fe County, New Mexico: Mining Engineering, v. 42, no. 8, p. 1007-1011.

Mosier, D.L., 1986, Grade and tonnage model of Homestake Au, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 245-247.

Mosier, D.L., and Menzie, W.D., 1986, Grade and tonnage model of epithermal quartz-alunite Au, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 159-161.

Mosier, D.L., and Sato, Takeo, 1986, Grade and tonnage model of Sado epithermal veins, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 155-157.

Mosier, D.L., Sato, Takeo, and Singer, D.A., 1986a, Grade and tonnage model of Creede epithermal veins, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 146-149.

Mosier, D.L., Singer, D.A., and Berger, B.R., 1986b, Grade and tonnage model of Comstock epithermal veins, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 151-153.

Mosier, D.L., Singer, D.A., Bagby, W.C., and Menzie, W.D., 1992, Grade and tonnage model of sediment-hosted Au, in Bliss, J.D., ed., Developments in mineral deposits modeling: U.S. Geological Survey Bulletin 2004, [in press].

Musselman, T.E., 1987, A modified crustal source for the Colorado mineral belt; implications for REE buffering in CO2-rich fluids: Colorado School of Mines, M.S. thesis, 127 p.

Mutschler, F.E., Griffin, M.E., Stevens, D.S., and Shannon, S.S., Jr., 1985, Precious metal deposits related to alkaline rocks in the North American Cordillera--an interpretive review: Transactions of the Geological Society of South Africa, no. 88, p. 355-377.

Rock, N.M.S., 1988, Numerical geology: New York, Springer-Verlag, 427 p.

Saunders, J.A., 1986, Petrology, mineralogy, and geochemistry of representative gold telluride ore from Colorado: Golden, Colorado School of Mines, Ph.D. thesis, 171 p.

Shand, S.J., 1922, The problem of the alkaline rocks: Proceedings of the Geological Society of South Africa, no. 25, p. 16-33.

Singer, D.A., and Bliss, J.D., 1990, Program to prepare standard figures for grade-tonnage model on a Macintosh, in Hanley, J.T., and Merriam, D.F., eds., Microcomputer applications in geology, II: New York, Pergamon Press, p. 241-250.

Theodore, T.G., Orris, G.J., Hammarstrom, J.M., and Bliss, J.D., 1991, Gold-bearing skarns: U.S. Geological Survey Bulletin 1930, 90 p.

Thorpe, R.I., and Franklin, J.M., 1984, Intrusion-associated gold, in Eckstrand, O.R., ed., Canadian mineral deposit types: a geological synopsis: Geological Survey of Canada Economic Geology Report 36, p. 47.

Westra, Gerhard, and Keith, S.B., 1981, Classification and genesis of stockwork molybdenum deposits: Economic Geology, v. 76, no. 4, p. 844-873.

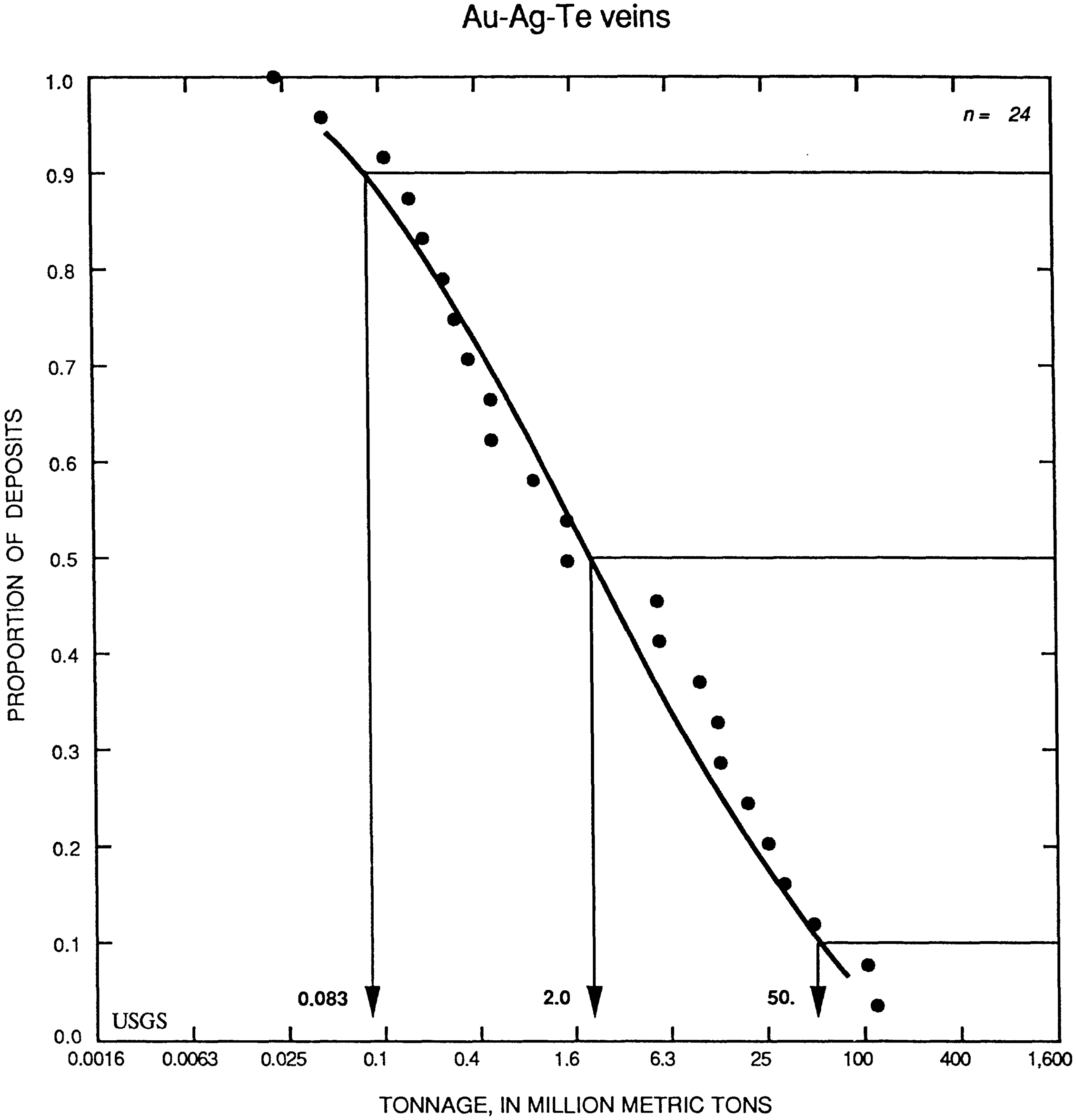

Figure 1. Tonnage of Au-Ag-Te veins associated with alkalic rocks.

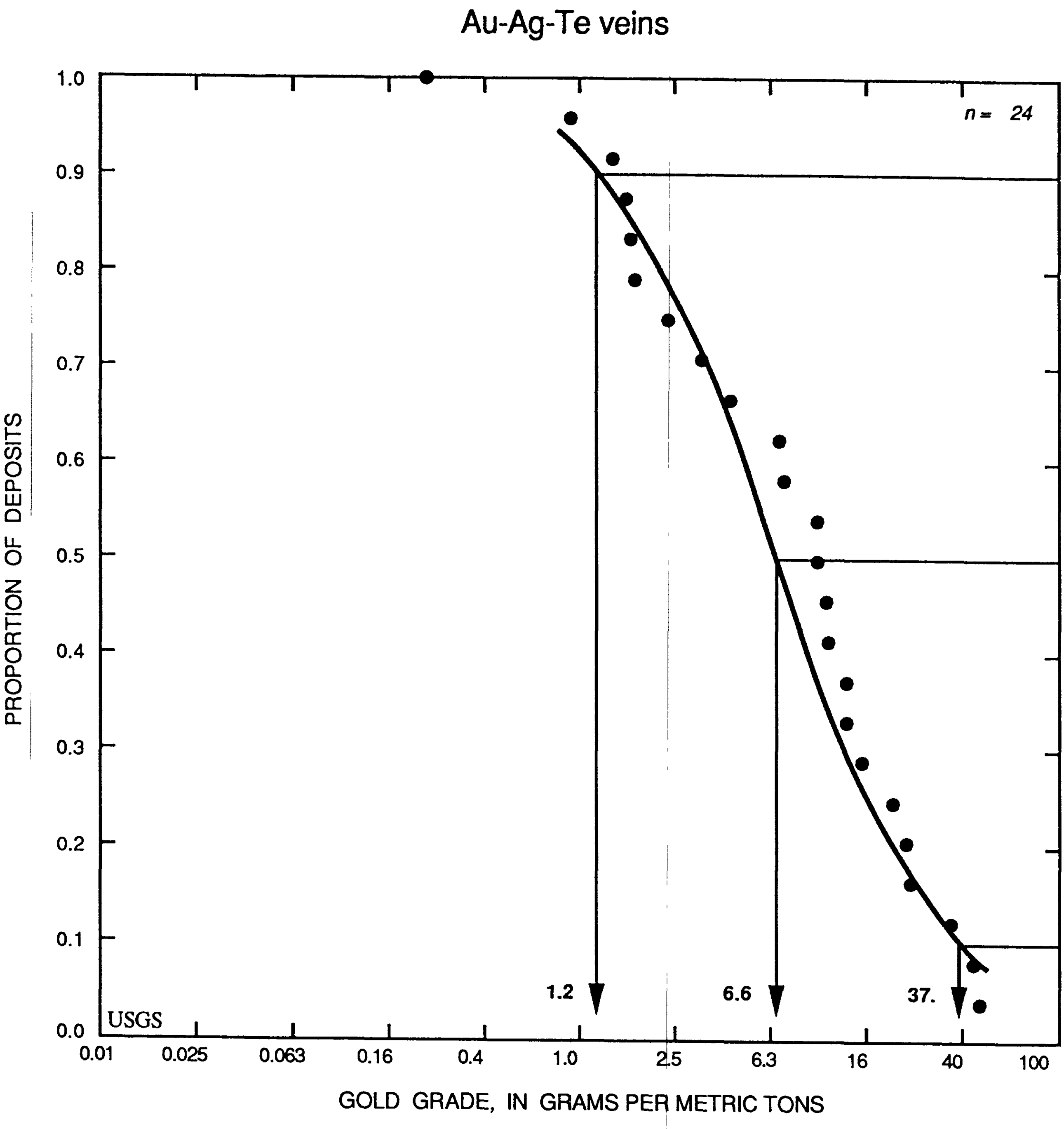

Figure 2. Gold grades of Au-Ag-Te veins associated with alkalic rocks.

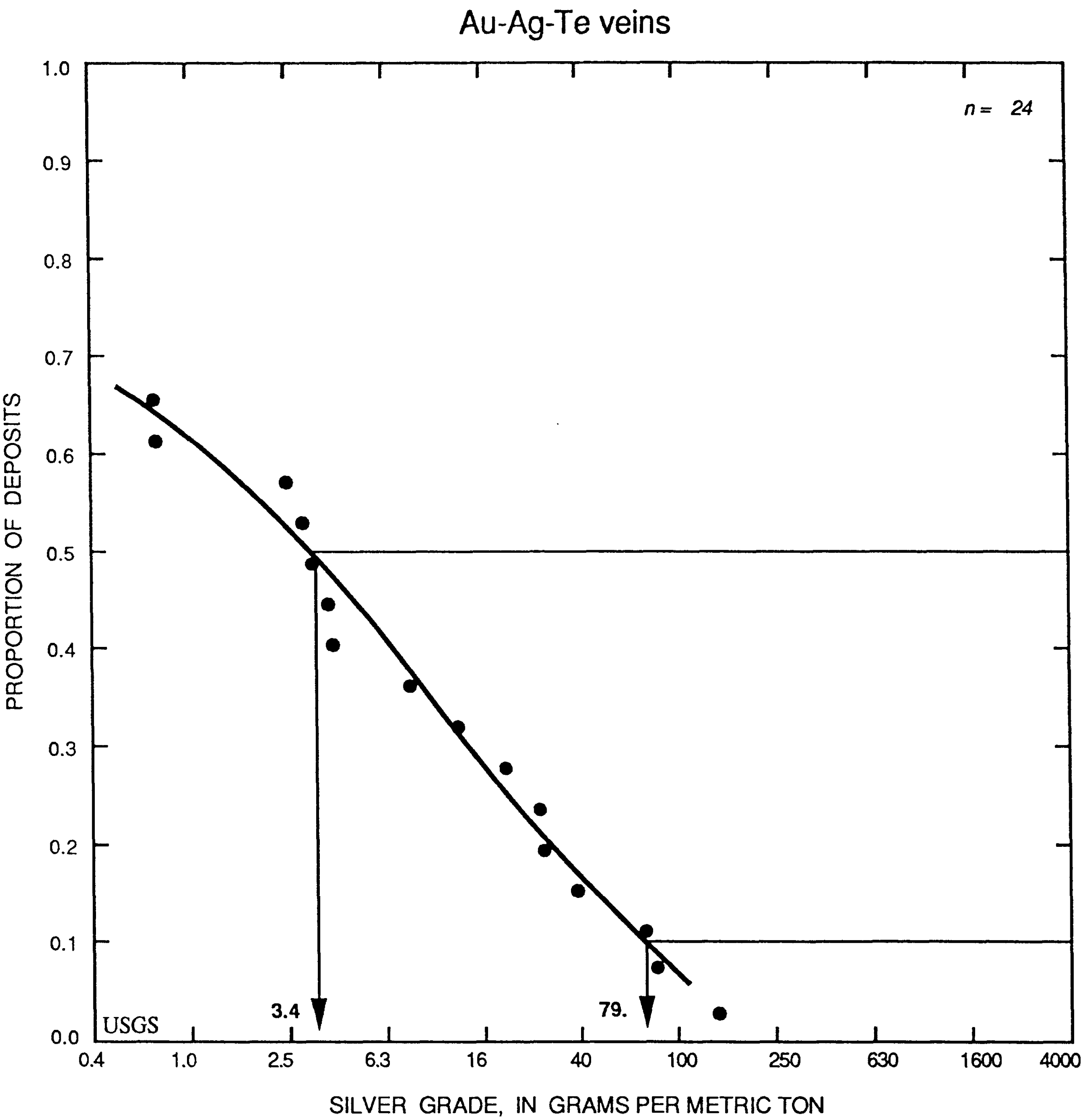

Figure 3. Silver grades of Au-Ag-Te veins associated with alkalic rocks.

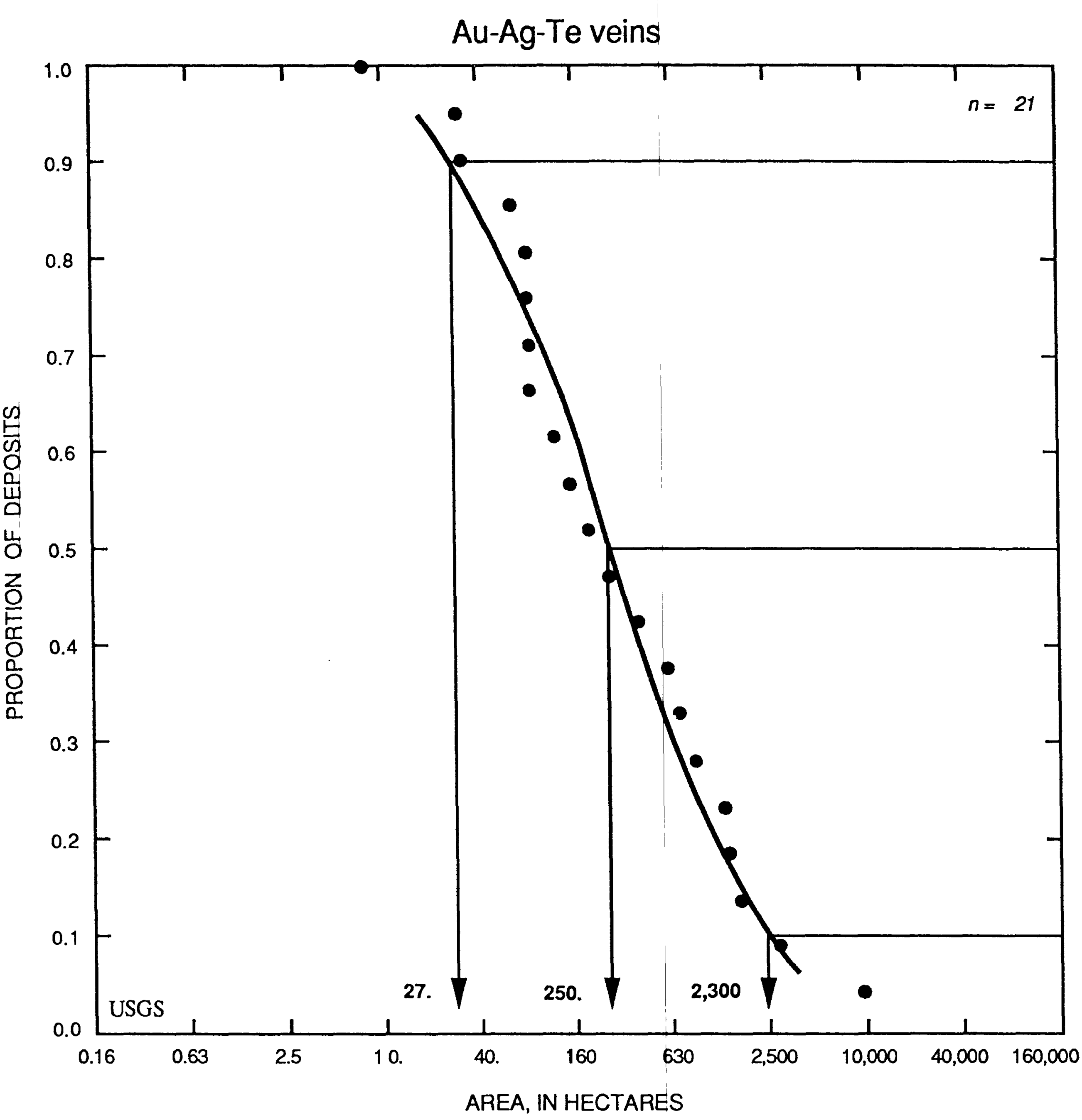

Figure 4. Target areas of Au-Ag-Te veins associated with alkalic rocks. (One hundred hectares (ha) equals one square kilometer. One hectare equals 2.47 acres or 0.0039 square miles.)