UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

U.S. GEOLOGICAL SURVEY-INGEOMINAS

MINERAL RESOURCE ASSESSMENT OF COLOMBIA

By

Carroll Ann Hodges, Dennis P. Cox, Donald A. Singer,
James E. Case, Byron R. Berger, and John P. Albers

U.S. Geological Survey

and

Francisco Zambrano-Ortiz, Fernando Etayo-Serna, Dario Barrero Lozano,
Hernando Lozano Quiroga, Armando Espinosa Baquero, Humberto Gonzalez Iregui,
Abigail Orrego Lopez, Alfonso Arias Tauta, Carlos Cedeno Ochoa,
Oscar Pulido Ulloa, Alvaro Murillo Rodriquez, Manuel Jose Diaz,
Hermann Duque-Caro, Rodrigo Vargas Higuera, Alberto Nunez Tello,
Jairo Alvarez Agudelo, Clemente Ropain Ulloa, Joaquin Buenaventura Arango,
Hernando Mendoza Forero, Gloria Rodriquez Sierra, and Luis Jaramillo Cortes

Instituto Nacional de Investigaciones Geologico-Mineras

Open-File Report
84-345

This report is preliminary and
has not been reviewed for
conformity with U.S. Geological
Survey editorial standards.

Menlo Park, California
1984

Contents

Contents

(Supplement)

Illustrations

[Plates are in pocket]

Contents

(Supplement)

MINERAL RESOURCE ASSESSMENT OF COLOMBIA

U.S. GEOLOGICAL SURVEY-INGEOMINAS

Summary

An assessment of the non-fuels, principally metallic, mineral resources of Colombia, completed by the Instituto Nacional de Investigaciones Geologico-Mineras and the U.S. Geological Survey in October, 1983, provides a synthesis of existing information useful as a basis for planning future minerals exploration programs. The complex geologic history and varied lithologic environments of Colombia are permissive for a wide range of mineral deposit types. In addition to new deposits of gold, silver, and platinum group elements, significant resources of lead, zinc, chromite, manganese, and possibly cobalt and bauxite may be discovered in the Cordilleran terranes by applying advanced concepts in ore deposit modeling as well as new exploration techniques. The vast and virtually unexplored areas of the Llanos Basin-Guayana Shield offer substantial possibilities for the occurrence of bauxite, iron, uranium, gold, diamonds, rare earths, possibly tin and tungsten; known deposits of such minerals in adjacent areas of Brazil and Venezuela suggest that eastern Colombia may be similarly endowed.

A broad program of exploration is encouraged. (1) Systematic geologic mapping already begun at scale 1:100,000 is fundamental to a comprehensive assessment of mineral resources and must remain a task of high priority. (2) Extensive geochemical sampling of stream sediments and geophysical surveying, particularly in the largely unknown eastern shield areas, are highly recommended. (3) Tertiary/Quaternary volcanic rocks of the Cordillera Central are favorable hosts for hot spring gold-silver deposits and should be an immediate focus for exploration efforts. (4) Cretaceous strata of the Cundinamarca Basin within the Cordillera Oriental offer excellent possibilities for discoveries of large-tonnage, shale-hosted lead-zinc-silver, bedded barite, and sedimentary manganese deposits. (5) Resources of fertilizer minerals, specifically phosphate, are potentially large in the Cordillera Oriental, and these should be assessed in detail; they are not addressed in this report.

Results of this assessment are summarized at scale 1:1,000,000 on two mineral resource maps of western and eastern Colombia. Domains in which the geologic environment is permissive for specific mineral deposit types are outlined on these maps; an accompanying table to which the maps are keyed lists the deposit types and accessory information on known deposits, stratigraphy, lithology and miscellaneous comments. The only non-metallic minerals included are barite and emeralds. The text that follows presents detailed descriptions of selected deposit types, including possibilities for their occurrence in Colombia, as well as exploration guides and recommendations. Two appendices provide compilations of ore deposit models and grade-tonnage models, and are referenced in the text.

Information and recommendations contained in this report should provide a basis for long-range planning of exploration and development strategy in Colombia, for national decisions on mineral policy and land use, and for establishing goals for research efforts.

Introduction

In October, 1982, the U.S. Geological Survey and the Instituto Nacional de Investigaciones Geologico-Mineras began a cooperative year-long project to synthesize existing information on the non-fuels mineral resources of Colombia and to assess the potential for new mineral discoveries within the framework of lithostratigraphic terranes (Coney et al, 1980; Albers, 1981; 1983). The products of the project are: 1) a mineral resource map (plates 1 and 2) at a scale of 1:1,000,000 that combines geologic, metallogenic, and geochemical data with terrane analyses and indicates favorable exploration areas (domains) for given mineral deposit types; 2) a descriptive table, to which the map is keyed, listing deposit types permitted by the geologic environment of each domain; and 3) the following text that describes selected deposit types, together with exploration guides and recommendations. In addition, the present report includes two appendices: (A) a compendium of ore deposit models, and (B) a compendium of grade/tonnage models. The scope of this one-year effort was limited to metallic resources, with the exception of emeralds and barite. The assessment is based primarily on deposit types rather than on commodity occurrences.

Currently, Colombia produces significant quantities of platinum and gold, and is the world's largest producer of gem-quality emeralds; in addition, barite, silver, iron, and, since 1982, nickel are mined. Several porphyry copper deposits have been discovered and are currently being evaluated. The complex and varied geologic setting of the country is permissive for a broad range of mineral deposits. The Cordilleran terranes include ultramafic intrusive bodies, oceanic basalts, metasedimentary and metavolcanic rocks, felsic intrusive rocks, Phanerozoic sedimentary rocks, including Tertiary basin deposits, and Precambrian metasedimentary and metaigneous rocks. Significant new resources of sedimentary barite, shale-hosted lead-zinc-silver, hot spring gold-silver and mercury, platinum-group elements and chromite in stratiform mafic complexes, sedimentary manganese, and possibly cobalt and bauxite, may be found in these geologic environments. The vast and largely unexplored areas of the Llanos Basin-Guayana Shield offer excellent possibilities for the occurrence of bauxite, sandstone-hosted lead-zinc, iron formation, uranium, paleoplacer gold and diamonds, rare earths, and possibly tin and tungsten vein deposits.

In the pages that follow, selected deposit types known in or permitted by the geologic setting of specific lithostratigraphic terranes are described, together with a map showing those regions or domains (in some cases coincident with terranes; more often, parts of terranes) in which a deposit type is most likely to occur. Included for each is a paragraph outlining exploration guides and recommended prospecting techniques. Additional information on the deposit types is referred to in Appendices A and B; the Table of Contents for Appendix A shows the classification and numbering scheme.

Aside from the quidelines regarding exploration for specific deposit types, some recommendations for attaining a more comprehensive assessment of Colombia's mineral resources are as follows:

1) Geologic mapping--Because probability of success in finding ore deposits is strongly dependent on the level of detail in geologic mapping, a continued strong program of systematic regional mapping at scale 1:100,000 throughout the country is fundamental to more comprehensive assessment of mineral resources. Regional geologic mapping should be supplemented by

more detailed mapping at 1:24,000 scale or larger in selected mineralized areas.

2) Guayana Shield-Llanos Basin--The resource potential of this vast portion of eastern Colombia is largely unknown. Existing geochemical and geophysical data should be compiled, and an intensive program of stream-sediment sampling and geophysical surveying throughout the region, begun. The geologic environment of the shield areas appears especially promising for discovery of a wide range of mineral deposits, based on analogy with adjacent areas in Brazil and Venezuela. An initial reconnaissance should be made by means of river traverses.

3) Epithermal gold--Tertiary/Quaternary volcanic rocks are permissive for hot spring gold-silver deposits, commonly of low grade but large tonnage. Reconnaissance mapping and sampling of altered and mineralized zones in young volcanic rocks of the Cordillera Central and southern Cordillera Occidental may well be rewarding.

4) Detailed study of Cretaceous section in Cordillera Oriental--Excellent possibilities exist for discovery of large tonnage, shale-hosted Pb-Zn-Ag, bedded barite, and sedimentary manganese deposits in the thick sequence of Cretaceous sandstones and shales of the Cordillera Oriental, especially in the Cundinamarca Basin. Detailed stratigraphic, structural, and geochemical investigations of these rocks, with emphasis on the black shales, is highly recommended.

5) Aeromagnetic survey--Aeromagnetic data are needed for the entire country. Such data are valuable in identifying major rock units and their continuity and, in some cases, local targets for ground exploration.

6) Geochemistry--Geochemical sampling and analyses are essential in any program of exploration and are commonly instrumental in defining target areas. Emphasis on improving analytical techniques and expanding basic sampling coverage is encouraged.

7) Non-metallic mineral deposits--A comprehensive assessment of fertilizer and industrial minerals important to Colombia's economy should be undertaken. Such a study could be done in much the same style as this one and could serve similarly as a reference framework to be added to as new information becomes available.

8) Studies in classic mineral localities--A program of travel for Colombian geologists to visit classic ore deposits throughout the world would be immensely helpful in broadening the experience and perspective of those responsible for exploration programs.

9) Investigations of ore-forming processes--Detailed petrographic and geochemical analyses in specific districts, particularly those having unusally complex mineralogy (such as the California-Vetas district) would be useful, not only for exploration in Colombia but elsewhere as well. Thorough studies are warranted in a number of districts, and government support of graduate theses in such areas may be appropriate.

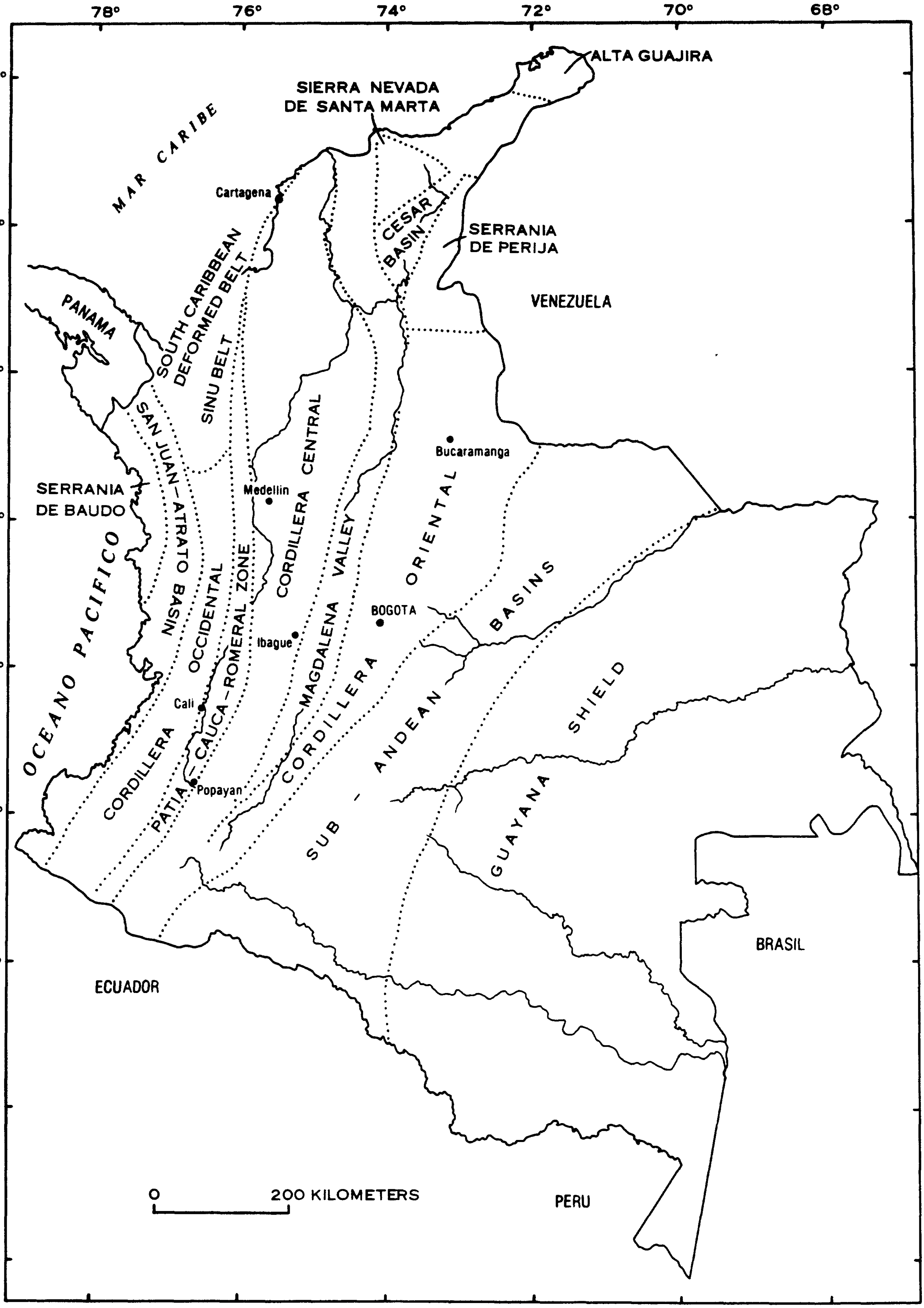


Figure 1.--Geologic provinces of Colombia.

The documents resulting from this pilot project are intended to provide a basis for national decisions regarding long-range mineral policy and land-use in Colombia, for outlining exploration and development strategy, for recommendations regarding further data acquisition and research, and for a basic inventory to be augmented and improved as new data become available.

Geologic Framework of Colombia

Colombia comprises 9 major geological elements (figure 1). From southeast to north and west, they are briefly outlined as follows. (1) The Precambrian Guayana Shield. (2) The sub-Andean basins east and south of the Andes of Colombia and Venezüela (analogous to the Denver Basin and other basins east of the Rocky Mountains front of the United States). (3) The Cordillera Oriental and Serrania de Perija, which contain cores of Precambrian and Paleozoic metamorphic rocks intruded by Paleozoic and Mesozoic plutons; Triassic-Jurassic rift-related volcanic rocks and redbeds are prominent, and a thick basin sequence of Cretaceous sandstones and shales dominates the central part of the Cordillera Oriental (Etayo-Serna and others, 1976). Deformation occurred at several Paleozoic intervals and in Late Cretaceous-early Tertiary time, followed by vigorous uplift in post-middle Miocene time. (4) The Cordillera Central, which contains Precambrian and Paleozoic crystalline terranes, a mix of Mesozoic cratonic and oceanic deposits, and a superjacent cover of Tertiary sedimentary and neo-volcanic deposits; plutons range in age from late Paleozoic to early Tertiary. The crust is probably continental or transitional. As elsewhere in the Colombian Andes, the vertical uplift is post-middle Miocene. The Sierra Nevada de Santa Marta, a triangular-shaped fault-bounded block on the Carribbean coast, is probably a geologial extension of the Cordillera Central. (5) The Cordillera Occidental, composed of late Mesozoic oceanic crust upon which have been superimposed primitive magmatic (tholeiitic) to calc-alkaline rocks of late Mesozoic to Paleogene age. The range is intruded by Paleogene to Miocene plutons, some of which contain porphyry copper-molybdenum deposits. (6) The Pacific coastal range, the Serrania de Baudo, an uplifted block of late Mesozoic oceanic crust that contains elements of primitive magmatic arc to calc-alkaline magmatic arc deposits. (7) A great suture zone, the Cauca-Patia-Romeral system, separating the Cordillera Central (continental) from the Cordillera Occidental (oceanic). This zone, in the subsurface, separates the San Jacinto belt from the Sinu belt in the Tertiary basins of northern Colombia. (8) Deformed Tertiary basins, which lie between the Cordilleras Oriental and Central (Magdalena Valley), the Cordilleras Central and Occidental (Cauca-Patia Valley), the Cordillera Occidental and Serrania de Baudo (San Juan-Atrato Basin), the Serrania de Perija and Sierra Nevada de Santa Marta (Cesar Basin), and along the Caribbean margin (Sinu belt, South Caribbean deformed belt). (9) Complex ranges and small basins of the Guajira Peninsula. Comprehensive summaries of the geology of Colombia can be found in Burgl (1961, 1967, 1973), Campbell (1974), and Irving (1975).

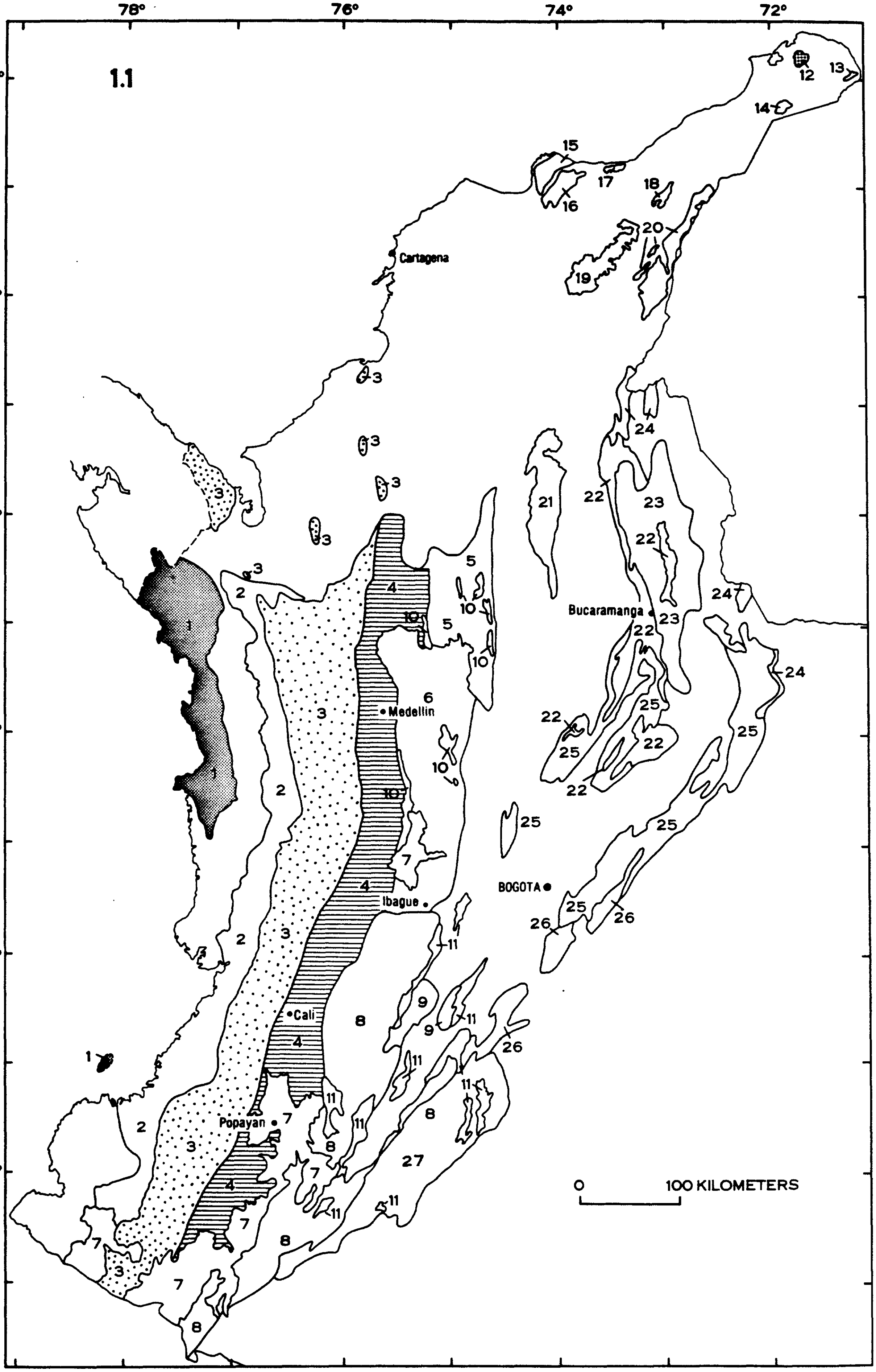


Figure 2.--Podiform chromite.

1.1 PODIFORM CHROMITE — Domains 1, 3, 4, 12

Deposit Description

Lenticular or rudely tabular pods ranging in size from a few pounds to several million tons in irregular peridotite masses or peridotite-gabbro complexes of the alpine type. (Appendix A, p. 1-2)

Tonnage and Grade Characteristics

Ten percent of the deposits from the California-Oregon region in the United States contain 1,800 tonnes or more, whereas the upper tenth elsewhere in the world contain 200,000 tonnes or more. (Appendix B, p. 3-12)

Geologic Environment in Colombia

Chromite is specifically associated with dunite or serpentinized dunite in upper parts of peridotite masses. Such intrusives are known along the Romeral-Cauca suture zone and may also occur along the Atrato fault. Chromite has been produced in Colombia from the Santa Elena podiform deposit, associated with serpentine southeast of Medellin; reserves there were estimated at 20,000 tons Cr_2O_3 in 1975 (Angulo, 1978; Alvarez, 1983). See Appendix A for hypothetical model and genesis.

Exploration Guides and Recommendations

At least 99 percent of the world's known chromite bodies have been found by surface prospecting. Therefore the search for chromite in Colombia should begin with an exhaustive search for all masses of ultramafic rocks by conventional prospecting methods. Geophysical techniques may be helpful in detecting concealed deposits. Ground magnetic surveys can be effective, and detailed gravity surveys were used successfully in Cuba (Davis and others, 1957; 1960; 1980; Hammer and others, 1945). Electrical and seismic techniques, including spectral induced polarization (SIP), produced encouraging results in northern California (Wynn and Hasbrouck, in press). Reconnaissance geochemical exploration may be helpful in delineating target areas. The magnetic fraction of panned stream sediments is the most valuable sample medium.

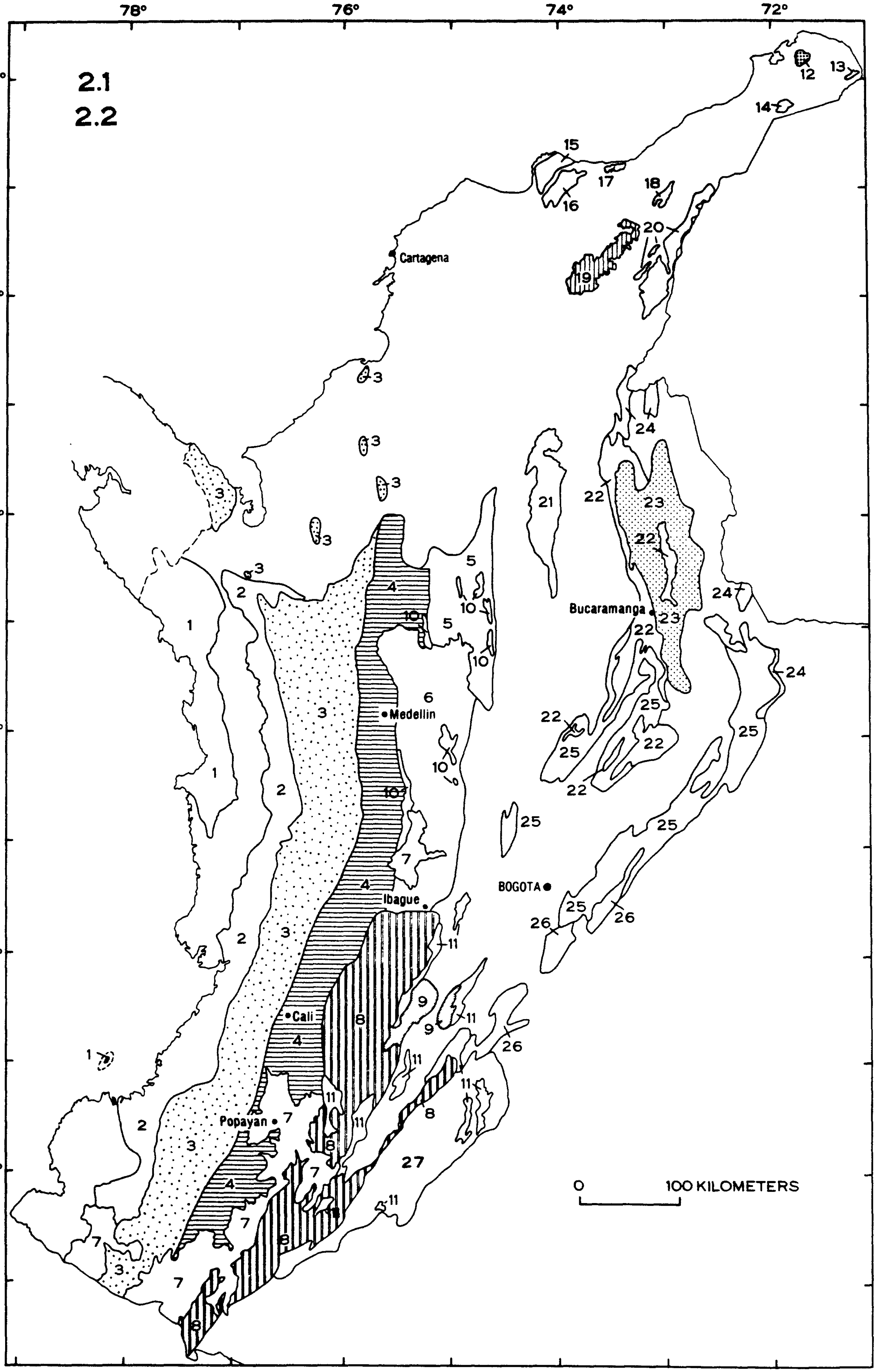


Figure 3.--Porphyry copper - Mo-rich; Au-rich.

2.1 PORPHYRY COPPER, Mo-rich — Domains 3, 4, 8, 9, 12, 19, 23

2.2 PORPHYRY COPPER, Au-rich

Deposit Description

Large tonnage deposits containing veinlets and disseminations of copper and molybdenum sulfides in hypabyssal intrusions and their reactive country rocks--Enrichment during weathering can result in high-grade blanket-like ore bodies above lower grade primary mineralization. Two subtypes are known, one rich in molybdenite and pyrite, the other rich in gold and magnetite. Some deposits have no recoverable gold or molybdenum, others have both. (Appendix A, p. 13-16)

Tonnage and Grade Characteristics

The median tonnage of well-explored deposits is 140 million tonnes and 10 percent of the deposits have 1,100 million tonnes or more. Median grade is 0.5 percent Cu, secondary enrichment zones may contain 1 to 2 percent Cu. Median Mo grade of molybdenum-rich deposits is 0.4 percent. Median gold grade of gold-rich deposits is 0.31 grams per tonne Au. (Appendix B, p. 32-50)

Geologic Environment in Colombia

Numerous porphyry deposits and prospects are known in the Western and Central Cordilleras of Colombia, mainly in domains 3, 4, and 8 (Angulo, 1978), and in the Eastern Cordillera at the California-Vetas District (Domain 23) (Sillitoe and others, 1982). Undiscovered deposits may exist in some epizonal granitic plutons in the Guajira Peninsula (Domain 12) and Sierra Nevada de Santa Marta (Domain 19).

Exploration Guides and Recommendations

Exploration for porphyry deposits has been carried out in Colombia since the early 1960's, mainly by regional geochemical sampling and follow-up geologic mapping and detailed sampling. Since the major part of this work was accomplished, new information has been developed on the geologic attributes of gold-rich porphyry copper systems. (See Appendix, model 2.2, for description and bibliographic references.)

In gold-rich porphyry systems, gold is recoverable from the disseminated copper ore within the porphyry intrusion. These systems may occur in the same tectonic environment as molybdenum-rich systems but are probably formed at higher levels in the plutonic-volcanic column. Breccias containing intrusive rock and coeval volcanic rocks are especially significant in identifying such high level igneous environments. Magnetite, in veinlets and disseminations associated with potassic alteration in the porphyry intrusion, is a dependable indicator of a gold-rich system (Sillitoe, 1979). Pyrite may not be abundant in the copper ore and, for this reason, the strong bleaching of rock and iron staining of fractures usually associated with weathering of mineralized porphyry outcrops may be absent. Supergene concentration of copper may also be weak or absent. Pyrite along with sericite and clay may form in late stage phyllic alteration, overprinted on the copper-gold mineralization and is commonly abundant in a halo surrounding the ore zone and the porphyry intrusion.

Detailed magnetic surveys of gold-rich systems should indicate a ring-shaped magnetic low (caused by pyrrhotite or by the pyritization or oxidation of magnetite) surrounding a magnetic high caused by the abundant magnetite in the copper ore body (Jones and others, 1964; Case and Nelson, in press). Electromagnetic methods may be useful in location of both sulfide and magnetite-rich zones, especially induced polarization (IP), spectral induced polarization (SIP), self potential (SP), and audio-magnetotelluric methods (AMT) (Bruce Smith, personal commun., 1983). Analysis of rock samples may show molybdenum anomalies in the pyrite halo, and anomalies of lead, zinc, silver, and manganese in zones peripheral to the gold-rich system. Sampling the -100 mesh portion of stream sediments may also show anomalous concentrations of copper-gold and peripheral lead, zinc, silver, and manganese anomalies. Formation of a peripheral anomaly may be closely related to late sericite-clay-pyrite alteration overprinted on a copper-gold porphyry (Cox, D. P., unpublished data). If such alteration is absent, peripheral lead, zinc, silver, and manganese anomalies may also be lacking.

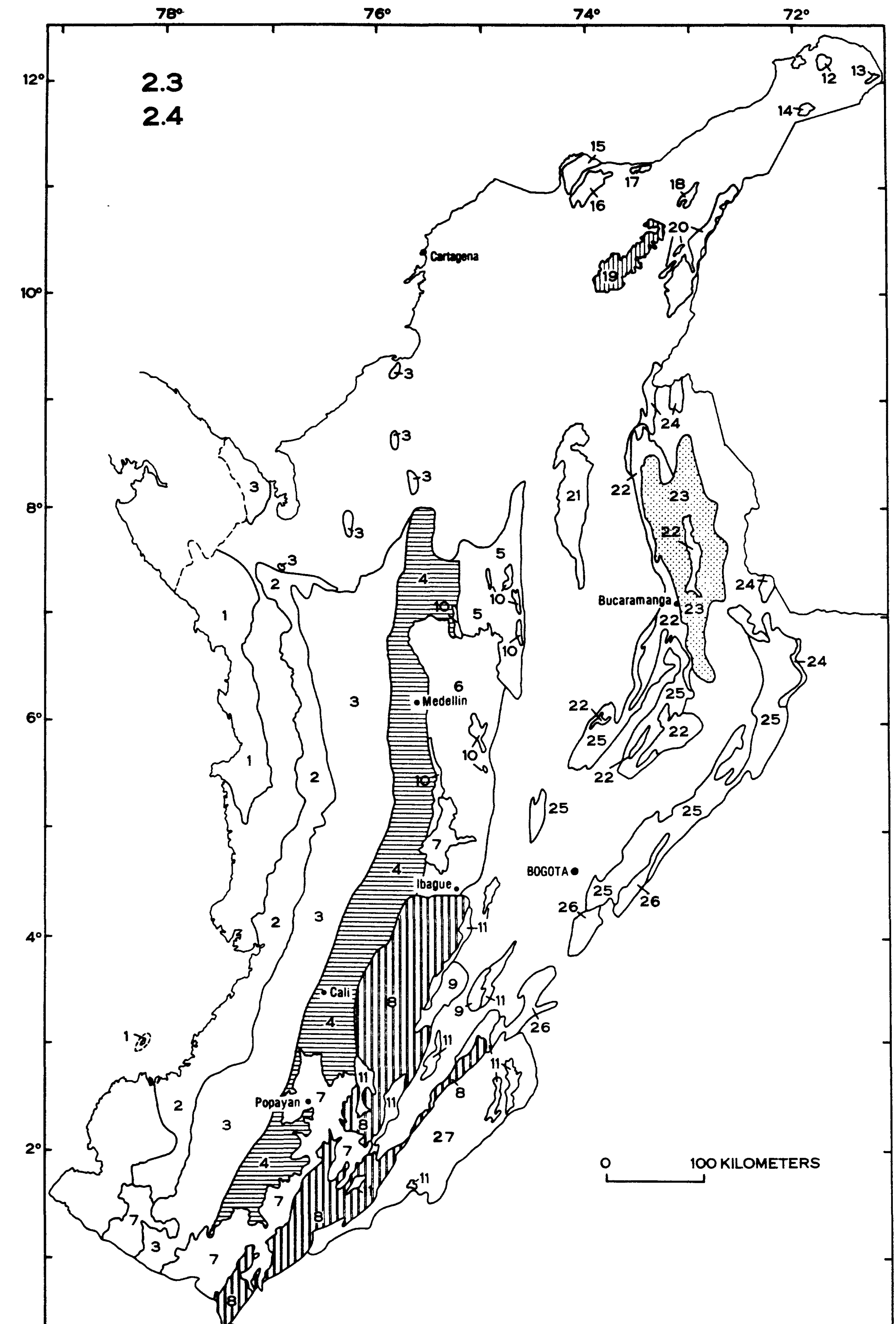


Figure 4.--Molybdenum porphyry - Climax type; low F.

2.3 MOLYBDENUM PORPHYRY, CLIMAX TYPE — Domains 4, 19, 23
2.4 MOLYBENUM PORPHYRY, LOW F — Domains 4, 8

Deposit Description

Large-tonnage deposits of disseminated molybdenite, of low but fairly uniform grade, in porphyry stocks and altered country rock in cratonic rocks--Climax-type deposits have abundant fluorite associated with the ore stockwork and occur in granitic or rhyolitic intrusions in rifted cratonic areas. Low-fluorine-type deposits are found in less silicic stocks in accretionary continental margins. (Appendix A, p. 17-18)

Tonnage and Grade Characteristics

Median tonnage of nine well-explored Climax-type deposits is 230 million tonnes; the largest 10 percent of deposits contains 910 million tonnes or more. Median Mo grades for nine Climax and 33 low-fluorine-type deposits are 0.19 percent and 0.084 percent respectively. Tungsten and tin may be byproducts. (Appendix B, p. 51-56)

Geologic Environment in Colombia

No major molybdenum porphyry has yet been discovered in the Andean Cordillera. In Colombia, a low-fluorine-type deposit may exist at the locality of Santo Domingo south of Ibague in Domain 8 (Buitrago and Buenaventura, 1975, p. 488). Climax-type deposits may exist in areas of Mesozoic granitic and rhyolitic rocks in the Guajira Peninsula (Domain 14) and Sierra Nevada de Santa Marta (Domain 19). The Santander Massif (Domain 23) is, by analogy with the Central Rocky Mountains of North America, a favorable tectonic environment for Climax-type deposits; however, high-silica granites or rhyolites in this region have not been noted thus far.

Exploration Guides and Recommendations

Deposits are recognized in outcrop by their dense quartz stockwork, stable potassium feldspar in altered rocks, and yellow ferrimolybdite stains. Peripheral vein deposits of base-metal sulfides with gold, silver, tungsten, and bismuth may be associated with low-fluorine types. Peripheral fluorite in veins and breccia pipes as well as rhodochrosite, rhodonite, and spessartine in altered igneous rocks suggest environments permissive for the presence of Climax-type deposits. Flat magnetic gradients or magnetic lows commonly occur over zones where magnetite has been altered to sulfides or to nonmagnetic oxides. Electromagnetic techniques useful in exploration for porphyry copper deposits (2.1, 2.2) may also be applicable to molybdenum porphyry exploration, although pyrite content may be lower in the molybdenum porphyries. Geochemical exploration should include stream-sediment analyses for molybdenum, tungsten, fluorine, bismuth, and the base and precious metals. Molybdenum values of 3 ppm or higher in the -100 mesh fraction of stream sediments are generally considered to be anomalous (Howarth and Martin, 1979).

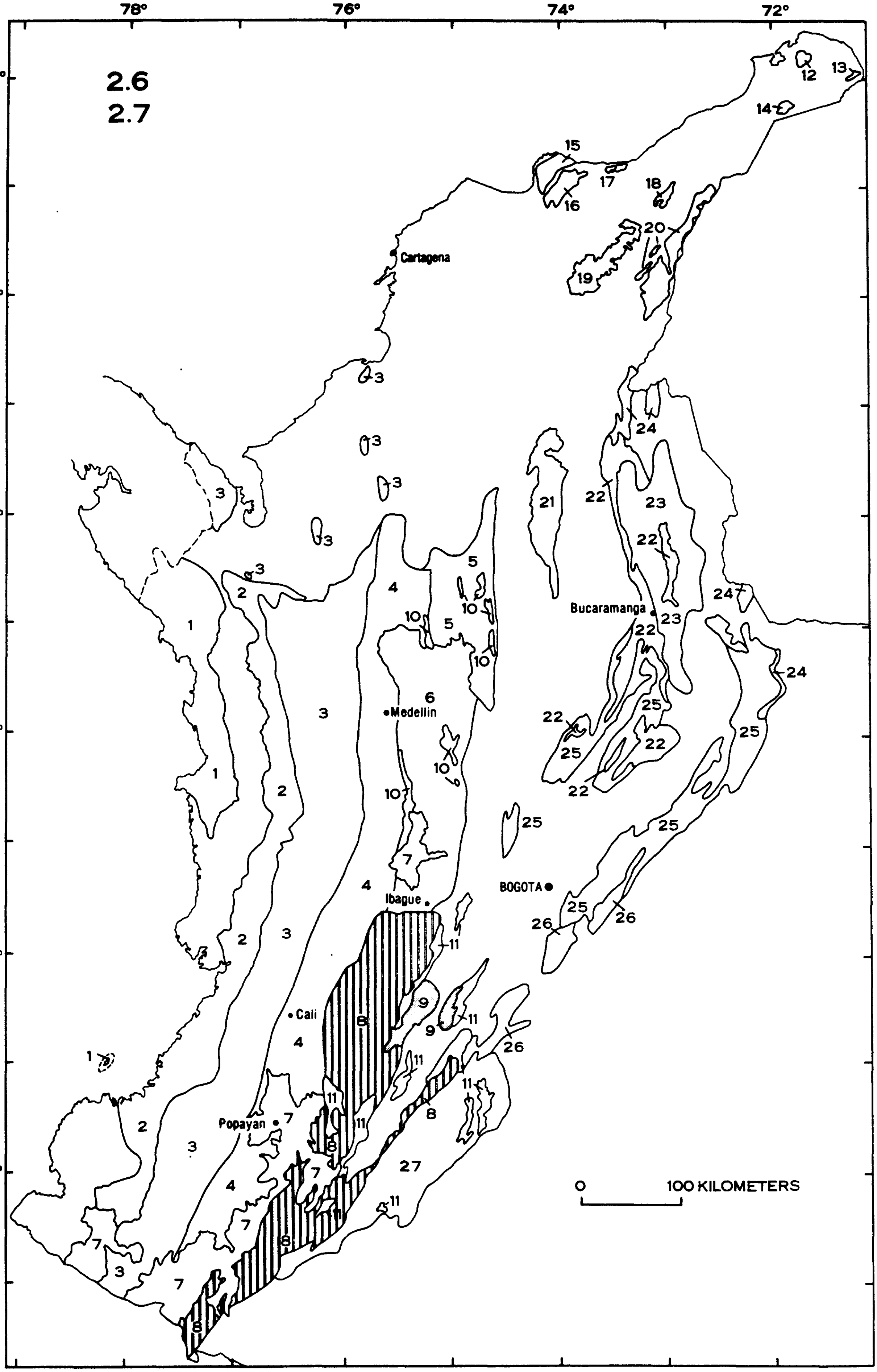


Figure 5.--Copper skarn; lead-zinc skarn.

2.6 COPPER SKARN — Domains 8, 9

2.7 LEAD-ZINC SKARN — Domains 8, 9

Deposit Description

Deposits of chalcopyrite, or sphalerite and galena in limestone altered to calc-silicate rock near contacts with felsic to intermediate plutons. (Appendix A, p. 20-22)

Tonnage and Grade Characteristics

Median tonnage of well-explored copper skarns is 600,000 tonnes and median copper grade is 1.7 percent. Median tonnage of lead-zinc skarns is 2.1 million tonnes and median lead and zinc grades are 3.6 percent and 5.8 percent respectively. (Appendix B, p. 61-77)

Geologic Environment in Colombia

Carbonate rocks of the Payandé and other Mesozoic formations in the southern Cordillera Central contain numerous deposits of this type (Domain 8) (Buitrago and Buenaventura, 1975). Additional deposits may occur in Domain 9 where the Payandé lies at various depths below the cover of post-Payandé volcanics.

Exploration Guides and Recommendations

Exploration should start with reconnaissance mapping of skarn mineral assemblages in carbonate rocks of the southern Cordillera Central. Special attention should be given to areas where hydrous silicates such as amphibole and chlorite replace garnet or pyroxene because hydrous minerals commonly accompany sulfide deposition.

A search for calc-silicate minerals in boulders and pebbles in streams, if successful, should be followed by geophysical and geochemical surveys. Detailed magnetic surveys would identify skarn magnetite and pyrrhotite that may be associated with base-metal deposits. Standard electromagnetic surveys may be effective in areas where geochemical anomalies suggest possible targets. Heavy mineral separates of panned concentrates analyzed for tungsten, bismuth, tin, and the base and precious metals are useful geochemical guides. Mineralized skarns may be zoned outward from the intrusive contact from Cu-Au-Ag to Au-Ag to outermost zones rich in Pb-Zn-Ag.

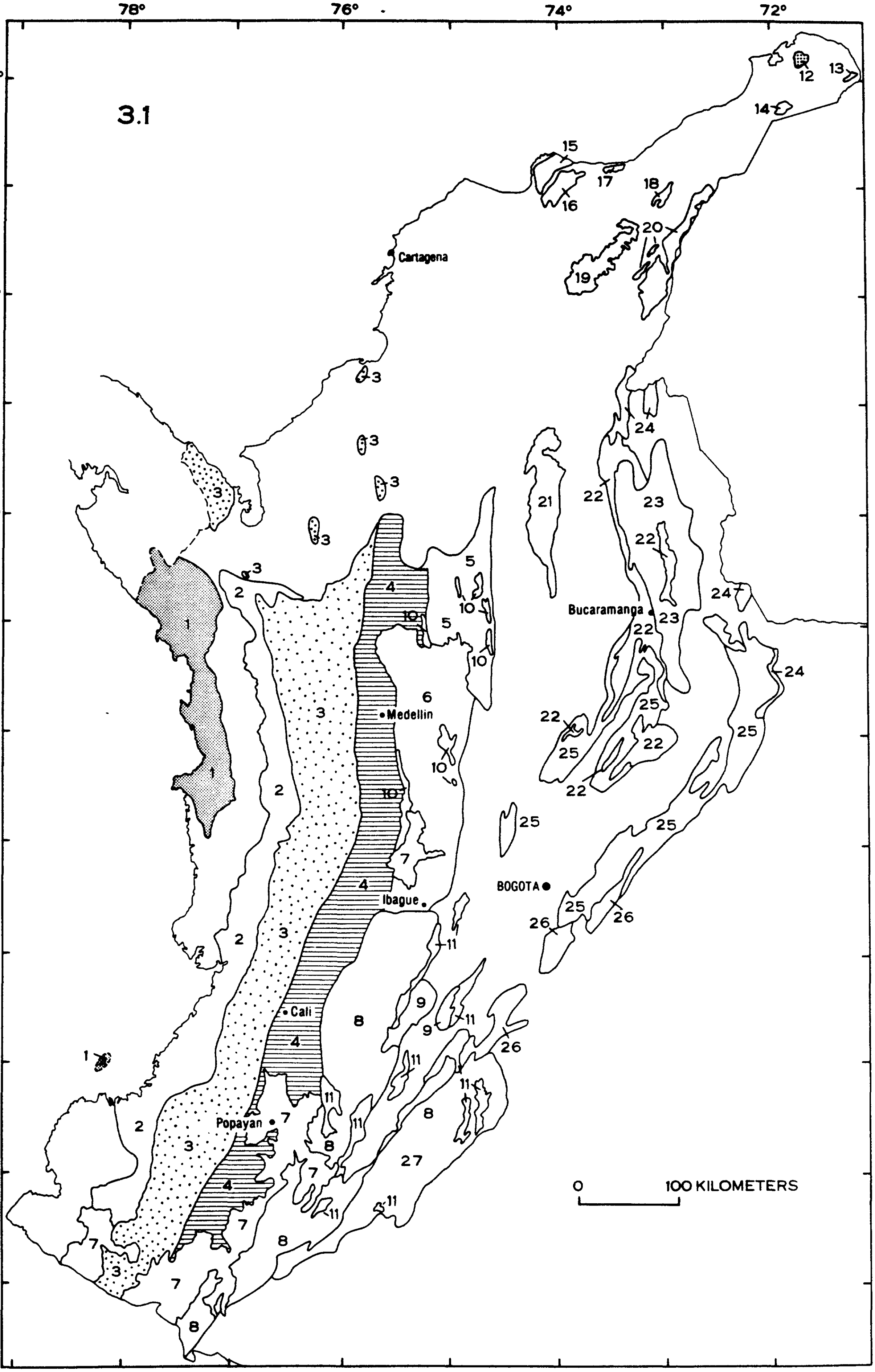


Figure 6.--Massive sulfide, Cyprus-type.

3.1 MASSIVE SULFIDE, CYPRUS-TYPE Domains 1, 3, 4, 12

Deposit Description

Massive pyrite, chalcopyrite, and sphalerite in or near pillow basalt and diabase dikes--These deposits may have overlying or interbedded chert, shale, and graywacke; an associated stringer zone (stockwork) containing pyrite or pyrrhotite and chalcopyrite may commonly underlie the massive sulfide. (Appendix A, p. 25-26)

Tonnage and Grade Characteristics

The median tonnage of well-explored deposits is 1.6 million tonnes and the largest 10 percent contain 17 million tonnes or more. Ninety percent of the deposits contain at least 0.63 percent copper; the richest one-tenth contain more than 3.9 percent copper. Lead is present in trace amounts only. Ten percent of the deposits contain at least 2.1 percent zinc. Gold is present in minor amounts, and 10 percent of the deposits contain at least 27 g/t silver. (Appendix B, p. 81-87)

Geologic Environment in Colombia

Conditions favorable for Cyprus-type deposits exist in the Cretaceous ophiolites (oceanic crust terranes) of western Colombia, as described by Barrero-Lozano (1979), and possibly in other ophiolites in the north (Domain 12). The nearest well-explored deposit, Oxec in Guatemala (Peterson and Zantop, 1980), apparently is about the same age as the basalts and diabases of the Western Cordillera of Colombia.

Exploration Guides and Recommendations

The stratigraphic position of deposits is most likely at or close to the contact between submarine pillow basalts and overlying pelagic strata so field mapping may identify favorable areas. Electromagnetic surveying is probably essential in establishing drilling targets in heavily covered areas, particularly time-domain electromagnetic (TEM) and frequency-domain electromagnetic (FEM) profiling and sounding (Bruce Smith, personal commun., 1983). Geochemical anomalies are unlikely to extend a great distance from these deposits, so fairly dense sampling is required. Gossans or sulfides that crop out should be sampled closely for geochemical anomalies. Geochemical sampling should be concentrated near known or possible pillow basalts and diabase dikes. Anomalies discovered should be followed up with detailed rock and soil sampling and ground geophysics. Because mafic volcanic rocks intrinsically contain high concentrations of base metals, it is useful to use an analytical procedure that selectively extracts sulfide or oxide mineral phases, leaving the silicate-bound metals undissolved. Flat or negative magnetic anomalies commonly occur in alteration zones of pillow basalt or sheeted dike sequences and thus may constitute indirect exploration guides (Case and others, 1979). Spectral induced polarization may aid in recognition of veins.

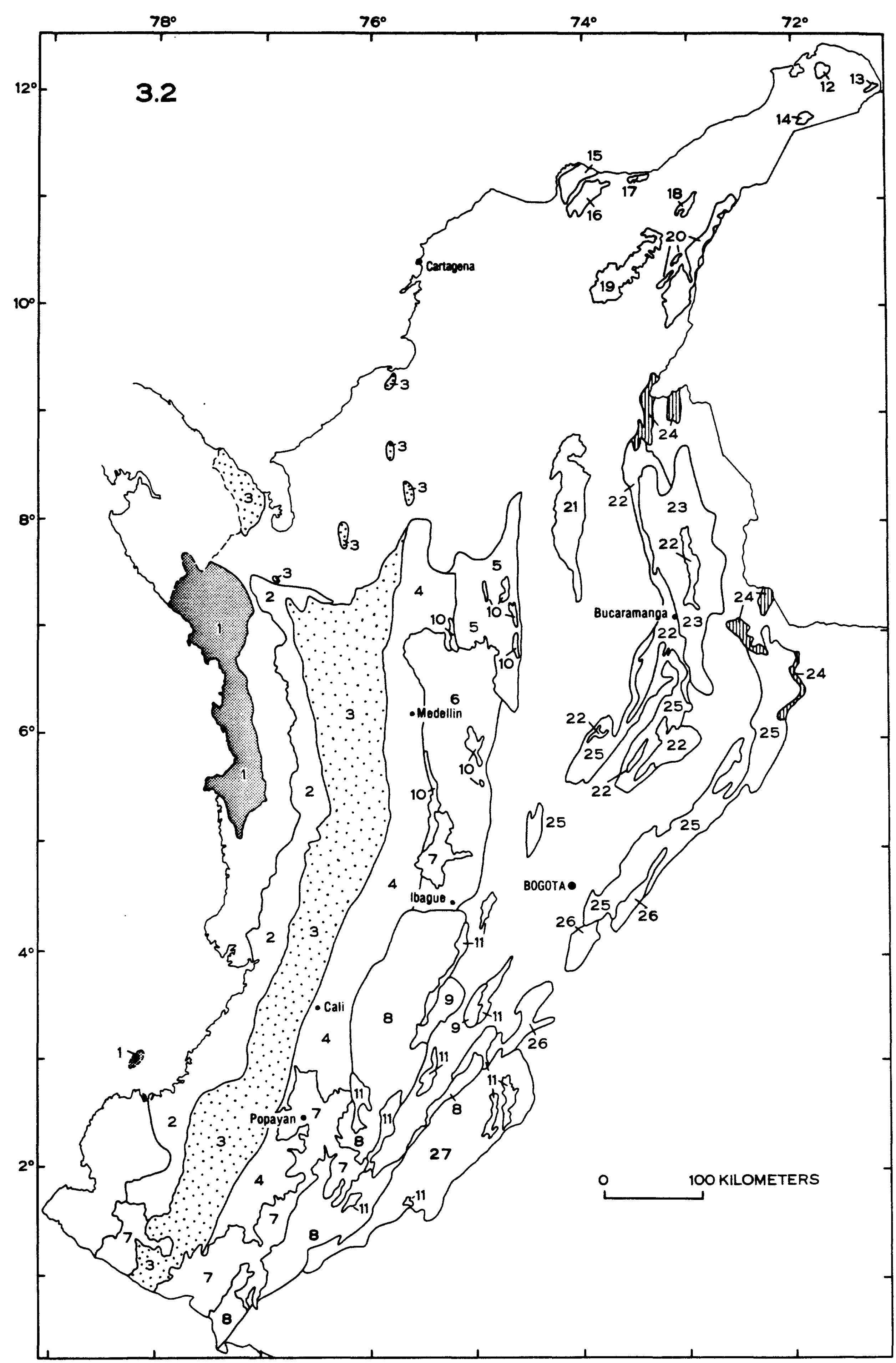


Figure 7.--Massive sulfide in felsic and intermediate rocks.

3.2 MASSIVE SULFIDE IN FELSIC AND INTERMEDIATE ROCKS Domains 1, 3, 24

Deposit Description

Massive pyrite, chalcopyrite, and sphalerite in marine volcanic rocks of intermediate to felsic composition--Such deposits may be in flows, tuffs, pyroclastic rocks, breccias, felsic domes, or associated sediments. (Appendix A, p. 27-28)

Tonnage and Grade Characteristics

The median tonnage is 1.6 million tonnes; the largest tenth of the deposits contain 19 million tonnes or more. Fifty percent of the deposits have average copper grades of 1.3 percent or more, and the richest tenth have at least 3.5 percent copper. Average zinc grades of 2 percent or more are reported in half of the deposits. The richest tenth contain at least 1.9 percent lead. Precious metals are reported in over half the deposits with the richest tenth having at least 2.3 g/t gold; the median silver grade is 11 g/t whereas 10 percent of the deposits contain 98 g/t or more silver. (Appendix B, p. 88-97)

Geologic Environment in Colombia

Marine volcanic rocks of intermediate to felsic composition apparently are not common in Colombia. In the Western Cordillera volcanic rocks of intermediate and locally felsic composition are present. The Macuchi deposit in Ecuador (Stoll, 1962) is a well-explored example nearest to the Western Cordillera of Colombia. Some of the Paleozoic rocks of the Central and Eastern Cordillera are probably marine volcanic rocks of felsic and intermediate composition. The Bailadores deposit in Venezuela (Carlson, 1977) is a Paleozoic example. The shield areas of eastern Colombia are largely unmapped but could contain extensive areas favorable for massive sulfide deposits.

Exploration Guides and Recommendations

Areas near known or possible felsic to intermediate volcanic rocks should be identified with aeromagnetic surveys and geologic mapping. Centers of felsic volcanism should be located by careful mapping and geophysical surveys. Exploration efforts should be targeted in areas near felsic volcanic centers. Any gossans discovered should be analyzed for gold and base metals. Geochemical sampling of rocks and stream sediments may be helpful for finding deposits. Electromagnetic surveying is probably essential in establishing drilling targets in heavily covered areas. For the shield areas, results of the multi-element geochemical surveys conducted for uranium should be plotted to identify possible environments of interest.

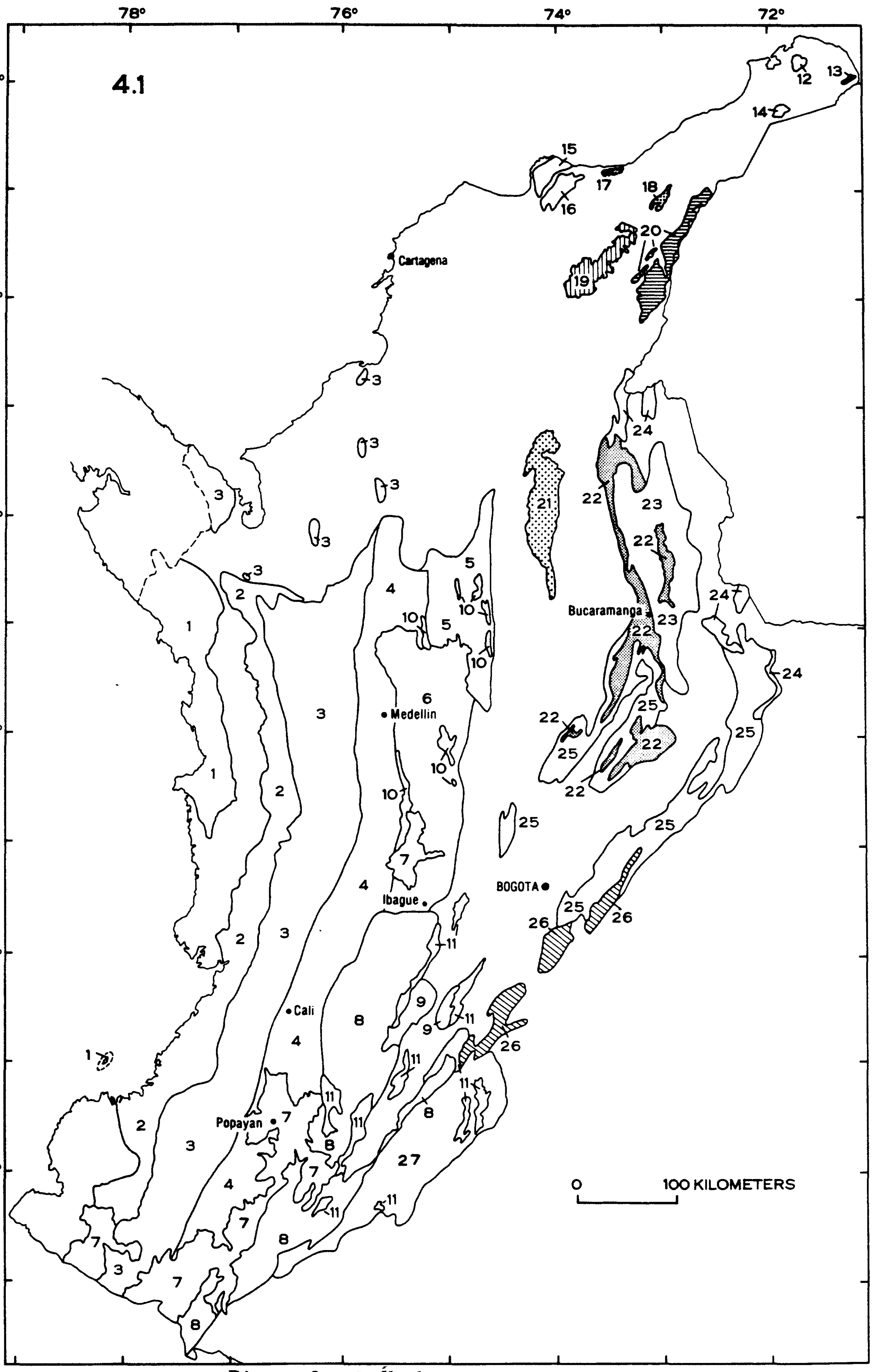


Figure 8.--Redbed-greenbed copper.

4.1 REDBED-GREENBED COPPER — Domains 13, 17, 18, 19, 20, 21, 22, 26

Deposit Description

Stratabound, disseminated Cu sulfides in reduced beds of redbed sequence, containing green or gray shale, siltstone, sandstone, local channel conglomerates, and thin carbonate or evaporite beds. (Appendix A, p. 32)

Tonnage and Grade Characteristics

The median tonnage is 17 million tonnes whereas the largest 10 percent of the deposits contain 400 million tonnes or more. Copper grades range from 2.0 percent or more for the richest half of the deposits to 4.2 percent or more in the richest tenth of the deposits. The richest tenth of the deposits contain 38 g/t or more silver (D. A. Singer and D. L. Mosier, unpublished data).

Geologic Environment in Colombia

Mesozoic redbed sequences with intercalated volcanic rocks, occur in the Cordillera Oriental, at the southeast margin of the Sierra Nevada de Santa Marta, and in the Serrania de Perijá (Maze, 1982), and include the Guatapuri, Los Portales and Giron Formations, each of which contains minor copper deposits. The El Rincon deposit, in undivided Mesozoic red beds, consists only of oxidized copper minerals in quartz veins with high concentrations of accessory silver; sulfide ores possibly, but not necesarily, occur at depth (Tschanz and others, 1970). The most promising sequence of rocks in the Cordillera Oriental is the Triassic-Jurassic Giron Formation, consisting of a deltaic-fluviatile redbed sequence that includes conglomerate, sandstones, siltstones, mudstones, and gray to black shales (Cediel, 1968). Genesis of a redbed-greenbed deposit requires a reducing, low pH environment for precipitation of metal sulfides from hydrothermal saline solutions or basinal brines (Gustafson and Williams, 1981). Direct precipitation from brines can occur in anoxic basins, and some Cu mineralization is known in black shales of the thick Cretaceous section in the Cundinamarca basin (Gil, 1976; Marino, 1976; Fabre and Delaloye, 1983). The redbed sequence as described in the Cordillera Oriental, however, appears to be largely fluvio-deltaic (Cediel, 1968).

Exploration Guides and Recommendations

Reduced or organic-rich sediments in redbed sequences are favorable prospecting environments, particularly in association with evaporites in a rift setting. Uranium is commonly associated and may be a useful geochemical guide, along with elevated concentrations of Mo, V, Pb, Zn, and Ag. Analyses of insoluble residues from associated carbonates (southeast Santa Marta region, for example) could be useful in detecting geochemical anomalies; this technique was successful in exploration of the Viburnum Zn-Pb district of southeast Missouri, U.S.A. (Pratt, 1981). Electromagnetic techniques may indicate sulfide deposit if they have sufficient volume and thickness, but such techniques are warranted only where geochemical anomalies have been defined. Both time-domain electromagnetic (TEM) and frequency-domain electromagnetic (FEM) sounding, as well as audio-magnetotelluric (AMT) and spectral induced polarization (SIP) may be useful (Bruce Smith, personal commun., 1983).

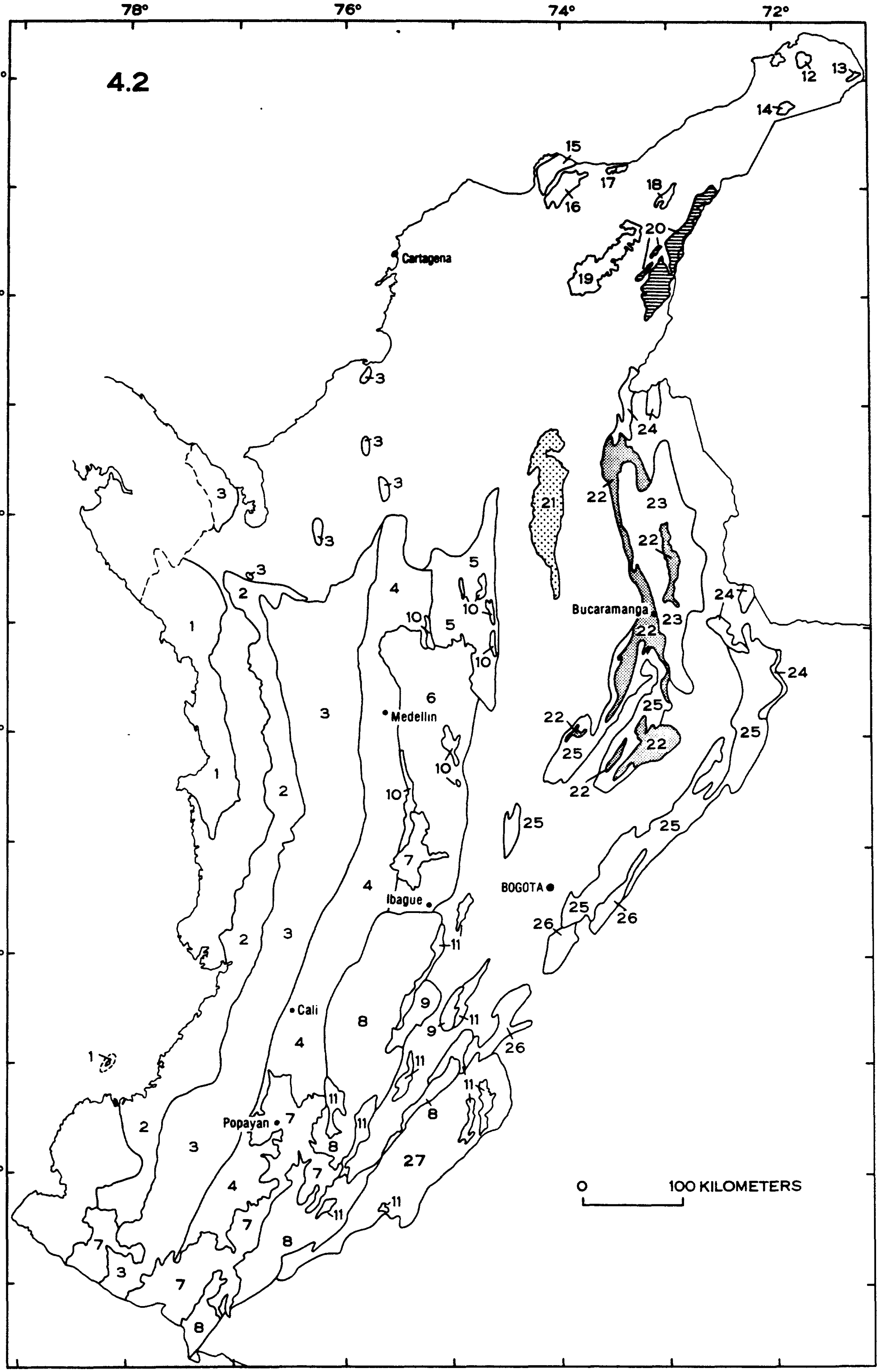


Figure 9.--Volcanic native copper.

4.2 VOLCANIC NATIVE COPPER — Domains 20, 21, 22

Deposit Description

Amygdaloidal and disseminated native copper and copper sulfides in subaerial basalt flows and copper sulfides in overlying sedimentary beds, including breccias, red beds, limestones, and black shales. (Appendix A, p. 33)

Tonnage and Grade Characteristics

Deposits in basalts range from less than 1,000,000 tonnes to 55,000,000 tonnes and from 0.6 to 4.5 percent Cu. Deposits in overlying shales may be very large (White Pine, Michigan: 500,000,000 tonnes at 1.23 percent Cu), and deposits in overlying limestone may be very high grade (Kennecott, Alaska: 4,200,000 tonnes at 12.8 percent Cu).

Geologic Environment in Colombia

The best known occurrences of this deposit type are in the Serrania de Perijá, where basalt flows are interbedded with Mesozoic clastic strata (Champetier de Ribes and others, 1963). Copper deposits described from the La Quinta Formation in adjacent parts of the Perijá region in Venezuela include native copper in mafic flow tops; copper sulfides in sedimentary rocks, copper-iron sulfides in felsic volcanic rocks, copper sulfide and petroleum in sedimentary rocks, and copper iron sulfides at mafic dike-sediment interfaces (Maze, 1982).

Exploration Guides and Recommendations

Presence of a reducing environment in shale and carbonate rocks and permeable, porous host rock, such as basalt flow-top breccias, sandstone, and conglomerate, are important factors in localization of ore; faults and fissures provided conduits for mineralizing solutions (Maze, 1982). Stream sediment sampling and analyses for Ag, Zn, and Co as well as Cu are appropriate. Cu nuggets in float and streams are obvious indicators of amygdaloidal deposits. Electromagnetic techniques applicable to exploration for redbed copper deposits (4.1) may also be effective (Bruce Smith, personal commun., 1983). Volcanic sequences should be identifiable by ground or aeromagnetic anomalies.

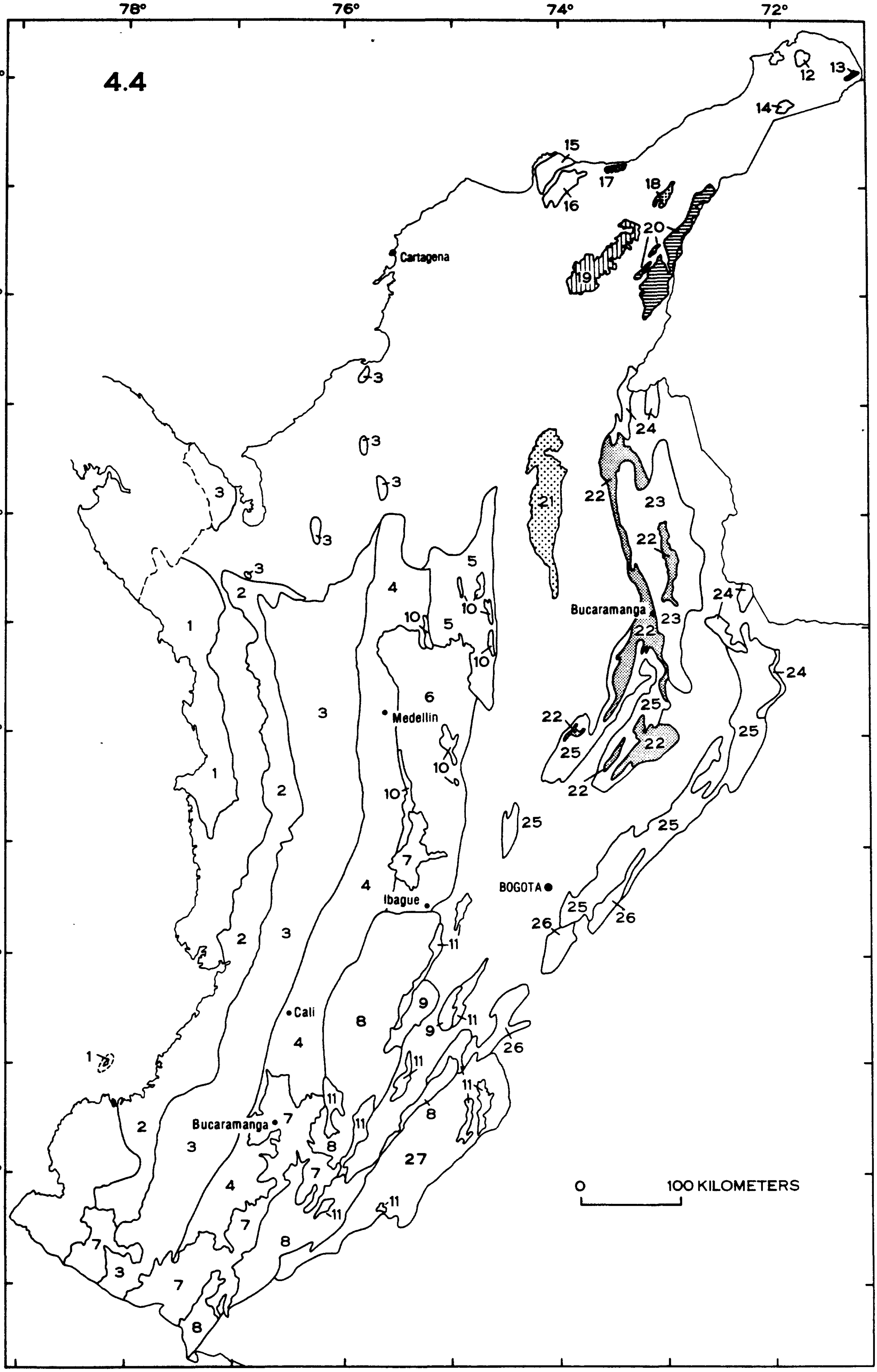


Figure 10.--Sandstone (sedimentary) uranium.

4.4 SANDSTONE (SEDIMENTARY) URANIUM Domains 13, 17, 18, 19, 20, 21, 22

Deposit Description

Uranium oxides localized within reduced environments of medium to coarse-grained clastic beds, commonly tuffaceous. (Appendix A, p. 35-36)

Tonnage and Grade Characteristics

No statistical data compiled.

Geologic Environment in Colombia

Principal uranium source rocks are arkosic or tuffaceous sedimentary rocks most favorably situated above or lateral to the potential host rocks (Nash and others, 1981). In Colombia, extensive red-bed sequences with intercalated volcanic units occur in the domains listed above and comprise the Giron, Guatapuri and La Quinta Formations in the Cordillera Oriental, Santa Marta, and Perijá regions, respectively. Additionally, sedimentary uranium occurs in transgressive lower Cretaceous black shales in the Cordillera Central "Berlin" basin area (Cameron and others, 1980).

Exploration Guides and Recommendations

The most effective and efficient means of exploration for sedimentary uranium deposits is the aerial gamma-ray spectrometry survey, whereby target areas can be identified for follow-up ground surveys. Precambrian terranes in the eastern shield area of Colombia are especially favorable for uranium exploration. The Cordillera Oriental is clearly the most promising of the Andean chains, and effort might well be focused on both east and west flanks where fluvial systems have drained thick Mesozoic and Paleozoic sedimentary sequences, as well as felsic plutonic rocks of the Santander and Floresta Massifs, into deep Tertiary basins. Excellent potential exists for discovery of Colorado Plateau-type channel deposits, localized by organic debris. In bedded clastic deposits, molybdenum is a common indicator mineral in yellow or blue oxides (ilsemannite, $Mo_3O_8 \cdot n\,H_2O$). Uranium occurrences and exploration recommendations are thoroughly reviewed in the IUREP report (Cameron and others, 1980). Geophysical techniques useful in locating uranium deposits elsewhere include induced polarization (IP), spectral induced polarization (SIP), time-domain and frequency-domain electromagnetic profiling (TEM-FEM), and self-potential (SP) (Bruce Smith, personal commun., 1983).

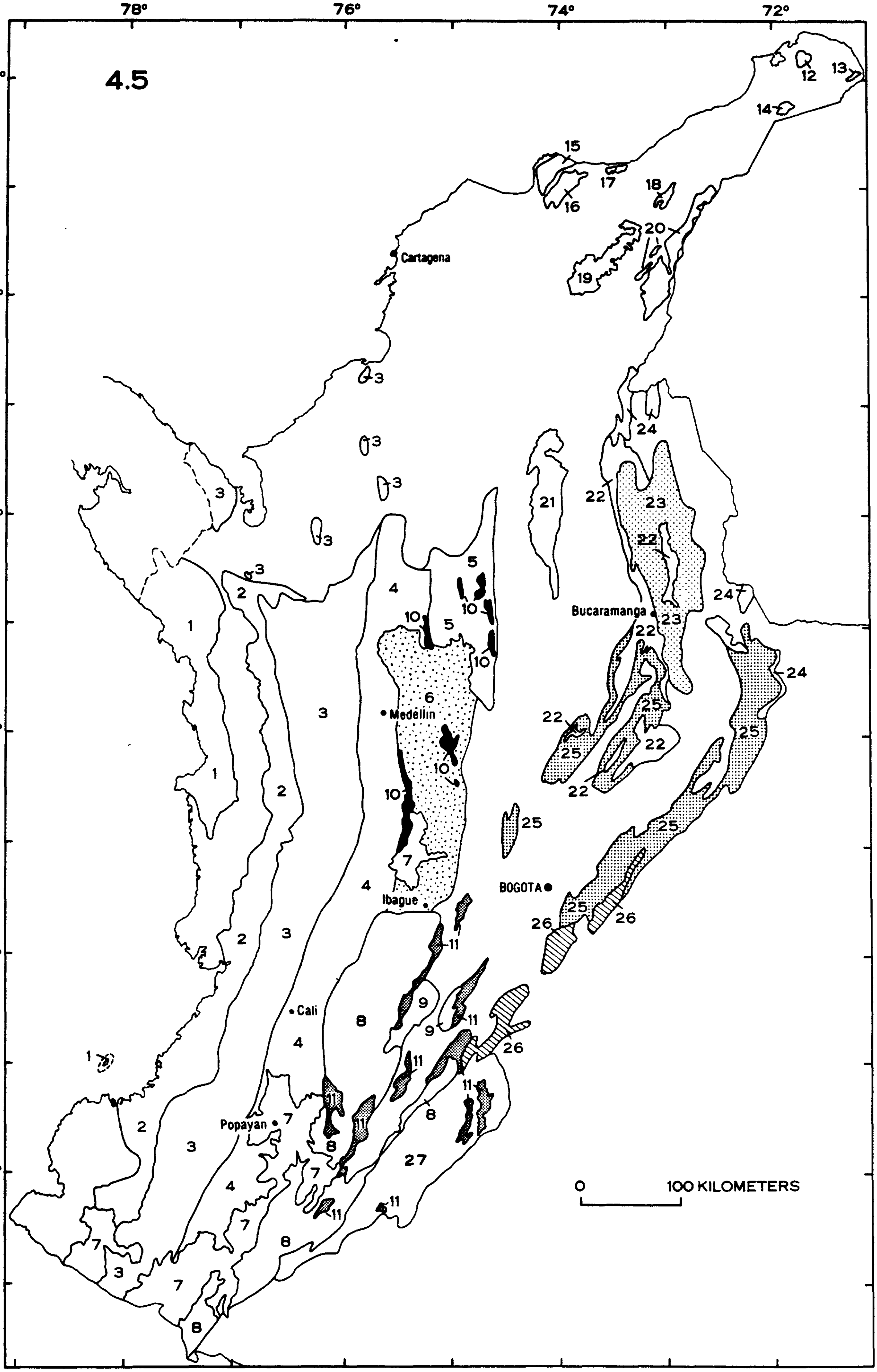


Figure 11.--Sediment-hosted submarine exhalative Zn-Pb.

4.5 SEDIMENT-HOSTED SUBMARINE EXHALATIVE Zn-Pb Domains 6, 10, 11, 23, 25, 26

Deposit Description

Beds of lead and zinc sulfide, commonly fine grained, in black shale, localized in marine basins with restricted circulation and consequent high salinity and euxinic environments--Metals may be introduced along deep tensional faults prior to lithification of sedmiments. (Appendix A, p. 37-38)

Tonnage and Grade Characteristics

Among the world's largest and highest grade base-metal concentrations, these deposits have median tonnages of 11 million tonnes. The largest 10 percent contain 150 million tonnes or more. Median zinc and lead grades are 6.3 and 4.4 percent respectively. Nearly all deposits have a reported silver grade, the median being 59 gms/tonne. (Appendix B, p. 117-121)

Geologic Environment in Colombia

Although all known deposits of this type are found in Proterozoic and early Paleozoic rocks, conditions favorable for their formation in Colombia are best developed in Cretaceous strata of the Cundinamarca basin in the Cordillera Oriental where deposition of black shale and evaporites in a restricted basin in the Lower Cretaceous was accompanied by block faulting and intrusion of basaltic dikes (Etayo-Serna and others, 1976). These conditions may have promoted circulation of fluids depositing numerous small metal-sulfide veins in the basin and may have concentrated large tonnages of sulfide in the reducing environments of black shales and siltstones.

Exploration Guides and Recommendations

Detailed stratigraphic and structural analyses of the Cundinamarca basin will facilitate location of: (1) small scale restricted basins within the major basin, (2) persistent synsedimentary faults marked by slump breccias and localized, intense penecontemporanceous deformation of sediments, and (3) igneous heat sources. Coincidence of these features with galena, sphalerite, or barite occurrences and sulfide-rich layers in the shales would indicate promising areas for detailed mapping, rock sampling, and stream sediment sampling. Analysis of samples for barium, boron, and manganese as well as for lead, zinc, and silver would aid in detecting favorable environments. Various electromagnetic methods could be applied to target areas as follow-up, after initial definition by geochemical criteria. Magnetic surveys may be useful in locating basaltic dikes.

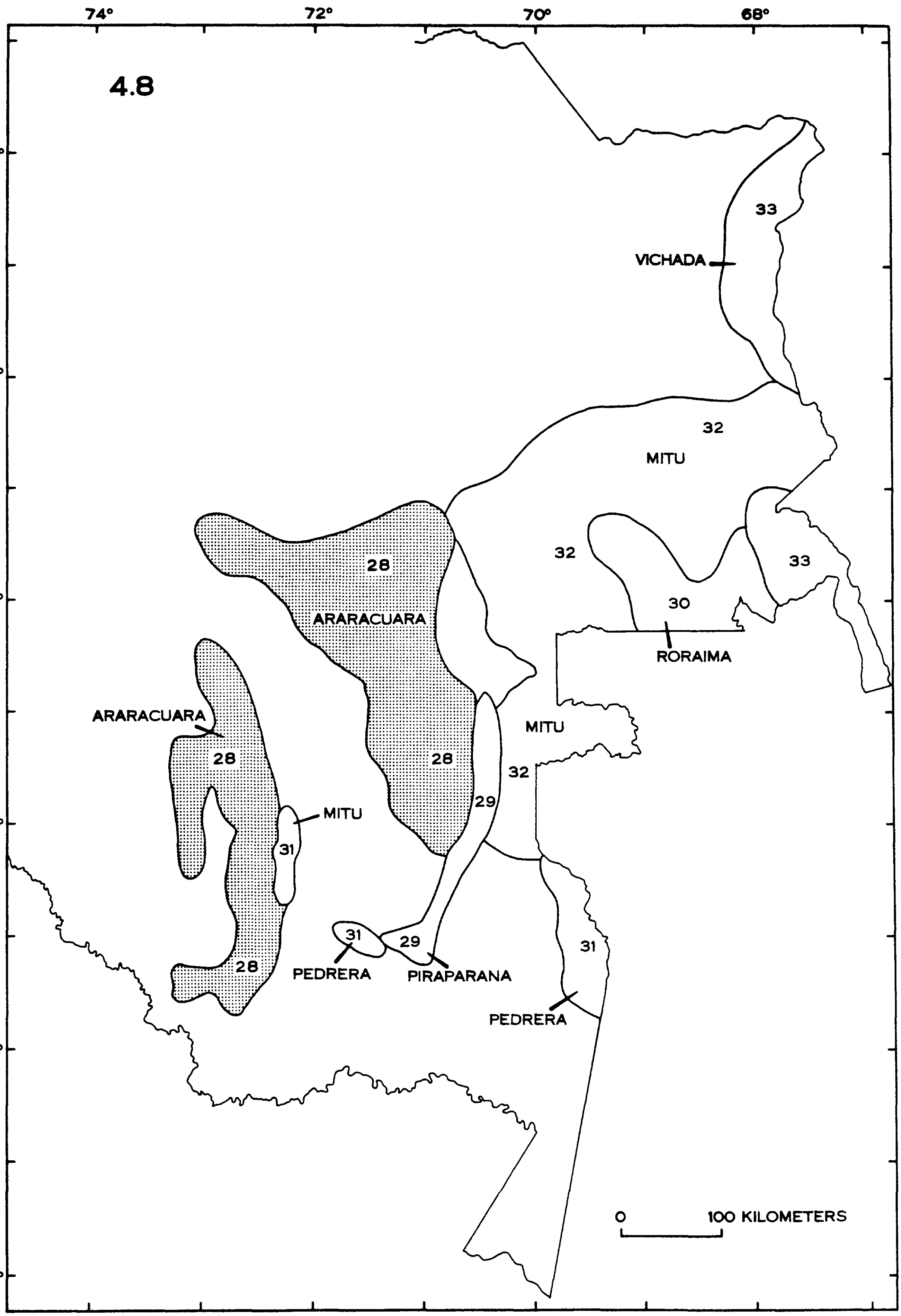


Figure 12.--Sandstone-hosted lead-zinc deposits.

4.8 SANDSTONE-HOSTED LEAD-ZINC DEPOSITS Domain 28

Deposit Description

Stratabound deposits of massive to disseminated galena and other sulfides forming thin, sheetlike ore bodies in sandstone and quartzite. (Appendix A, p. 43-44)

Tonnage and Grade Characteristics

The median tonnage of 21 well-explored sandstone lead deposits is 5.5 million tonnes. The largest 10 percent contain 66 million tonnes or more. The deposits are relatively low grade compared to other lead deposits, their median grade being 2.6 percent Pb. The richest one-tenth contains more than 4.6 percent lead. Seventy percent of known deposits have reported zinc grades and 42 percent have reported silver; the richest tenth contain 46 grams or more Ag per tonne. (Appendix B, p. 122-126)

Geologic Environment in Colombia

Sandstone lead deposits are unknown in the South American continent but conditions permissive for their occurrence are present in the Aracuara domain (28) in eastern Colombia (Galvis and others, 1979). There, flat-lying lower Paleozoic sandstones on crystalline basement rocks may have been aquifers carrying metal-rich fluids filter-pressed from geosynclinal, lower Paleozoic sediments in the fold belt of Silurian age in the present site of the Cordillera Oriental. This situation is similar to that of the Laisvall deposit east of the Caledonian fold belt in Sweden (Rickard and others, 1979).

Exploration Guides and Recommendations

Exploration in the Aracuara should concentrate on the lower hundred meters of the Cambrian quartzites. Recognition of deposits may be difficult because of surface leaching and because lead-zinc oxide minerals are difficult to recognize. Pb, Zn, and Ag analyses of heavy mineral concentrates from stream sediments in the vicinity of paleochannels and basement ridges in the quartzite should be made with special attention given to areas where the quartzite contains traces of organic carbon. Various electromagnetic sounding and profiling techniques as well as induced polarization (IP) and self-potential (SP) methods have been used successfully elsewhere in the world (Bruce Smith, personal commun., 1983).

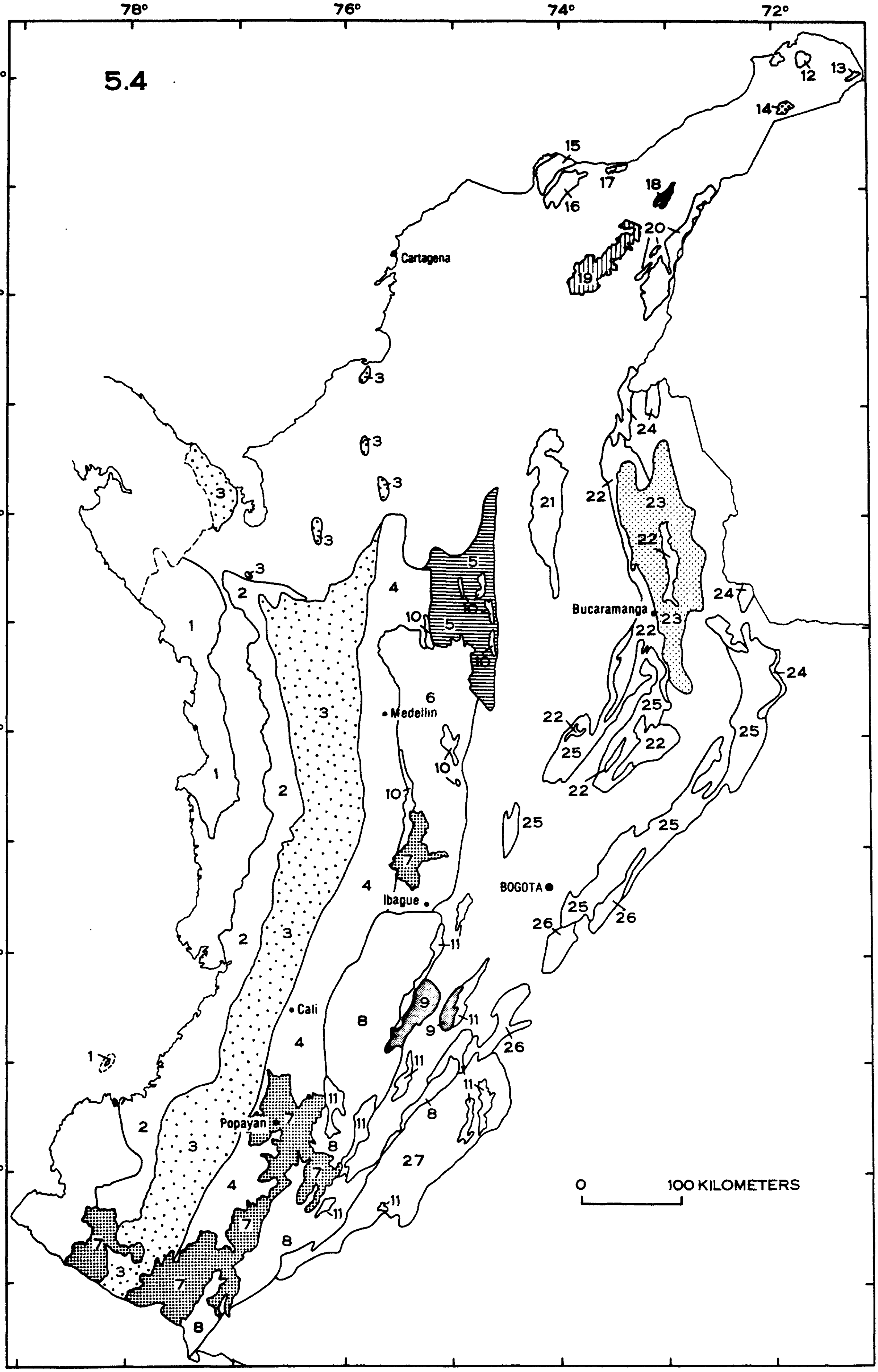


Figure 13.--Epithermal gold, quartz-adularia type.

5.4 EPITHERMAL GOLD, QUARTZ-ADULARIA TYPE Domains 3, 5, 7, 9, 14, 18, 19, 23

Deposit Description

Open-space vein filling and associated stockwork deposits of complex silver sulfides, simple base-metal sulfides, and some native gold with pyrite--Large, open fissures are commonly filled with banded quartz (occasionally amethystine quartz and adularia). Wallrock alteration consists mainly of illite, adularia, chlorite, epidote, and calcite. Deposits occur most commonly within or adjacent to nonmarine volcanic rocks and (or) hypabyssal intrusions. (Appendix A, p. 51-52)

Tonnage and Grade Characteristics

Fifty percent of epithermal gold-quartz-adularia deposits contain 0.7 million tonnes or more; ten percent contain 14 million tonnes or more. Gold grades range from 4.3 g/t or more for the richest half of the deposits to 19 g/t or more in the richest tenth of the deposits. Silver grades vary from 130 g/t, or more, in the richest half, whereas ten percent of the deposits contain 600 g/t or more. Copper grades are low, and reported zinc grades are low for most deposits, but ten percent of the deposits contain 5.1 percent or more zinc. (Appendix B, p. 138-145)

Geologic Environment in Colombia

Epithermal fissure-vein gold-silver deposits are widespread in South America, with the largest deposits occurring in nonmarine intermediate to silicic volcanic rocks. Smaller deposits occur peripheral to and (or) within the upper parts of felsic igneous stocks. Nonmarine volcanic environments favorable for epithermal deposits occur on the Guajira Peninsula, near Manizales, and in the vicinity of Popayan.

Exploration Guides and Recommendations

The Tertiary-Quaternary volcanic fields should be the highest priority exploration areas. Areas of subvolcanic intrusions in conjunction with through-going fracture systems are likely targets. Commonly favorable structures include large normal faults, ring-fracture zones around calderas, and keystone grabens. Altered zones hundreds of meters wide commonly exist around these deposits characterized by chlorite-epidote-pyrite and Fe-rich carbonates. Using wet chemical techniques, altered rocks should be analyzed for gold, silver, arsenic, antimony and zinc; stream sediments should be analyzed for arsenic, antimony, zinc, and mercury. Gold in these types of deposits is usually very fine grained and detectable only by chemical analysis, thus explaining why they were often missed by early prospectors.

Ground and aeromagnetic surveys are of general use in defining locations of intrusive and extrusive rocks. Centers of mineralization may be identified by using magnetic data and various electromagnetic techniques in conjunction with geochemical data (Case and others, 1981). Altered areas may be expressed by flat or negative magnetic anomalies and by spectral induced polarization (IP) anomalies.

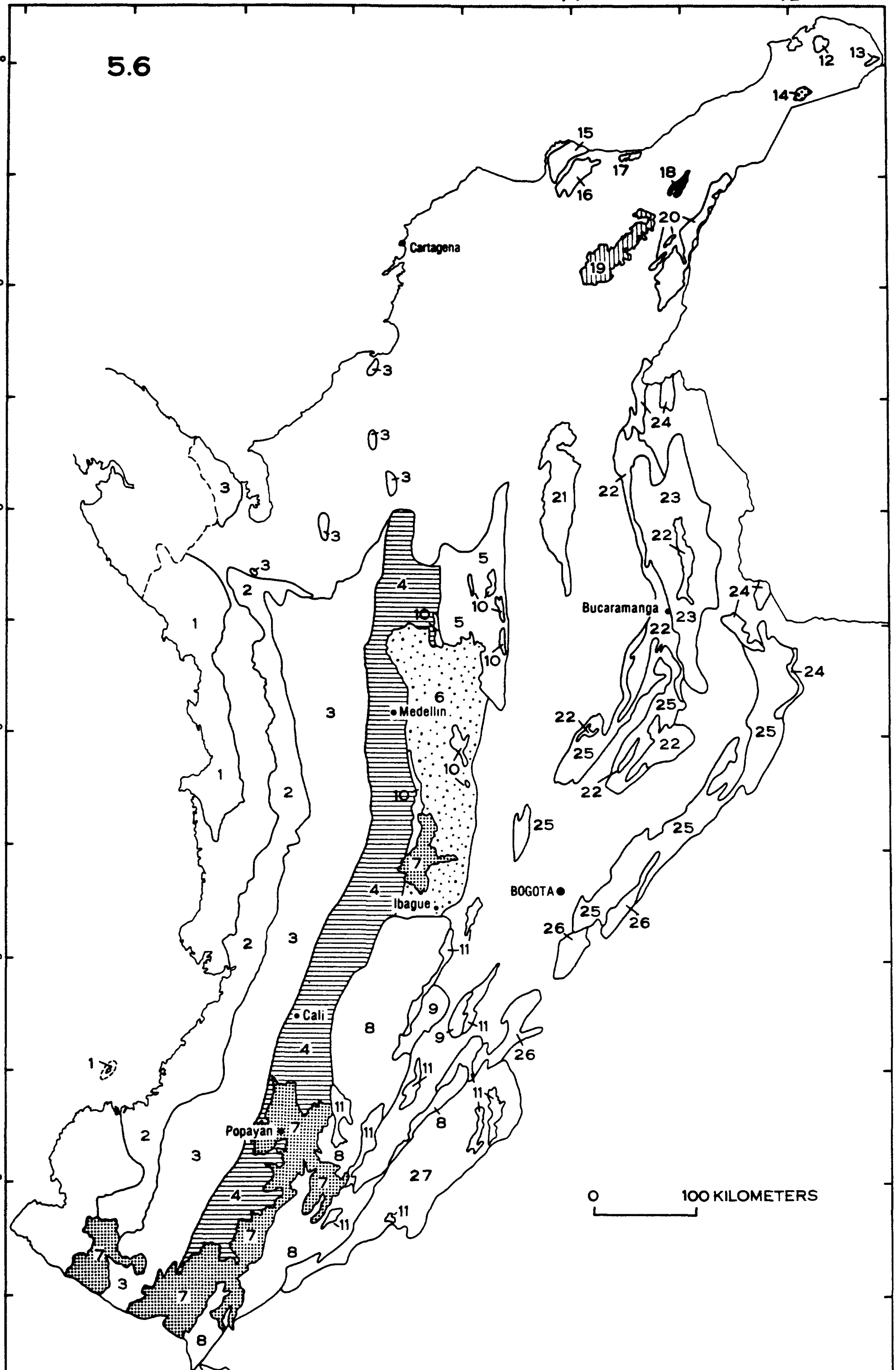


Figure 14.--Hot springs gold-silver deposits.

5.6 HOT SPRINGS GOLD-SILVER DEPOSITS Domains 4, 6, 7, 14, 18, 19

Deposit Description

Vein and disseminated and (or) stockwork deposits of native gold and silver-bearing sulfides with pyrite, generally associated with simple sulfides of antimony, arsenic, and mercury--Ore bodies within and adjacent to fractures and (or) abundant hydrothermal breccias are commonly in nonmarine silicic volcanic rocks, but may occur in any type of host rock. (Appendix A, p. 55-56)

Tonnage and Grade Characteristics

The few well-studied deposits contain more than 10 million tonnes and as much as 200 million tonnes. Gold grades probably range from 2 to 14 g/t. Silver may be present in grades slightly higher than gold grades. (No statistical data compiled.)

Geologic Environment in Colombia

Permissive conditions for this deposit type occur in Colombia in the young volcanic rocks near Popayan and Manizales. Some older deposits may still be preserved in areas of silicic ash-flow volcanism such as in Cretaceous rocks on the Guajira Peninsula and in the Sierra Nevada de Santa Marta. Any areas of known thermal activity related to magmatic heat sources are favorable.

Exploration Guides and Recommendations

Exploration in the Popayan and Manizales volcanic terranes should focus on (1) areas of thermal spring activity producing siliceous sinters; (2) areas of silicification and brecciation; (3) areas of stockwork fracturing with quartz-adularia veinlets; and (4) areas of intrusive and exogenous rhyolite domes. The metallization is commonly subtle due to low total sulfide concentrations. Wet chemistry analyses are recommended as follows: (a) rocks--for gold, silver, arsenic, antimony, and mercury; (b) stream sediments--for arsenic, antimony, and mercury; and (c) heavy mineral concentrates--for gold. New methods using NH_4 as a guide to gold mineralization have been tested in Nevada (Bloomstein, in press) but have not been evaluated in tropical environments. The areas of silicification usually have surrounding argillic alteration but it may be eroded away. The gold is often very fine-grained and detectable only using chemical analysis; thus early prospectors often missed these types of deposits. Shallow electrical methods may be applied but usually are not effective if deposits are disseminated.

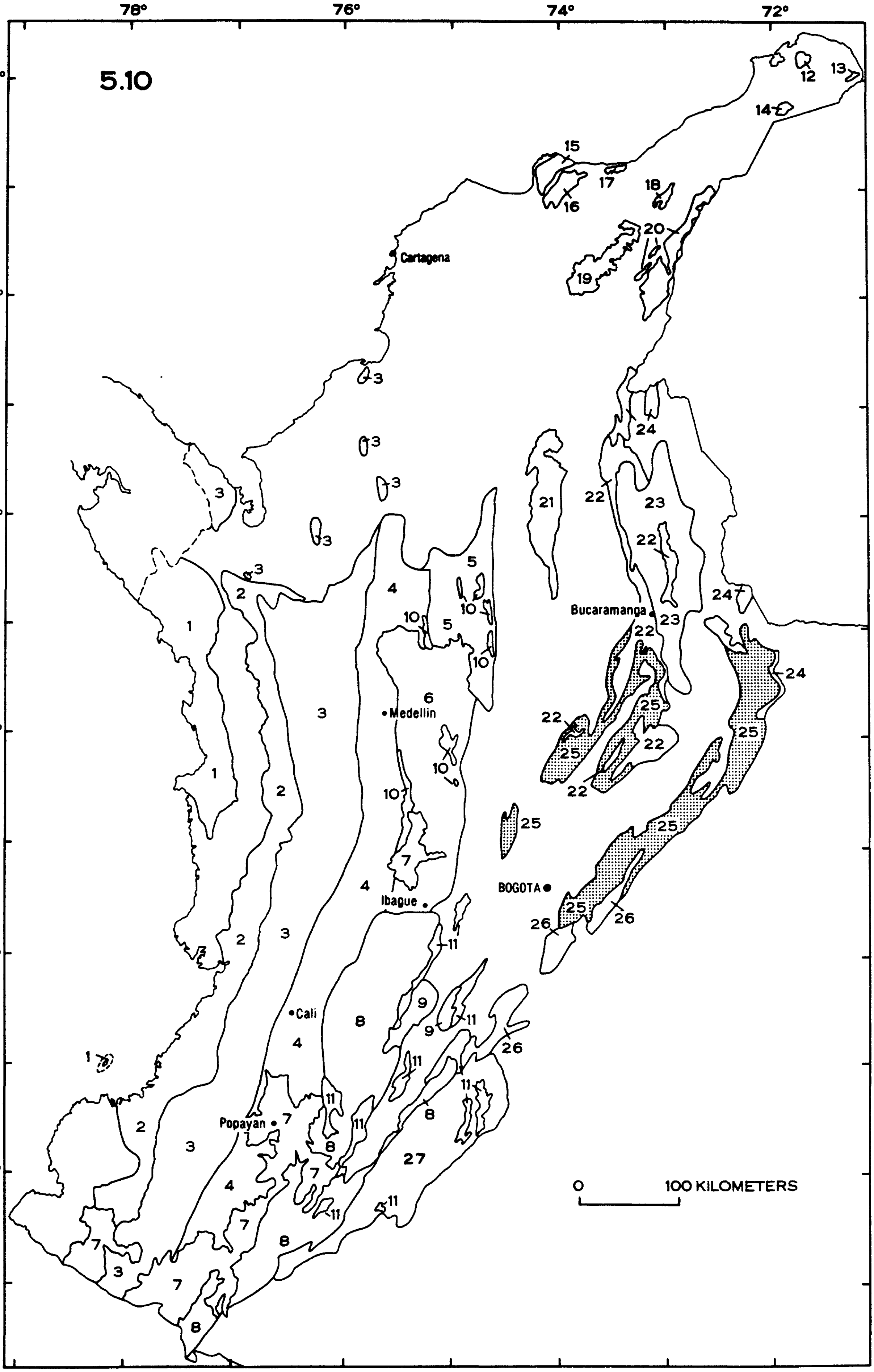


Figure 15.--Emerald veins.

5.10 EMERALD VEINS — Domain 25

Deposit Description

Emeralds in plagioclase-dolomite veins in black shale, associated with faults. (Appendix A, p. 60)

Tonnage and Grade Characteristics

Specific numbers not known but Colombia is the World's major producer of gem quality emeralds. The value per unit weight is among the highest for gems.

Geologic Environment in Colombia

The two main districts in Colombia are located near Muzo and Ubata in lower to middle Cretaceous shales (Angulo, 1978). Emerald-bearing oligoclase-dolomite veins occur in or near faults which cut the Cretaceous shales and limestones. Although their origin is uncertain, several pieces of evidence suggest the veins are related to nearby alkaline dikes that occur in the Muzo district. High salinity fluid inclusions suggest temperatures of 275^{o}-$350^{o}C$ at the time of formation (Escovar, 1979).

Exploration Guides and Recommendations

Assuming that dikes are a necessary source of heat for the formation of the emerald deposits, an aeromagnetic survey over the Cretaceous shales might be an effective way to search for favorable areas. A preliminary ground magnetic survey at a known district should indicate feasibility of using the magnetic technique. Exploration in favorable areas should be near faults, and techniques should include rock geochemistry. Based on earlier geochemical studies, altered areas near mineralized veins have high values of Mo, Ni, Cu, and Na (Escovar, 1979). High sodium concentration may be common near many faults and may not be related to emerald mineralization.

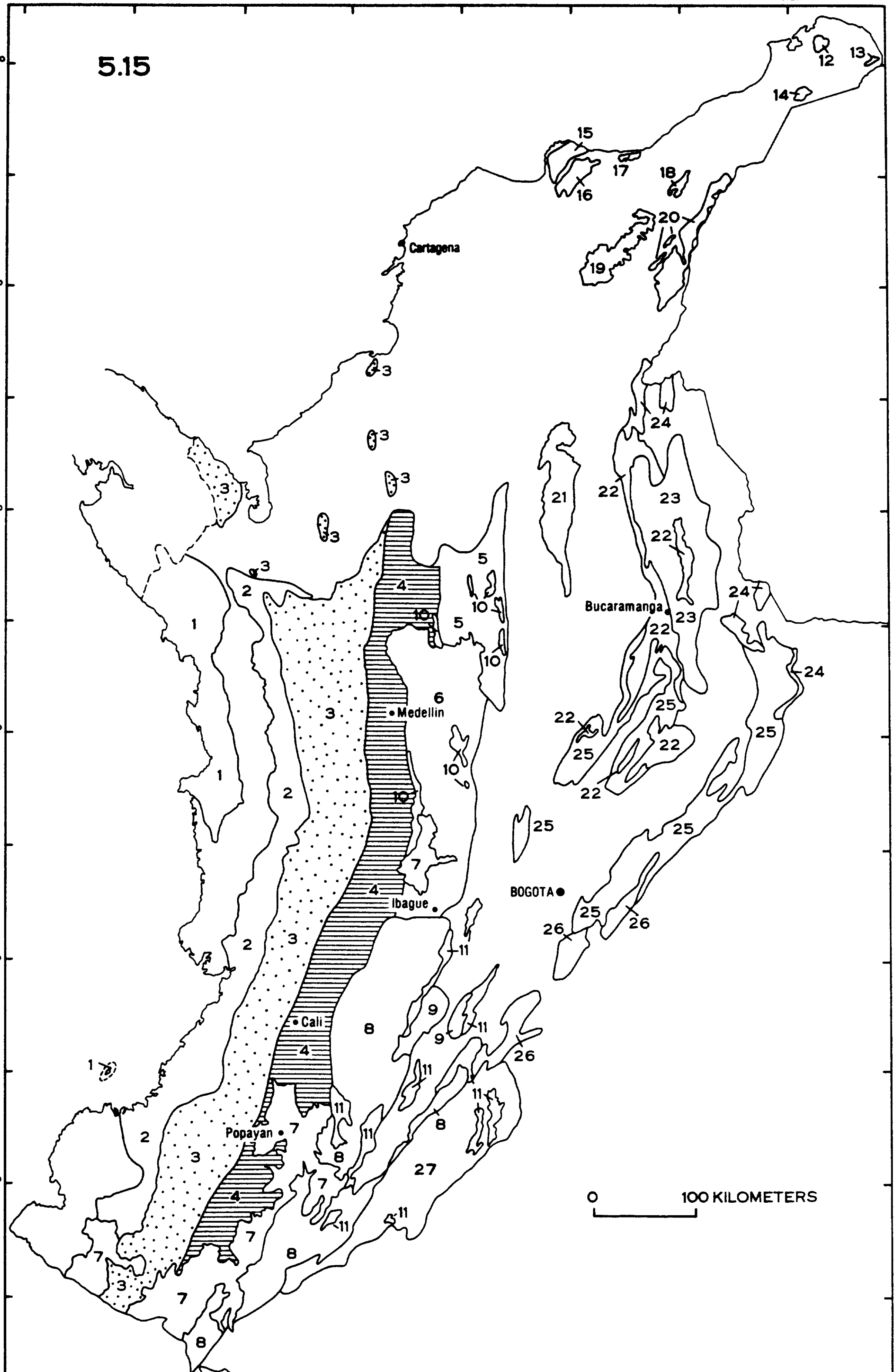


Figure 16.--Volcanic-hosted massive replacement.

5.15 VOLCANIC-HOSTED MASSIVE REPLACEMENT — Domains 3, 4

Deposit Description

Massive to breccia-filling deposits of copper sulfosalts, mainly enargite-luzonite or tetrahedrite, and other sulfides in volcanic rocks showing strong pyrophyllite or alunite alteration--Deposits are characteristically situated above or adjacent to porphyry copper systems (Sillitoe, 1983). (Appendix A, p. 67)

Tonnage and Grade Characteristics

No tonnage data have been analyzed for these deposits. Small deposits are about 2 million tonnes, the largest 27 million tonnes. Copper grades are as high as 2 percent. Zinc may be recoverable. Silver and gold grades are sufficiently high in themselves to make many deposits profitable. Antimony and arsenic may be byproducts.

Geologic Environment in Colombia

No deposits of this type have been discovered in Colombia. They are known in western Canada and the Philippines in geologic environments similar to those of Domains 3 and 4. All porphyry copper prospects in volcanic terranes in Colombia are permissive environments for these deposits.

Exploration Guides and Recommendations

Hydrothermal fluids escaping from porphyry systems may migrate to cooler (epithermal) environments along fracture zones or breccia pipes or along layers of open volcanic breccia or other paleoaquifers in the volcanic pile. Known deposits lie 500 to 1,000 m from a porphyry system (Sillitoe, 1983). Mineral occurrences near porphyry systems should be examined to identify sulfosalts. Alteration zones should be examined to identify alumina-rich alteration minerals, and other indicator minerals such as dumortierite and scorzalite (both a distinct blue color). Geochemical data should be examined to identify anomalous Ag-Sb-As zones near porphyry prospects. Flat magnetic gradients or relative magnetic lows commonly occur over zones where magnetite has been altered to sulfides or to nonmagnetic oxides.

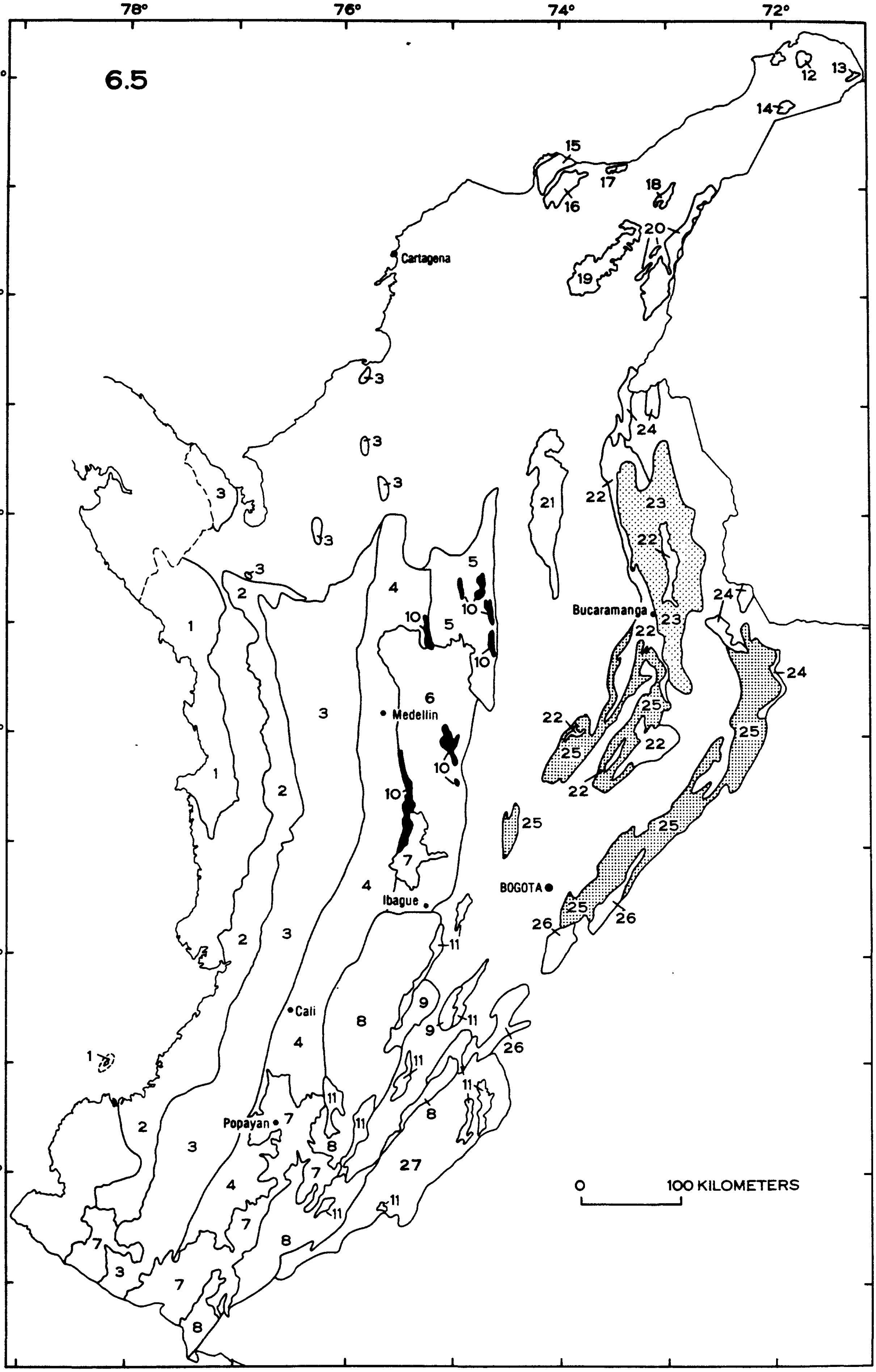


Figure 17.--Sedimentary manganese.

6.5 SEDIMENTARY MANGANESE Domains 10, 23, 25

Deposit Description

Stratiform concentrations of manganese carbonate and oxide minerals in transgressive clastic or carbonate sedimentary rocks in cratonic rocks. (Appendix A, p. 73)

Tonnage and Grade Characteristics

Median tonnage of well-explored deposits is 8.9 million tonnes and the largest 10 percent of the deposits contain 460 million tonnes or more of ore. Median Mn grade is 33 percent. (Appendix B, p. 173-176)

Geologic Environment in Colombia

Cretaceous strata of upper Magdalena Valley and northern Cordillera Central (Domain 10) and Cordillera Oriental (Domains 23 and 25) are permissive environments for sedimentary manganese deposits. Manganese ores are formed where anoxic conditions develop in restricted black shale basins and where marine transgression coincides with periods of world-wide marine anoxic conditions (Cannon and Force, 1983). The latter situation is best developed in the upper Magdalena Valley in rocks of Aptian-Albian age (Etayo-Serna and others, 1976).

Exploration Guides and Recommendations

Sedimentary manganese carbonate ores have few identifying characteristics other than slightly anomalous specific gravity and, locally, stains of black manganese oxides along fractures and weathering surfaces. Pelletal structure may be present. Suspicious looking rocks should be analyzed for Mn by quantitative wet chemical methods rather than by spectrograph because the latter method normally does not differentiate concentrations above 5 weight percent Mn. Manganese ores may occur in close proximity to iron oxide-rich sediments. Research is needed to determine if various electrical or electromagnetic techniques can be applied with reasonable chance of success.

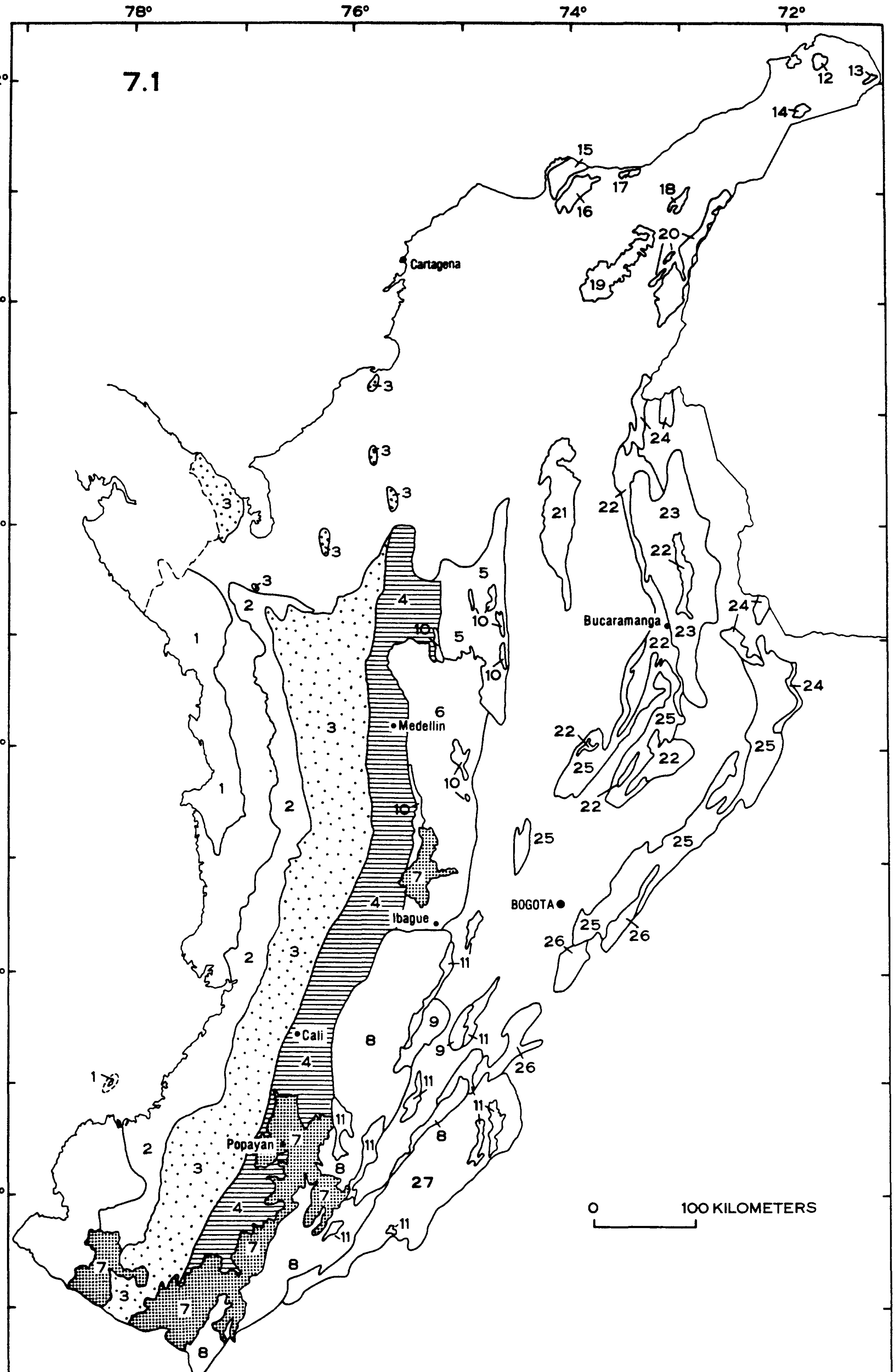


Figure 18a.--Bauxite.

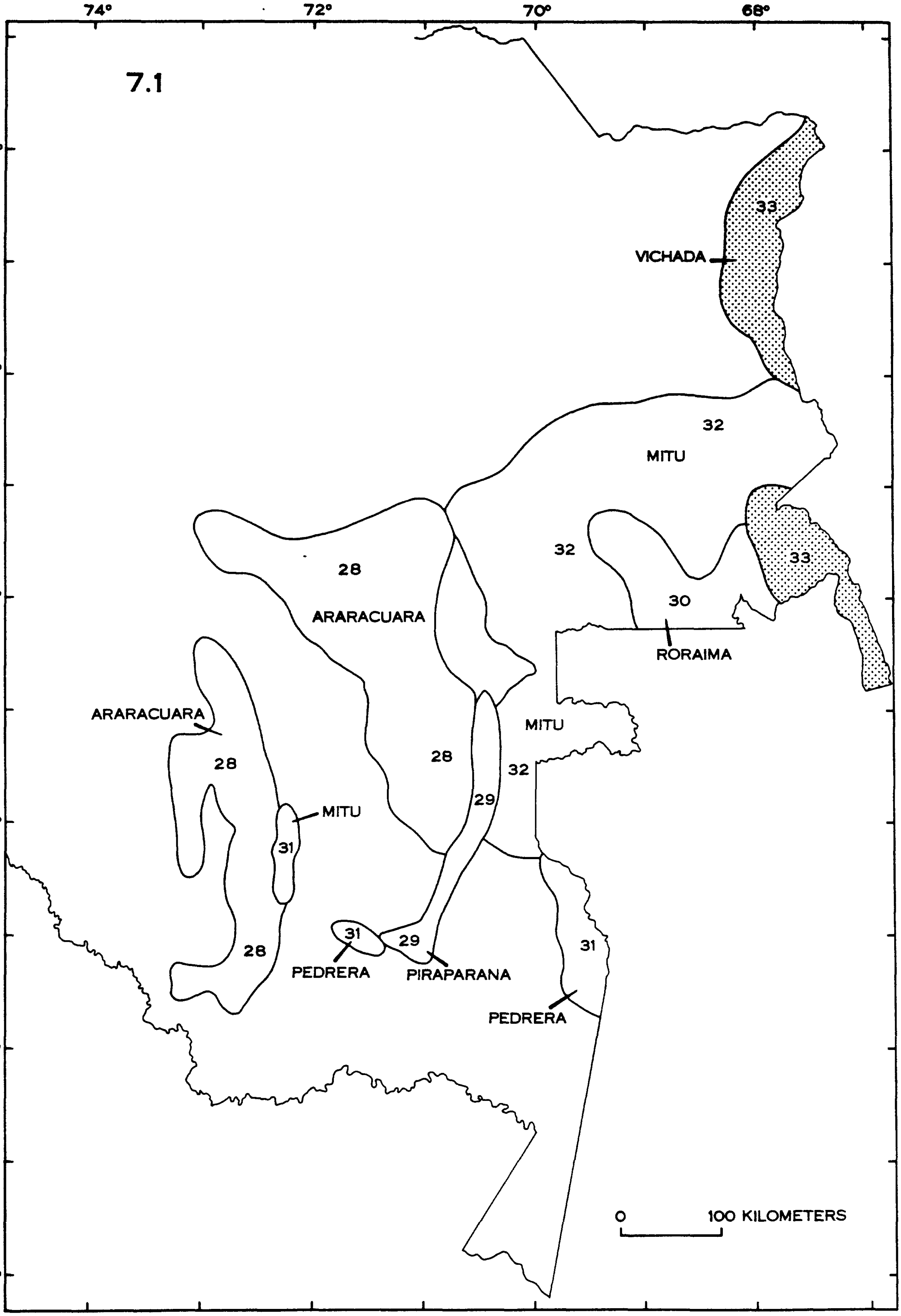


Figure 18b.--Bauxite.

7.1 BAUXITE

Domains 3, 4, 7, 33

Deposit Description

Irregular mantle of extremely weathered aluminous rocks exposed in surface or near surface environments, often covering large areas. (Appendix A, p. 76)

Tonnage and Grade Characteristics

No statistical data compiled.

Geologic Environment in Colombia

Conditions favorable for formation of bauxite are (1) warm tropical climate, (2) abundant rainfall, (3) aluminous parent rocks having high permeability and good subsurface drainage, and (4) long periods of tectonic stability that permit deep weathering and preservation of land surfaces. In Colombia, aluminous laterites are present in water-laid tuff in the uppermost part of the Popayan Formation.

Exploration Guides and Recommendations

Because chemical weathering removes essential plant nutrients, soils developed on bauxite deposits commonly support a cover of dwarfed, undernourished vegetation. Recognition of dwarfed vegetation on old land surfaces has led to discovery of bauxite deposits in Oregon and Hawaii and several very large deposits in other parts of the world. A large deposit fairly close to the Colombian border in western Venezuela is in weathered Precambrian rapakivi granite. Rapakivi granites of Venezuela have moderate to locally strong magnetization, and aeromagnetic data might provide a regional guide for such granites in Colombia. Electromagnetic sounding and profiling and, possibly, spectral induced polarization might be appropriate exploration techniques.

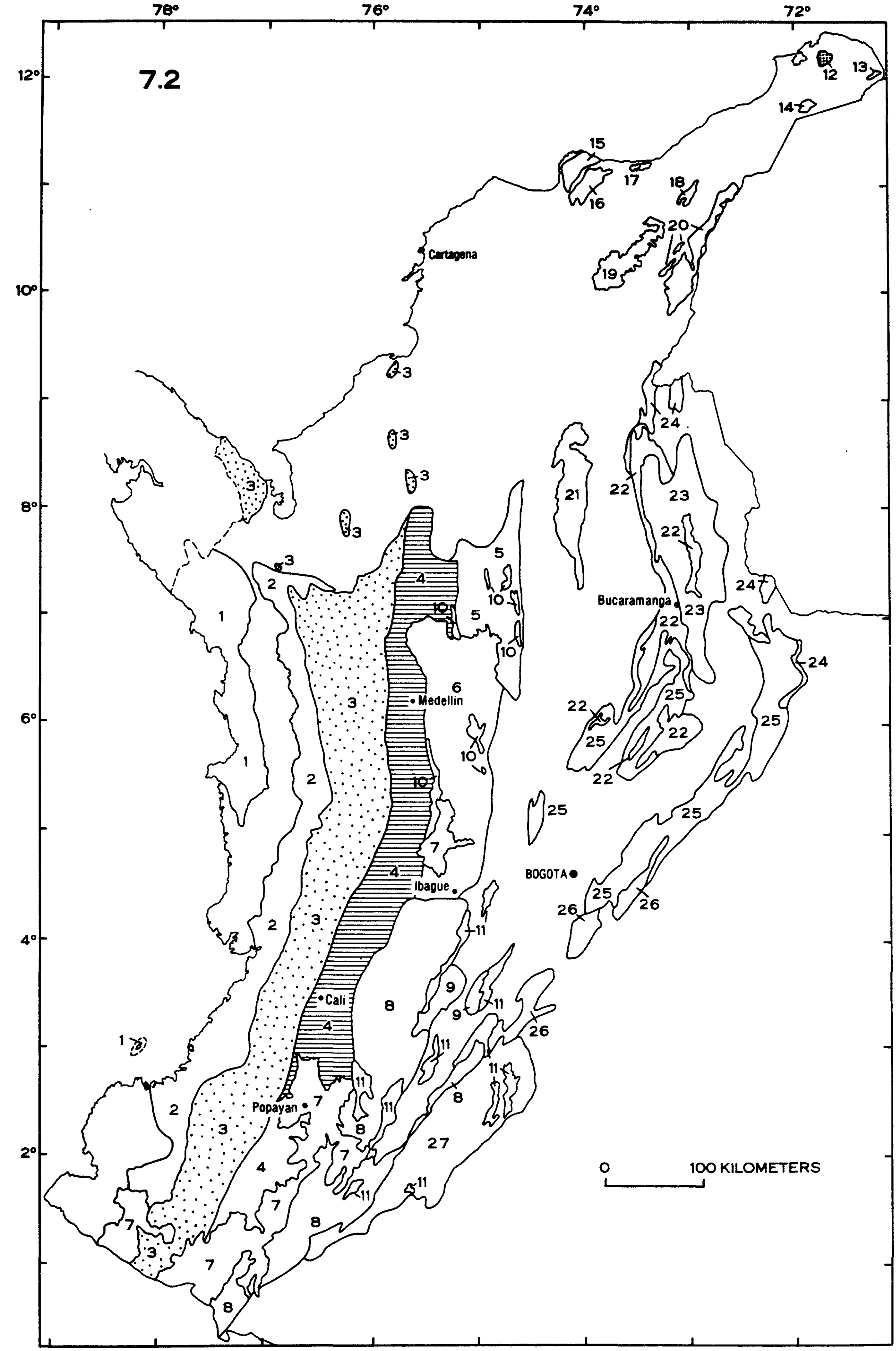


Figure 19.--Nickel laterite.

7.2 NICKEL LATERITE Domains 3, 4, 12

Deposit Description

Irregular mantle of extremely weathered rock overlying peridotite or serpentinite--Laterites may cover large areas and be as much as 30 meters thick. (Appendix A, p. 77)

Tonnage and Grade Characteristics

The median tonnage is 44 million tonnes; the largest tenth contain 250 million tonnes or more. The richest tenth of the deposits contain at least 1.9 percent nickel. Cobalt is usually present in minor amounts. (Appendix B, p. 187-190)

Geologic Environment in Colombia

Laterites typically form in regions of low relief having humid tropical to subtropical climates and abundant rainfall. Long periods of tectonic stability that permit deep weathering and preservation of land surfaces favor formation of these deposits. Weathering of peridotite or serpentinite typically yields laterite containing 45-55 percent Fe and about 1 percent Ni and 0.1 percent Co. In Colombia, ultramafic intrusives that are potential parent bodies occur along the Romeral suture zone, which marks the contact between oceanic and continental crust. Laterite deposits being mined at Cerro Matoso, in the department of Cordoba, contain 2.6 percent Ni, 0.06 percent Co, and 16.2 percent Fe; reserves of 66 million tons average about 1.9 percent Ni (Alvarez, 1983).

Exploration Guides and Recommendations

Nickel laterite develops only as a weathering product of ultramafic rocks, and target areas are, therefore, restricted to areas underlain by such rocks. Sparse, stunted vegetation is typical of areas underlain by ultramafic rocks as well as laterites. All ultramafic rocks should be mapped and explored for overlying laterites. Many laterites are not expressed by magnetic anomalies, but positive gravity anomalies may occur if peridotite has sufficient thickness. Serpentinites commonly are magnetic, but they are of low density and rarely have significant gravity expression. Electrical sounding methods and induced polarization (IP) have been used successfully in exploration.

References

Albers, J. P., 1981, A lithologic-tectonic framework for the metallogenic provinces of California: Economic Geology Bulletin, v. 76, p. 765-790.

_____ 1983, Distribution of mineral deposits in accreted terranes and cratonal rocks of western United States: Canadian Journal of Earth Sciences, v. 20, p. 1019-1029.

Alvarez A., Jairo, 1983, Rocas ultramaficas-maficas en Colombia y depositos minerales asociados: INGEOMINAS, Informe Nro., 67 p.

Angulo C., R., ed., 1978, Recursos Minerales de Colombia: INGEOMINAS, Publicaciones Geologicas Especiales, no. 1, 544 p.

Barrero-Lozano, Dario, 1979, Geology of the central Western Cordillera, west of Buga and Roldanillo, Colombia: INGEOMINAS, Publ. Especial, no. 4, 75 p.

Bloomstein, E. I., 1984, Ammonia alteration is a geochemical link in gold deposits of the Carlin-Midas belt [abs.]: Association of Exploration Geochemists, Symposium: Exploration for ore deposits of the North American Cordillera, March 1984, Reno, Nevada [in press].

Buitrago, C. J., and Buenaventura, J. A. 1975, Ocurrencias minerales en la region central del Departamento del Tolima, Part 3: INGEOMINAS, Informe no. 1672.

Burgl, Hans, 1961, Historia Geológica de Colombia: Revista de la Academia Colombiana de Ciencias Exactas, Fisicas y Naturales, v. 11, no. 43, Bogotá

_____ 1967, The orogenesis in the Andean System of Colombia: Tectonophysics, v. 4, p. 429-443.

_____ 1973, Precambrian to Middle Cretaceous stratigraphy of Colombia: Charles G. Allen (translator and publisher), Bogotá, 214 p.

Cameron, J., Meunier, A. R., and Tauchid, M., 1980, IUREP Orientation phase mission report--Columbia: International Atomic Energy Agency, International Uranium Resources Evaluation Project, 166 p.

Campbell, C. J., 1974, Colombian Andes, in Spencer, A. M., ed., Mesozoic-Cenozoic orogenic belts: Geological Society of London, Special Publication no. 4, p. 705-724.

Cannon, W. F., and Force, E. R., 1983, Potential for high-grade shallow-marine manganese deposits in North America: [in press].

Carlson, G. G., 1977, Geology of the Bailadores, Venezuela, massive sulfide deposit: Economic Geology, v. 72, p. 1131-1140.

Case, J. E., Cox, D. P., Detra, D. E., Detterman, R. L., and Wilson, F. H., 1981, Maps showing aeromagnetic survey and geologic interpretation of the Chignik and Sutwik Island quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-1053-B, scale 1:250,000.

Case, J. E., and Nelson, W. H., Geologic interpretation of aeromagnetic map of the Lake Clark quadrangle, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF- , scale 1:250,000 [in press].

Case, J. E., Tysdal, R. G., Hillhouse, J. W., and Gromme, C. S., 1979, Geologic interpretation of aeromagnetic map of the Seward and Blying Sound quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-880D, scale 1:250,000.

Cediel, Fabio, 1968, El grupo Giron, una molasa Mesozoica de la Cordillera Oriental: Colombia Servicio Geologico Nacional, Boletin Geologico, v. 16, p. 5-96.

Champetier de Ribes, G., Pagnacco, P., Radelli, L., and Weekstein, G., 1963, Geologia y mineralizaciones cupriferas de la Serrania de Perijá entre Becerril y Villaneuva (Guajira, Magdalena): Colombia Servicio Geologico Nacional, Boletin Geologico, v. 11, p. 133-138.
Coney, P. J., Jones, D. L., and Monger, J. W. H., 1980, Cordilleran suspect terranes: Nature, v. 288, p. 329-333.
Cox, D. P., Wright, N. A., and Coakely, G. J., 1981, The nature and use of copper reserve and resource data: U.S. Geological Survey Professional Paper 907F, 20 p.
Davis, W. E., Jackson, W. H., and Richter, D. H., 1957, Gravity prospecting for chromite deposits in Camagüey Province, Cuba: Geophysics, v. 22, no. 4, p. 848-869.
_____ 1960, Application of gravity surveys to chromite exploration in Camagüey Province, Cuba, in Geological Survey Research in 1960: U.S. Geological Survey Professional Paper 400-B, p. B133-B136.
_____ 1980, Exploration for chromite deposits in the Camagüey district, Camagüey Province, Cuba, 1954-1956: U.S. Geological Survey Open-File Report 80-1061, 132 p.
Escovar R., Ricardo, 1979, Geologia y geoquimica de las minas de esmeraldas de Gachala, Cundinamarca: INGEOMINAS, Boletin Geologico, v. 22, no. 3, p. 118-153.
Etayo-Serna, F., Renzoni, G., and Barrero, D., 1976, Contornos sucesivos del mar Cretaceo en Colombia: Primer Congreso Colombiano de Geologia, Separata, p. 217-252.
Fabre, Antoine, and Delaloye, Michel, 1983, Intrusiones básicas cretácicas en las sedimentitas de la parte central de la Cordillera Oriental: Geologia Norandina, Diciembre 1982, no. 6, p. 19-28.
Galvis V., Jaime, Huguett G., Alcides, and Ruge T., Primitivo, 1979, Geologia de la Amazonia Colombiana: INGEOMINAS, Boletin Geologico, v. 22, no. 3, p. 3-86.
Gil R., Efrén Enrique, 1976, Ocurrencias minerales en el Departamento de Cundinamarca: INGEOMINAS, Informe no. 1708, 40 p.
Gustafson, L. B., and Williams, Neil, 1981, Sediment-hosted stratiform deposits of copper, lead and zinc: Economic Geology, 75th Anniversary volume, p. 139-178.
Hammer, Sigmund, Nettleton, L. L., and Hastings, W. K., 1945, Gravimeter prospecting for chromite in Cuba: Geophysics v. 10, no. 1, p. 34-49.
Howarth, R. J., and Martin, L., 1979, Computer-based techniques in the compilation, mapping, and interpretation of exploration geochemical data, in Hood, P. J., ed., Geophysics and geochemistry in the search for metallic ores: Geological Survey of Canada, Economic Geology Report 31, p. 545-574.
Irving, E. M., 1975, Structural evolution of the northernmost Andes, Colombia: U.S. Geological Survey Professional paper 846, 47 p.
Jones, W. R., Case, J. E., and Pratt, W. P., 1964, Aeromagnetic and geologic map of the Silver City Mining region, Grant County, New Mexico: U.S. Geological Survey Geophysical Investigations Map GP-424.
Mariño Mendoza, Jesús, A., 1976, Ocurrencias minerales en el Departamento de Boyaca: INGEOMINAS, Informe no. 1710, 41 p.
Maze, W. B., 1982, Geology and copper mineralization of the Jurassic la Quinta Formation in the Sierra de Perijá, northwestern Venezuela: Transactions, 9th Caribbean Geological Conference, Santo Domingo, 1980, p. 283-294.

Nash, J. T., Granger, H. C., and Adams, S. S., 1981, Geology and concepts of genesis of important types of uranium deposits: Economic Geology, 75th Anniversary volume, p. 63-116.

Peterson, E. U., and Zantop, Half, 1980, The Oxec deposit, Guatemala: an ophiolite copper occurrence: Economic Geology, v. 75, p. 1053-1065.

Pratt, W. P., ed., 1981, Metallic mineral-resource potential of the Rolla 1^{o} x 2^{o} quadrangle, Missouri, as appraised in September 1980: U.S. Geological Survey Open-File Report 81-518, 77 p.

Rickard, D. T., Willden, M. Y., Marinder, N. E., and Donnelly, T. H., 1979, Studies on the genesis of the Laisvall sandstone lead-zinc deposits, Sweden: Economic Geology, v. 74, p. 1255-1285.

Sillitoe, R. H., 1979, Some thoughts on gold-rich porphyry copper deposits: Mineralium Deposita, v. 14, p. 161-174.

_____ 1983, Enargite-bearing massive sulfide deposits, high in porphyry copper systems: Economic Geology, v. 78, p. 348-352.

Sillitoe, R. H., Jaramillo, Luis, Damon, P. E., Shafiqullah, Muhammed, and Esovar, Ricardo, 1982, Setting, characteristics and age of the Andean porphyry copper belt in Colombia: Economic Geology, v. 77, p. 1837-1850.

Stoll, W. C., 1962, Notes on the mineral resources of Ecuador: Ecomonic Geology, v. 57, p. 799-808.

Tschanz, C. M., Jimeno V., Andres, and Cruz B., Jaime, 1970, The mineral resources of the Sierra Nevada de Santa Marta, Colombia (Zone 1): U.S. Geological Survey Open-File Report, 79 p.

Weege, R. J., and Pollack, J. P., 1971, Recent developments in the native copper district of Michigan, in White, W. S., ed., Guidebook for Field Conference, Michigan Copper District: Michigan Technological University Press, Houghton, Michigan, p. 18-43.

Wynn, J. C., and Hasbrouck, W. P., Geophysical studies of chromite deposits in the Josephine Peridotite of northwestern California and southwestern Oregon, U.S. Geological Survey Bulletin 1546-D [in press].

Table 1.--Mineral resource domains, as numbered on accompanying maps (Plates 1 and 2); each characterized by geologic environment permissive for specific mineral deposit types listed. Known occurrences representative of given deposit type are named, and pertinent stratigraphic, lithologic, and structural information is summarized; available geophysical data and miscellaneous comments are included in the final column.

Domain #1.--BAUDO-GORGONA Terranes: Baudo-Gorgona

Deposit type	Known deposits	Rock environments	Comments
Massive sulfide (3.1, 3.2)	None	Marine basalt, andesite and tuff. Chert and argillite of Late Cretaceous and early Tertiary age	Accreted island arc
Volcanogenic Mn (3.5)	None		Serrania de Baudo characterized by large positive gravity anomalies and by high amplitude, short wavelength magnetic anomalies.
Podiform chromite (1.1)	None	Peridotites (not found to date)	Ultramafic intrusive rocks reported in Serrania de Baudo, not documented
Komatiite Ni-Cu (3.4)	None	Ultramafic rocks with komatiitic textures (Gorgona Is).	
Placers--magnetite-ilmenite-chromite, PGE, gold (6.3)	Bahia Solano	Beach sands, alluvial deposits	

Domain #2.--ATRATO-SAN JUAN BASIN Terrane: Atrato-San Juan Basin

Deposit type	Known deposits	Rock environments	Comments
Placer PGE and Au (6.3)	Rio Sucio; East tributaries of Rio Atrato and Rio San Juan	Quaternary alluvium. Source rocks are ophiolite complexes and zoned ultramafic plutons in Cordillera Occidental.	Magnetic anomalies indicate shallow basement near headwater of Rio San Juan

Domain #3.--CORDILLERA OCCIDENTAL Terrane: Dagua-Canas Gordas-Cauca-Romeral

Deposit type	Known deposits	Rock environments	Comments
Massive Sulfide (3.1, 3.2)	El Roble (Choco); Macuchi, (Ecuador)	Pillow basalts, diabase dikes	Cu anomalies; Kennecott field study
Porphyry Cu, Mo (2.1)	Acandi, Pantanos, Piedrancha, Andagueda, Rio Blanco, La Verde, Ramos	Tertiary felsic intrusive rocks including quartz porphyry locally intruding tonalite batholiths	Cordillera Occidental characterized by large positive gravity anomalies. Refraction and gravity data indicate that the foundation of the range is oceanic crust. Incomplete magnetic data indicate presence of plutons of diverse composition.
Porphyry Cu Au (2.2)	Murindo		
Epithermal Au, quartz adularia type (5.4)	Las Equis (Antioquia), Barbacoas, Sotomayor, Guachavez (Narino)	Veins cutting host rocks of Tertiary intrusives, especially near porphyry copper centers	
Epithermal Au, Quartz-alunite type (5.5)	None	Rhyolite near Las Equis	
Volcanic hosted massive replacement (5.15)	None		
Volcanogenic Mn (3.5)	Numerous localities: Buenaventura (Valle), Valleci (Antioquia) Curcuel, Samaniego (Narino)	Chert and other pelagic rocks associated with mafic to intermediate volcanic rocks	
Low sulfide Au quartz veins (5.3)	Frontino; other localitites (Antioquia)	Mafic volcanic and sedimentary rocks intruded by intermediate plutons	
Podiform chromite (1.1)	None	Peridotite; serpentinite	
Nickel laterite (7.2)	Cerro Matoso		
Placer Au, PGE (6.3)	Numerous localitites: Rio San Francisco, Guapi (Cauca) Telembi (Nariño)	Alluvial deposits. Special attention to areas draining zoned ultramafic plutons (1.2)	

Domain #3.--CORDILLERA OCCIDENTAL--(continued) Terrane: Dagua-Canas Gordas-Cauca-Romeral

Deposit type	Known deposits	Rock environments	Comments
Silica-carbonate Hg (5.8)	None		
Disseminated HgS (Type unknown)	Marilopez, Rio Blanco (Cauca)	Cinnabar disseminated in soils over meta-pillow basalts	
Bauxite (7.1)	La Cumbre Bitaco Darian	Lateritized basalt	

Domain #4.--CAUCA-PATIA-ROMERAL Terranes: Cajemarca-Cauca-Romeral

Deposit type	Known deposits	Rock environments	Comments
Cyprus type massive sulfide (3.1)	Paso de Bobo, (Cauca), La Marina, (Valle)	Pillow basalt, diabase, chert, sedimentary rocks	Steep gravity gradients indicate that the Cauca-Patia-Romeral zone serves as boundary between oceanic crust to the west and continental or transitional crust to the east. Copper anomalies
Volcanogenic Mn (3.5)	Numerous occurrences: La Loma, Santa Barbara (Antioquia)		Copper anomalies from upper levels of La Loma
Porphyry Cu (2.1, 2.2)	El Pieno Piedra, Sentada (Cauca), Alumbral (Narino)	Felsic intrusive rocks of Tertiary age	
Epithermal Au Ag (5.5, 5.6)	Marmato, Buenos Aires, Almaguer Districts	Veins and stockworks in various rocks usually in or near Tertiary intrusive stocks. Deposits cluster around Tertiary-Quatenary volcanic fields	Numerous anomalies in Cu, Pb, Ag, Zn
Volcanic hosted massive replacement (5.15)	None		
Silica-carbonate Hg (5.8)	None	Serpentine and siltstone	
Disseminated Hg (5.7)	Aranzazu	Cretaceous clastic rocks near andesitic dikes	Localized along Romeral fault zone
Podiform chromite (1.1)	Santa Elena, numerous small occurrences	Dunite, peridotite, serpentinite	Detailed gravity and magnetic data used in prospecting in Medellin region
Ni laterite (7.2)	None	Peridotite underlying erosional surfaces of low relief	
Porph. Mo (2.4)	La Teta (Cauca)	Dacite porphyry	Mo anomalies, peripheral Cu, Au
Bauxite (7.1)	Morales-Cajibio (Cauca)	Laterites of Popayan Fm.	

Domain #5.--SEGOVIA REGION Terrane: Puqui-Campamento

Deposit type	Known deposits	Rock environments	Comments
Epithermal Au, Ag Quartz adularia (5.4)	Segovia District	Hornblende diorite host rocks (age 160 m.y.), metamorphic wall rocks	Sparse gravity data suggest transitional or continental crust

Domain #6.--CORDILLERA CENTRAL, NORTH Terrane: Cajamarca

Deposit type	Known deposits	Rock environments	Comments
Epithermal Au Ag (5.4, 5.5, 5.6)	Numerous small veins, generally rich in galena and stibnite, locally cinnabar. Guadalupe (Antioquia)	Alteration zones in Cajamarca Schist near dacitic stocks (5-6 m.y). Also in Antioquia batholith and near areas of recent volcanism (QTv) in south end of domain	Numerous anomalies in Cu, Pb, Ag. Veins localized along Palestina fault and other northeast-trending faults.
Sedimentary exhalative Pb-Zn, Cu-Zn (4.5, 4.10)	Small chalcopyrite, pyrrhotite occurrences	Graphitic schist, meta-volcanic rocks.	Sparse gravity data suggest that crust is continental or transitional in this domain

Domain #7.--PASTO AND NORTH TO POPAYAN, EAST OF MANIZALES — Terranes: Dagua-Cauca-Romeral-Cajamarca-Payande

Deposit type	Known deposits	Rock environments	Comments
Hot spring Au, Ag (5.6)	None	TQ volcanics near hot springs, sulfur deposits, siliceous sinter deposits.	Cu, Pb, Ag anomalies in TQV south of Popayan Gravity and refraction data indicate that this domain crosses oceanic crust in the west and continental or transitional crust in the east
Qtz. adularia Au, Ag (5.4)	None		
Qtz. alunite Au, Ag (5.5)	None		
Hot spring Hg (5.9)	None		
Bauxite (7.1)	Morales-Cajibio (Cauca)	Weathered TQ tuffs and lake sediments	

Domain #8.--CORDILLERA CENTRAL-SOUTH — Terrane: Cajamarca-Payande

Deposit type	Known deposits	Rock environments	Comments
Porphyry Cu Mo (2.1)	Dolores, Andes, Infierno Chili, Mocoa	Mainly Ibague batholith and younger stocks intruding batholith, Payande limestone, and other sediments (mineralization age 131 m.y.)	Widespread Cu Pb Ag anomalies.
Porphyry Mo, Low F (2.4)	Santo Domingo	Also alkalic plutons 160 m.y. near Dolores	Scant paleomagnetic deta suggest that post-Payande rocks formed 10 degrees south of present latitude. Scant gravity data suggest that crust is continental or transitional
Skarn Cu (2.6)	Mine Viejs Los Guayabas (Tolima) Granates (Huila)	Also Algeciras batholith and smaller plutons to south at contact with carbonate rocks of Triassic age.	
Skarn Fe (2.5)	Numerous localities		
Skarn Zn (2.7)	El Sapo, Mocoa Suspiro Las Palmitas (Huila) None		
Carbonate-hosted Au (5.2)	None		
Placer Au (6.3)	Rio Saldana	Recent fluvial deposits	

Domain #9.--UPPER MAGDALENA VALLEY — Terrane: Payande

Deposit type	Known deposits	Rock environments	Comments
Barite-celestite veins low in sulfides	Coyaime (Tolima) Tesalia (Huila)	Andesitic volanic rocks and small intrusives. Post Payande Triassic-Jurassic age.	Scant gravity data suggest that crust is continental
Porphyry Cu Mo (2.1)	None	Small veins of Cp+Py cutting volcanics	
Epithermal Au, quartz adularia type (5.4)	Natagaima		
Replacement Pb, Zn, Ag (5.1)	None	Payande limestone underlving Trissaic-Jurassic volcanic deposits intruded by small stocks	
Carbonate-hosted Au (5.2)	None		

Domain #10.--CORDILLERA CENTRAL, EAST FLANK — Terrane: Payande

Deposit type	Known deposits	Rock environments	Comments
Sedimentary Mn (6.5)	None	Restrictd anoxic basin; black shales of Hauterivian-Barremian (Early Cretaceous) age with intercalated tuffs and andesite flows of intermediate composition	
Submarine exhalative Pb Zn (4.5)	None		
Sedimentary or black shale-hosted U	Berlin Basin		

Domain #11.--UPPER MAGDALENA VALLEY — Terrane: Payande

Deposit type	Known deposits	Rock environments	Comments
Sedimentary hematite, limonite	Mal Nombre, Ortega, (Tolima); Palermo (Huila)	Cretaceous strata; transgressive shale and sandstone of anoxic oceanic period. Principally Aptian-Albian stages	
Sedimentary Mn (6.5)	None		
Sedimentery exhalative Pb Zn (4.5)	None	Hauterivian-Barremian black shale deposited in restricted epicontinental basins	
Sedimentary or black shale-hosted U	Ataco, Coyaima (Tolima)		

Domain #12.--GUAJIRA 1, NORTH — Terrane: Alta Guajira

Deposit type	Known deposits	Rock environments	Comments
Ni Laterite (7.2)	None	Upper Cretaceous-Etpana Fm.	Oceanic crust intuded by Tertiary quartz-diorite pluton
Podiform Cr (1.1)	Parashi; blocks of chromitite 1 m in diam.	Deep marine lithologies-serpentinites, talc, chlorite, and biotite schists, qtzite, meta gabbro intrusions, spilitic lavas	Large positive gravity anomalies
Cyprus-type massive sulfide (3.1)	None		
Cu, Mo porphyry (2.1)	None	Tertiary qtz. diorite Parashi pluton	Intrudes Upper K metasediments of accreted oceanic crust
Epithermal Au (5.4, 5.5)	None		

Domain #13.--GUAJIRA 2, EAST — Terrane: Alta Guajira

Deposit type	Known deposits	Rock environments	Comments
Red bed-green bed Cu (4.1)	None	Triassic-Jurassic sediments-La Quinta and Rancho Grande Fms. Thick beds of medium to coarse-grained sandstone, red-green-gray shales, conglomerate, red clastic rocks	Zero or negative gravity anomalies suggest continental transitional crust
Sandstone U (4.4)	None		

Domain #14.--GUAJIRA, SOUTH — Terrane: Cosinas

Deposit type	Known deposits	Rock environments	Comments
Epithermal Au (5.4, 5.5, 5.6)	None	Lower K-Ipapure Fm. Felsic volcanic rocks intruded by rhyolite dikes	Paleomagnetic data suggest large rotations

Domain #15.--SANTA MARTA-NW — Terrane: Sierra Nevada de Santa Marta

Deposit type	Known deposits	Rock environments	Comments
Sn-W Skarn (2.8, 2.9)	None	Mz--Santa Marta Group Micaceous schists, amphibolites, and marbles intruded by Tertiary intermediate plutons; possible mineralization in carbonate contact zones	Oceanic crust (?) intruded by felsic plutons

Domain #16.—SANTA MARTA-CENTRAL | Terrane: Sierra Nevada de Santa Marta

Deposit type	Known deposits	Rock environments	Comments
Plutonic anorthosite Ti, Fe	Float of layered magnetite at several localities—no certain outcrops; also veins of ilmenite, ilmenite-apatite	Precambrian anorthosite gneisses, cut by mafic dikes and veins of ilmenite and ilmenite-apatite, locally with pyroxenite layers, within Precambrian metamorphic rocks; also ultramafic intrusions	Very large positive gravity anomaly indicates shallow mantle beneath Sierra Nevada de Santa Marta terrane
Stratiform mafic complex Fe, Ti, V (1.6)			
Stratiform mafic complex Cr (1.4)	None		
Strataform mafic complex PGE (1.5)			
Strataform mafic complex Cu, Ni (1.3)	None		

Domain #17.—SANTA MARTA-NE | Terrane: Santa Marta-NE

Deposit type	Known deposits	Rock environments	Comments
Red-bed green-bed Cu (4.1)	None	Triassic red-beds and volcanogenic siltstones, breccias, and spilitic volcanic rocks	
Sandstone U (4.4)	None		

Domain #18.—SANTA MARTA-SE | Terrane: Santa Marta SE

Deposit type	Known deposits	Rock environments	Comments
Epithermal Au (5.4, 5.5, 5.6)	None	K-Golero Fm; rhyolitic ignimbrite breccias J-Los Clavos Fm; rhyodacitic and dacitic ignimbrite breccias	
Red-bed green-bed Cu (4.1)	None		
Sandstone U (4.4)	None	Triassic-Guatapuri Fm. Siltstone, red beds, breccias, and volcanic rocks.	Japanese aerial radiometric survey, 1979-80.

Domain #19.—SANTA MARTA-SOUTH | Terrane: Santa Marta-South

Deposit type	Known deposits	Rock environments	Comments
Cu Mo porphyry (2.1)	Few grains of molybdenite in granite intrusive	K—granite porphyry intrusive(s) assoc. with rhyolitic ignimbrites	Uplifted craton block
Mo porphyry-Climax (2.3)	None		Granite analysis showed 600 ppm Mo in one sample
Epithermal Au (5.4, 5.5, 5.6)	None		
Red-bed green-bed Cu (4.1)	Minor veins and dissem. Cu oxides	Mz—includes Guatapuri Fm. Red beds and intercalated volcanic rocks; ss, sh, conglom., spilites, and keratophyres	
Sandstone U (4.4)	None		No radiometric data

Domain #20.—PERIJA | Terrane: Perija

Deposit type	Known deposits	Rock environments	Comments
Red-bed green-bed Cu (4.1)	El Rincon veins; numerous occurrences of Cu oxides in lenses, veinlets, disseminated grains	Mz-red beds and, volcaniclastics, mainly Jurassic; locally includes Guatapuri, Los Portales, Rio Negro, La Quinta Fms.	Craton. Gravity data indicate continental crust
Sandstone U (4.4)	None		
Volcanic native Cu (4.2)	El Rincon, Seno, Zepalin	Mafic flow tops and shear zones that intersect mafic flows; native Cu also in red bed sandstones	

Domain #21.—SAN LUCAS Terrane: San Lucas

Deposit type	Known deposits	Rock environments	Comments
Red-bed green-bed Cu (4.1)	None	Mz—Complex sequence of volcanic rocks, volcaniclastic deposits, tuffs, minor intrusives	
Volcanic Native Cu (4.2)	None		Scant gravity data indicate transitional to continental crust
Sandstone U (4.4)	None		Aerial radiometric anomalies
Carbonate-hosted Au (5.2)	Minor Au occurrences of unknown type	White and black carbonaceous limestones of Cretaceous age in eastern foothills. Minor intrusive rocks	

Domain #22.—CORDILLERA ORIENTAL NORTH Terrane: Cordillera Oriental-Santander

Deposit type	Known deposits	Rock environments	Comments
Red-bed green-bed Cu (4.1)	San Calixto—Red SS Hacari—Red SS La Playa—Red SS El Tuto—Grey SS Cascajales—Grey SS	Jurassic-Triassic Giron Fm.; deltaic-fluviatile red bed sequence; congloms., ss, siltstones, mudstones; some gray-black sh.	Uplifted cratonic block. General negative gravity anomalies
Volcanic native Cu (4.2)	Minor occurrences associated with andesite-dacite dikes and flows	Some andesite-dacite dikes cut red beds near north end of domain	Synsedimentary movement on Bucaramanga Fault.
Sandstone U (4.4)	Zapatoca, Contratacion		Numerous aerial radiometric anomalies. U anomalies in stream sediments
Qtz.-pebble Conglomerate Au (6.1)	None	Basal Tambor Fm.	

Domain #23.—SANTANDER MASSIF Terrane: Santander

Deposit type	Known deposits	Rock environments	Comments
Epithermal Au qtz. adularia (5.4)	California-Vetas Districts	Precambrian Bucaramanga gneisses, schists, migmatites, amphibolites, mineralization post-lower K.	Cratonic block sparse gravity data indicate continental crust. High Cu, Pb, Zn, Ag, Mo, Mn
Porphyry Cu Mo (2.1)	Au, dissem. Cu, minor Mo, U veins	Mz intrusives—felsic to intermed. (dacite porphyry)	
Porphyry Mo-Climax type (2.3)			Minor W, Sn
Vein U (pitchblende) Au-qtz			
Sn-W veins (5.11)	Placer cassiterite-Rio Algodonal, Abrego Reported in qtz. veins		
Sedimentary Mn (6.5)	None	Lower K—ss, blk. sh., ls, glauconite-transgressive sequence	
Carbonate-hosted Pb Zn (4.6)	None	Lower K-ls, mainly in Boyaca Dept.	
Sed. exhal Pb Zn (4.5)	None	Lower K-blk. sh.	
Bedded Barite (4.9)	None		

Domain #24.—MERIDA ANDES EXTENSION Terrane: Santander

Deposit type	Known deposits	Rock environments	Comments
Massive Sulfide (3.2)	Bailadores in Venezuelan Andes	Carboniferous—Mixed marine; felsic to intermediate volcanic and sedimentary deposits Silgara Fm.—Low grade metamorphics	Scant gravity data indicate continental crust

Domain #25.—CUNDINAMARCA BASIN (AND ADJACENT CRETACEOUS DEPOSITS) Terrane: Cordillera Oriental

Deposit type	Known deposits	Rock environments	Comments
Emerald veins (5.10)	Gachala, Chivor, Muzo	Plagioclase-dolomite veins in lower K black sh; assoc. with NaCl. Diabase dikes near Muzo, gabbro stock 100 km NE of Gachala	Sedimentary basin; veins in cross-cutting faults; alteration marginal to veins shows high Mo, Ni, Cu, Na
Sediment-hosted submarine exhalative Pb-Zn (4.5)	El Rincon; small occurrences of sp, py, ga, siderite in veins	Lower K- sequence of basin sediments- conglom., ss, siltstone, ls, black-grey sh; mineralization largely in ls, sh	Large negative gravity anomalies indicate continental crust
Bedded barite (4.9)	None		
Sedimentary Mn (6.5)	Few occurrences	Lower K-transgressive sediments	

Domain #26.—QUETAME Terrane: Quetame

Deposit type	Known deposits	Rock environments	Comments
Red-bed green-bed Cu with Au, U (4.1)	Cano Negro	Devonian—Carboniferous Farallones Group—shallow marine to continental blk. mudstones, qtzites, ls, green & red lutites, and arenites	Scant gravity data suggest continental crust U-Cu-Ag anomalies
Dolomitic Cu-Co (4.3)	Cerro de Cobre	Devonian ls	
Sediment-hosted submarine exhalative Pb-Zn (4.5)	None	Devonian-Carboniferous-Permian ss, ls, sh; Gachala Fm.	
Au veins	Placers	Intrusive qtz. diorite	
Qtz.-pebble Conglom. Au (paleo placers) (6.1)	None	Devonian basal conglom. overlying early Paleozoic intrusives	

Domain #27.—GARZON Terrane: Macizo de Garzon

Deposit type	Known deposits	Rock environments	Comments
Sn-W veins (5.11) Sn placers	Sn occurrence near Florencia	Mesozoic and Precambrian granitoid plutons intruding Precambrian granulites gneisses, and migmatites	

Domain #28.—ARARACUARA Terrane:

Deposit type	Known deposits	Rock environments	Comments
Sandstone-hosted Pb-Zn (4.8)	None	Ordovician sandstone—very clean	Diabase dikes reportedly intruding situ-migmatite complex and Ordovician sandstone, based on interpretation of limited aeromagnetic data; apparent rift setting
Amethyst veins	None		
Rare earths	None	Nepheline Syenites	Relative positive gravity anomalies of 20-40 mgals occur over syenite bodies
Carbonatites	None		

Domain #29.—PIRAPARANA Terrane: Caquata Amazonas

Deposit type	Known deposits	Rock environments	Comments
Sn-W veins (5.11)	None	Granophyre	Granophyres here are same age (920 m.y.) as tin deposits elsewhere in Brazilian shield. Diabase dikes intruding La Pedrera Fm.; aeromagnetic and ground reconnaissance data

Domain #30.—RORAIMA Terrane: Meta-Vichada

Deposit type	Known deposits	Rock environments	Comments
Diamond Placers (6.2)	Rio Caroni (Venezuela)	Source beds—Conglomerates in Roraima Fm.	
Amethyst veins	Raudal Alto Cano Nabuquen	Roraima Fm.—quartz sandstone.	
Qtz. pebble conglomerate Au (paleoplacers) (6.1)	None	Conglomerates and sandstones	

Deposit type	Known deposits	Rock environments	Comments
Domain #31.—PEDRERA			**Terrane: Caqueta Amazonas**
Qtz. pebble conglomerate Au (paleoplacers) (6.1)	None	Possible in La Pedrera Fm.; sandstone, pelites; low metamorphic grade	
Domain #32.—MITU			**Terrane: Meta-Vichada**
Pegmatites	Numerous simple pegmatites; lower Rio Vaupes near Yavarate	Gneisses and granites	Some magnetic data available near Rio Inirida
Oolitic Fe	SW of Mitu, Rio Vaupes	Base of upper Tertiary, overlying Mitu Migmatite complex	
Cherty iron formation	None	Possible occurrences in oldest Precambrian rocks, similar to deposits in Brasil	
Domain #33.—Vichada			**Terrane: Meta-Vichada**
Bauxite (7.1)	Pijiguaos (Vanezuela)	Cenozoic Basin overlap Rapakivi granite	
Monazite paleoplacers	2% in Qtzite (paleo-placer) Bajo Guainia region between Danaco and Santa Elena	Precambrian quartzite	
Rare Earths	None	Parguaza granitic complex in Venezuela	
Pegmatites	Rio Negro, near village of La Guadelupe	Gneisses and granites	
Placer diamonds (6.2)	Tertiary placers in venezuela	Possible reworked placer diamonds in Tertiary sediments west of crystalline outcrops	
Placer Sn	None		

U.S. GEOLOGICAL SURVEY--INGEOMINAS

MINERAL RESOURCE ASSEMENT OF COLOMBIA

Appendix A: ORE DEPOSIT MODELS

By

Dennis P. Cox, Editor

PREFACE

This compendium of ore deposits models was assembled for the Colombia Mineral Resource Assessment Project. The objectives of the compendium are: (1) to define mineral deposit types so that all project members have a common vocabulary or deposit classification scheme to which mineral occurrences, favorable geologic environments, favorable geochemical anomalies, and tonnage-grade models may be related; (2) to provide data on the environments of ore deposition so that favorable rocks, structures, and tectonic settings can be easily recognized by project geologists; and (3) to relate possibly the associations of elements within geochemical anomalies to specific deposit types so that geochemical data may be more easily interpreted.

The compendium is not complete at this stage and many models useful in the Colombia assessment still need to be added. Appropriate models for the Proterozoic shield environments of eastern Colombia are needed.

The editor is pleased to acknowledge the cooperation of the authors of the models included in this report. Blank forms and instructions for their use are included in the following pages to encourage other authors to join in this effort. Send your models to Dennis P. Cox, Mail Stop 41, U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025.

EXPLANATION OF DEPOSIT MODEL FORM

Deposit type: Fill in your preferred name for the deposit type.

Subtype: Optional. Use if it is convenient for your classification scheme.

Author: Author of model.

Date: When you filled out the form.

Approximate synonym: Optional. A different, but well-known name used by another author.

Of (reference): The author that used the synonym.

Description: A short description so that the casual user will not have to read the whole form.

General reference: Optional. May be a volume of papers on one deposit type, or a single comprehensive article.

Rock types: Rocks typical of the geologic terrane in which the deposits are found. (For igneous rock, use terminology of Williams and Turner, and Gilbert, 1954.)

Textures: Special textures associated with the rocks.

Age range: Ages of known deposits and ages in which such deposits might have formed.

Depositional environment: Plutonic, volcanic, or sedimentary environments related to ore-forming process.

Tectonic setting(s): Regional tectonic features important in the genesis of the deposit type.

Associated deposits: Example, copper skarns associated with copper porphyries.

Metal concentrations: Regional geochemical anomalies that might be indicative of the deposit or related to associated deposits.

Ore minerals: List ore and gangue minerals in assemblages. Show zonal or temporal relation between assemblages. List essential minerals with (+) signs, and varietal minerals with (±) signs. Group trace minerals separately. List biproduct metals i.e., Au, Ag, that may not form minerals. Do not include secondary minerals except for deposits formed by weathering.

Texture/structure: Describe appearance of ore.

Alteration: Minerals produced by reaction of ore-forming fluids with rocks. List in assemblages. Show zonal or temporal relation between assemblages. Use terms such as potassic (potassium-feldspar+biotite), phyllic (white mica+pyrite), argillic (clay+white mica), advanced argillic (clay+pyrophyllite±alunite±Al_2O_3 minerals) as they apply. Include skarn mineral assemblages where appropriate.

Ore controls: List special stratigraphic, structural, or geochemical features that are believed to have influenced ore-mineral deposition.

Weathering: Optional. List any special weathering characteristics or secondary minerals that might serve as prospecting guides.

Geochemical signature: Elements expected to be anomalous (enriched or depleted) in and near the deposit. List element assemblages and show zonal arrangement where possible.

Examples: A Colombian or Andean example should be included where possible.

References: One reference for each example. Give name and year. Include complete reference on a separate sheet.

Additional information needed

Sketch: Where possible, include a well-labeled map or section of a deposit, or a cartoon of an ideal deposit, showing ore controls, zoning, and approximate dimensions.

Key words: Underline in red those words or word combinations that should appear in an index. Pillow basalt is a key word for Cyprus-type massive sulfides, for example.

DEPOSIT TYPE ____________ SUBTYPE ____________

AUTHOR ____________ DATE ____________

APPROXIMATE SYNONYM ____________ OF (REFERENCE) ____________

DESCRIPTION ____________

GENERAL REFERENCE ____________

GEOLOGICAL ENVIRONMENT

Rock Types ____________

Textures ____________

Age Range ____________

Depositional Environment ____________

Tectonic Setting(s) ____________

Associated Deposit Types ____________

Metal Concentrations ____________

DEPOSIT DESCRIPTION

Ore Minerals: ____________

Texture/Structure ____________

Alteration ____________

Ore Controls ____________

Weathering ____________

Geochemical Signature: ____________

Examples ____________ References ____________

TABLE OF CONTENTS

DEPOSIT TYPE Podiform chromite SUBTYPE

AUTHOR John P. Albers DATE December 6, 1982

APPROXIMATE SYNONYM Alpine type chromite OF (REFERENCE) Thayer, 1964

DESCRIPTION Podlike masses of chromitite in ultramafic parts of ophiolite complexes.

GENERAL REFERENCE Dickey, 1975.

GEOLOGICAL ENVIRONMENT

Rock Types Highly deformed dunite and harzburgite of ophiolite complexes; commonly serpentinized.

Textures Nodular, orbicular, gneissic, cumulate, pull-apart; most relict textures are modified or destroyed by flowage at magmatic temperatures.

Age Range Phanerozoic.

Depositional Environment Lower part of oceanic lithosphere.

Tectonic Setting(s) Magmatic cumulates in elongate magma pockets along accreting plate boundaries.

Associated Deposit Types "Disseminated" chromite.

Metal Concentrations Platinum-group metals are common accessories.

DEPOSIT DESCRIPTION

Ore Minerals: Chromite, olivine, serpentine minerals.

Texture/Structure As above.

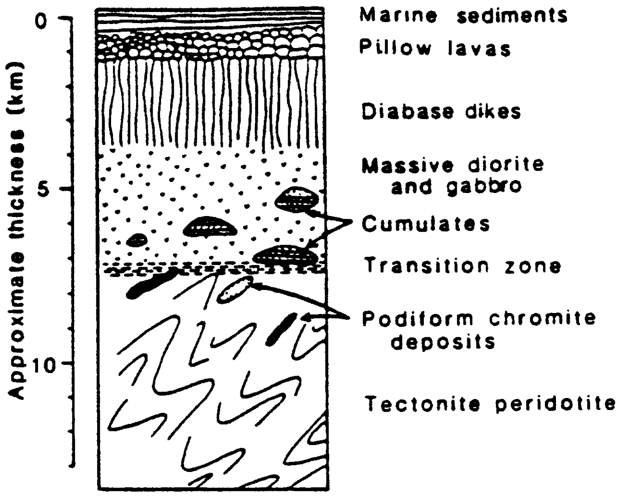
Alteration No

Ore Controls Restricted to dunite bodies in tectonized harzburgite.

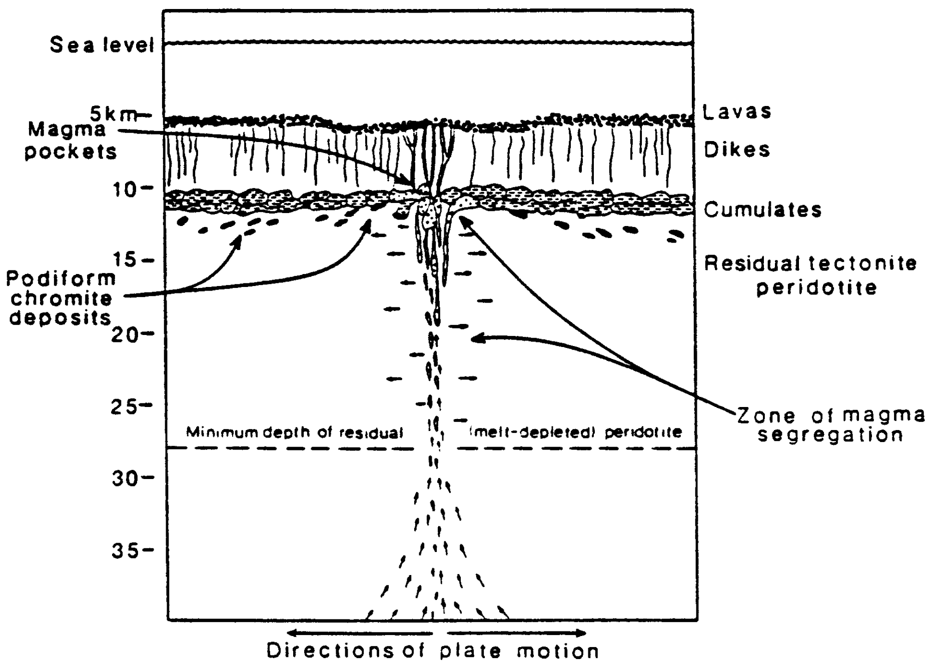
Weathering Highly resistant to weathering and oxidation but locally forms secondary minerals such as uvarovite.

Geochemical Signature: None recognized.

Examples High Plateau, Del Norte Cty, CA References Wells, F. G. et al 1946
Santa Helena, Antioquia, Colombia
Coto Mine, Luzan, P.I.



From Dickey, 1975



From Dickey, 1975

DEPOSIT TYPE Zoned ultramafic Cr Pt SUBTYPE

AUTHOR N. J Page DATE December 12, 1982

APPROXIMATE SYNONYM Alaskan, Uralan OF (REFERENCE)

DESCRIPTION Crosscutting ultramafic to felsic intrusives with approximately concentric zoning of rock types containing chromite, platinum and Ti- V-magnetite.

GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types Dunite, wehrlite, harzburgite, pyroxenite, magnetite-hornblende pyroxenite, 2 pyroxene gabbros, hornblende gabbro, hornblende clinopyroxenite hornblende magnetite clinopyroxenite, olivine gabbro, norite, tonalite, diorite.

Textures Cumulus textures poikilitic, mush flow textures, lineated fabrics, layered.

Age Range Precambrian to late Mesozoic, most Paleozoic and Mesozoic.

Depositional Environment Deposits occur in the layered ultramafic and mafic rocks that intrude into granodiorite terranes, island arc, or ophiolite terrains.

Tectonic Setting(s) Unstable tectonic areas.

Associated Deposit Types Platinum group elements (PGE) plus Au placer deposits.

Metal Concentrations Cr, Ni, PGE.

DEPOSIT DESCRIPTION

Ore Minerals: Assemblage 1: chromite, Pt-Fe alloys, Os-Ir alloys, PGE sulfides, pentlandite, pyrrhotite native gold, PGE arsenides. Assemblage 2: Ti-V magnetite, Pt-Fe alloys, Os-Ir alloys, cooperite, sulfides, arsenides, bornite, chalcopyrite.

Texture/Structure Assemblage 1: clots, pods, schlieren, wisps of chromite inclunite, clinopyroxenite, harzburgite. Assemblage 2: magnetite segregations, layers in wehrlites, pyroxenites, gabbro.

Alteration serpentinization—not as a result of the mineralization

Ore Controls Appear to be restricted to specific rock types by magmatic processes.

Weathering Mechanical weathering produces placers, chemical weathering could produce laterites.

Geochemical Signature: Cr, PGE, Cu, Ni, S, As, probably chondrite normalized PGE patterns from placer deposits are diagnostic.

Examples Urals, USSR	References Duparc and Tikonovitch, 1920
Duke Island, Alaska	Irvine, 1974
Choco River placer, Columbia	Wokitel, 1961, Taylor, 1967

DEPOSIT TYPE Stratiform mafic-ultramafic SUBTYPE Ni-Cu

AUTHOR Norman J Page DATE 8/10/83

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Ni, Cu sulfides at base of large repetitively layered mafic-ultramafic intrusion

GENERAL REFERENCE Geol. Soc. South Africa; Special Publication #1 (1969), Economic Geology, v. 77, no. 6, (1982) and v. 71, no. 7 (1976)

GEOLOGICAL ENVIRONMENT

Rock Types Layered intrusive contains norite, gabbro-norite, dunite hartzburgite, peridotite, pyroxenite, troctolite, anorthosite, and gabbro.
Textures Cumulate textures; layers with gradational proportions of euhedral crystals; locally with poikilitic matrix
Age Range Generally Precambrian, may be as young as Tertiary
Depositional Environment Intruded into granitic gneiss or volcano-sedimentary terrane.
Tectonic Setting(s) Cratonal, mostly in Precambrian shield areas.

Associated Deposit Types Layered chromitite, PGE in anorthosite-gabbro and magnetite ilmenite in intrusive complex. PGE placers.
Metal Concentrations Ni, PGE, Cr, Ti, high Mg, low Na, K, and P.

DEPOSIT DESCRIPTION

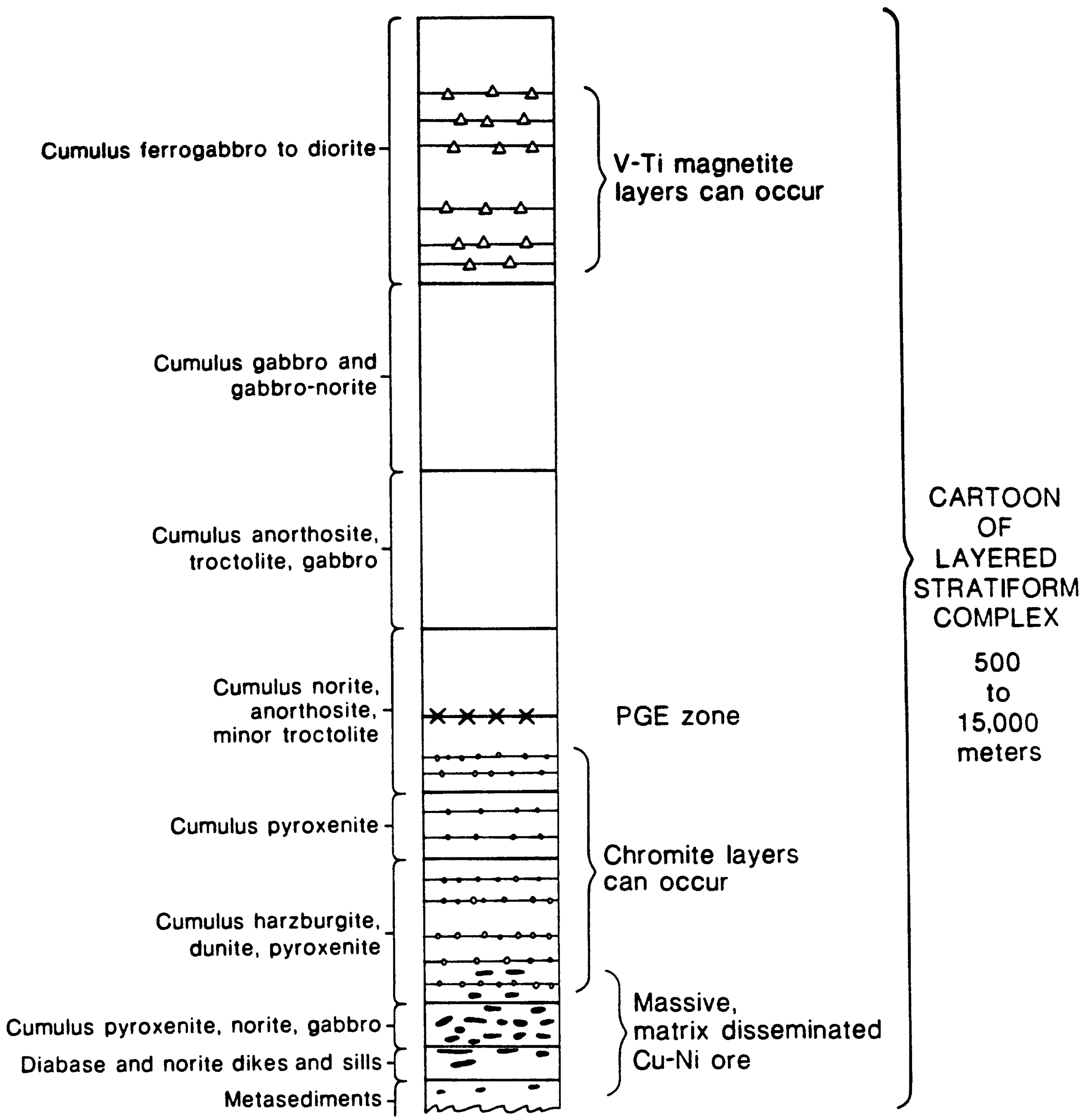
Ore Minerals: Pyrrhotite+chalcopyrite+pentlandite+cobalt+sulfides, by-product PGE.

Texture/Structure Massive; filling of silicate matrix; disseminated.

Alteration None related to ore
Ore Controls Basins in basal contact of intrusion with rapidly varying lithologies. Sulfides may intrude fractures in footwall country rock. Ingress of sulfur through fractures in footwall may be important ore control.
Weathering Gossan

Geochemical Signature: Cu, Ni, PGE, Co

Examples	References
Stillwater Complex	Page (1977)


Cumulus ferrogabbro to diorite
V-Ti magnetite layers can occur
Cumulus gabbro and gabbro-norite
Cumulus anorthosite, troctolite, gabbro
Cumulus norite, anorthosite, minor troctolite
PGE zone
Cumulus pyroxenite
Chromite layers can occur
Cumulus harzburgite, dunite, pyroxenite
Cumulus pyroxenite, norite, gabbro
Diabase and norite dikes and sills
Metasediments
Massive, matrix disseminated Cu-Ni ore
CARTOON OF LAYERED STRATIFORM COMPLEX
500 to 15,000 meters

DEPOSIT TYPE Stratiform mafic-ultramafic SUBTYPE Cr

AUTHOR Norman J Page DATE 8/10/83

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Layered chromitite in lower intermediate zone of large repetitively layered mafic-ultramafic intrusions

GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types Intrusion may contain norite, gabbro-norite, dunite, hartzburgite, peridotite, pyroxenite, troctolite, anorthosite, and gabbro.

Textures Cumulate textures; layers with gradational proportions of euhedral crystals; locally with poikilitic matrix.
Age Range Generally Precambrian, may be as young as Tertiary.

Depositional Environment Intruded into granitic gneiss or into volcano-sedimentary terrane.

Tectonic Setting(s) Cratonal, mostly in Precambrian shield areas.

Associated Deposit Types Ni, Cu sulfides at base; PGE and Fe, Ti, V deposits in gabbro-anorthosite above. PGE placers.

Metal Concentrations Ni, PGE Cr Ti, high Mg, low Na, K, P.

DEPOSIT DESCRIPTION

Ore Minerals: Chromite±ilmenite±magnetite±PGE minerals.

Texture/Structure Massive to disseminated layers, cumulus texture.

Alteration None related to ore.

Ore Controls May be in dunite, orthopyroxenite or anorthosite. Thickness increases in basinal depressions in layering.

Weathering Abundant blocks of chromitite in soil and alluvium.

Geochemical Signature: Cr, PGE

Examples	References
Bushveld Complex	Cameron & Desborough (1969)
Stillwater Complex	Jackson (1969)
Great Dyke	Bichan (1969)

DEPOSIT TYPE Stratiform mafic-ultramafic SUBTYPE Palladium-platinum

AUTHOR Norman J Page DATE 8/10/83

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Disseminated PGE-rich sulfides in olivine-rich rocks in anorthosite-gabbro zone of large layered intrusions.
GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types Norite, gabbro-norite, dunite, hartzburgite, peridotite, pyroxenite, troctolite, anorthosite, and gabbro.
Textures Cumulate textures; layers with gradational proportions of euhedral crystals; locally with poikilitic matrix.

Age Range Generally Precambrian, maybe as young as Tertiary.

Depositional Environment Intruded into granitic gneiss or into volcano-sedimentary terrane.

Tectonic Setting(s) Cratonal, mostly in Precambrian shield areas.

Associated Deposit Types

Metal Concentrations Ni, PGE Cr Ti, high Mg, low Na, K, P.

DEPOSIT DESCRIPTION

Ore Minerals: Pyrrhotite+chalcopyrite+pentlandite±chromite+sulfides, arsenides, tellurides, antimonides and alloys of platinum group metals. Maybe associated with pipes of Fe-rich olivine.
Texture/Structure Clots of massive sulfide and disseminated grains.
Alteration None related to ore

Ore Controls In layers near first reappearance of olivine as a cumulate phase after thick accumulation of plagioclase pyroxene rocks. May be related to introduction of new magma.
Weathering Difficult to see ore zone on weathered surface, exploration require extensive sampling and chemical analysis.

Geochemical Signature: PGE, Cu, Ni

Examples Bushveld
Stillwater Complex

References Vermaak & Hendriks (1976)
Todd et al (1982)

DEPOSIT TYPE Stratiform mafic-ultramafic SUBTYPE Fe, Ti, V

AUTHOR Norman J Page DATE 8/10/83

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Layers of Ti-V-rich magnetite in upper parts of large repetitively layered mafic-ultramafic intrusions

GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types Norite, gabbro-norite, dunite, hartzburgite, peridotite, pyroxenite, troctolite, anorlhosite, and gabbro
Textures Cumulate textures; layers with gradational proportions of euhedral crystals; locally with poikilitic matrix.
Age Range Generally Precambrian, may be as young as Tertiary.
Depositional Environment Intruded into granitic gneiss or into volcano-sedimentary terrane.
Tectonic Setting(s) Cratonal, mostly in Precambrian shield areas.

Associated Deposit Types

Metal Concentrations Ni, PGE Cr Ti, high Mg, low Na, K, P.

DEPOSIT DESCRIPTION

Ore Minerals: Vanadian magnetite±ilmenite±traces of sulfides

Texture/Structure Massive magnetite-ilmenite, cumulus textures

Alteration None related to ore

Ore Controls Layers near top of intrusion. Layers may be cut by pipes and veins rich in ilmenite.

Weathering Blocks of magnetite in soil and alluvium.

Geochemical Signature: Fe, Ti, V

Examples Bushveld Complex References Williams (1969) and Molyneux (1969)

DEPOSIT TYPE Synorogenic-Synvolcanic Ni SUBTYPE

AUTHOR Norman J Page DATE 10/11/83

APPROXIMATE SYNONYM Gabbroid class
Gabbroid associated of Marston, Groves, Hudson and Ross (1981)
OF (REFERENCE) Ross and Travis (1981)

DESCRIPTION Massive lenses, matrix and disseminated sulfide in small to medium sized gabbroic intrusion in greenstone belts.
GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types Norite, gabbro-norite, pyroxenite, peridotite, troctolite, anorthosite forming layered or composite igneous complexes.

Textures Phase and cryptic layering sometimes present, rocks usually cumulates.

Age Range Archean to Tertiary, predominantly Archean and Proterozoic.
Depositional Environment Intruded synvolcanically or during orogenic development of the terraine into metamorphic rocks or volcanic piles.
Tectonic Setting(s) Unstable, metamorphic belts, greenstone belts, mobile belts.

Associated Deposit Types Komatiitic Ni, Dunitic-Ni, talc-carbonate Ni-Au.

Metal Concentrations

DEPOSIT DESCRIPTION

Ore Minerals: Pyrrhotite+pentlandite+chalcopyrite±pyrite±Ti-magnetite±Cr-magnetite±graphite--by-product Co and PGE.

Texture/Structure Predominantly disseminated sulfides; often highly deformed and metamorphosed so primary textures and mineralogy have been altered. Deformation about the same age as the deposit.

Alteration None associated with ore.

Ore Controls Linear folded and faulted belts; basalt parts of the intrusion, however pipe-like discordant sulfides occur. Ores frequently in more ultramafic parts of the complex.
Weathering Lateritic
Geochemical Signature: Ni, Cu, Co, PGE

Examples
Sally Malay, Australia
Rana, Norway

References Thornett (1981)
Boyd and Mathiesen (1979)

DEPOSIT TYPE Dunitic-Ni | SUBTYPE

AUTHOR Norman J Page | DATE 8/10/83

APPROXIMATE SYNONYM | OF (REFERENCE)

DESCRIPTION Lowgrade (0.4-1% Ni) and high grade (1-3% Ni) disseminated sulfide mineralization in intrusive dunites.

GENERAL REFERENCE Marston, Goves, Hudson, and Ross (1981)

GEOLOGICAL ENVIRONMENT

Rock Types Olivinite, olivine peridotite in subconcordant lenses 500-1,000 m long, 50-1,100 m thick.
Textures Olivinite; coarse-grained (2-20 mm) subequant olivine ($Fo_{87}-_{95}$) interlocked to give polygonal to mosaic texture; olivine peridotite; ovate olivine with intercumulus pyroxene, sulfide and oxide minerals.
Age Range Precambrian

Depositional Environment Intruded into contacts between clastic sedimentary and felsic volcanic rocks and volcanic mafic to ultramafic rocks.
Tectonic Setting(s) Greenstone belts.

Associated Deposit Types Komatiitic Ni, Synorogenic-Synvolcanic-Ni Talc-carbonate Ni-Au, layered sedimentary Ni
Metal Concentrations Ni, Cr, Mg, PGE

DEPOSIT DESCRIPTION

Ore Minerals: High Grade: pyrrhotite+pentlandite+magnetite+pyrite+chalcopyrite+chromite; Low Grade: the same minerals±millerite±heazlewoodite±godlevskite±polydymite±vaesite±awaruite±bravolite±cobaltite±nickeliferous linnaeite±cubanite±Fe-Ni arsenides.
Texture/Structure Lenticular shoots of massive, matrix and breccia ores fine to medium grained and occur as interstitial films, olivine is commonly rounded when sulfide present.
Alteration Prograde and retrograde serpentinization after deposition; usually metamorphosed.

Ore Controls Dunitic lenses close to major strike slip faults and at high stratigraphic position in volcanic pile; most Ni-rich ores concentrated at one margin- perhaps base of intrusion.
Weathering Lateritic zones may be enriched in PGE.

Geochemical Signature: Ni, Cu, PGE, Cr, Co. Ni/Cu = 19-70+, Ni/Co=30-70. Massive sulfide ores 6-9 percent Ni, disseminated ores up to 3 percent Ni.

Examples Agnew (Perseverance)
Mt. Keith

References Martin and Allchurch (1975)
Burt and Sheppy (1975)

DEPOSIT TYPE Chrysotile asbestos SUBTYPE

AUTHOR Norman J Page DATE 8/15/83

APPROXIMATE SYNONYM Quebec Type OF (REFERENCE) Shride (1973)

DESCRIPTION Chyrsotile asbestos developed in stockworks in serpentinized ultramafic rocks.

GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types Serpentinites, dunite, harzburgite, pyroxenite

Textures Highly fractured and veined, serpentinized ultramafic rocks

Age Range Paleozoic-Mesozoic-Tertiary

Depositional Environment Usually part of an ophiolite sequence

Tectonic Setting(s) Unstable accreted oceanic terranes.

Associated Deposit Types Podiform chromite.

Metal Concentrations

DEPOSIT DESCRIPTION

Ore Minerals: Chrysotile asbestos±magnetite±brucite±talc±tremolite-actinolite

Texture/Structure Stockworks of veins in serpentinized ultramafic rocks.

Alteration None associated with ore, but silica-carbonate, talc may be developed.

Ore Controls Two periods of serpentinization, an earlier pervasive one and a later period near the end of intense deformation accompanied by hydrothermal activity perhaps as a function of intrusion of acidic, igneous rocks highly dependent upon major faulting, and fracture development.

Weathering

Geochemical Signature:

Examples Thetford-Black Lake deposit
Asbestos

References Riordon (1957)
Shride (1973)

DEPOSIT TYPE Porphyry Cu SUBTYPE Mo rich

AUTHOR D. P. Cox DATE December 1, 1982

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Stockwork veinlets of quartz, chalcopyrite and molybdenite in or near a porphyritic intrusion.

GENERAL REFERENCE Titley, S. R., 1982.

GEOLOGICAL ENVIRONMENT

Rock Types Quartz monzonite to tonalite intrusives and breccia pipes into older batholithic, volcanic or sedimentary rocks.

Textures Intrusions contemporaneous with ore are porphyries with fine to medium grained aplitic groundmass.

Age Range Mainly Mesozoic--Tertiary but can be any age.

Depositional Environment In intrusive porphyry or in country rock rich in mafic minerals or carbonate minerals.

Tectonic Setting(s) Numerous faults.

Associated Deposit Types Cu, Zn, or magnetite skarns may be rich in gold, gold+base metal sulfosalts in veins, gold placers

Metal Concentrations Cu, Mo, Pb, Zn, W, Au, Ag

DEPOSIT DESCRIPTION

Ore Minerals: Chalcopyrite+pyrite+molybdenite. Peripheral vein/replacement deposits with chalcopyrite+sphalerite+galena±gold. Outermost zone may have veins of Cu, Ag, Sb, sulfides and gold.

Texture/Structure Veinlets and disseminations or massive replacement of favorable country rocks.

Alteration Quartz+K-feldspar+biotite (chlorite)± anhydrite grading outward to propylitic. Late white mica+clay alteration may form capping or outer zone or may affect the entire deposit.

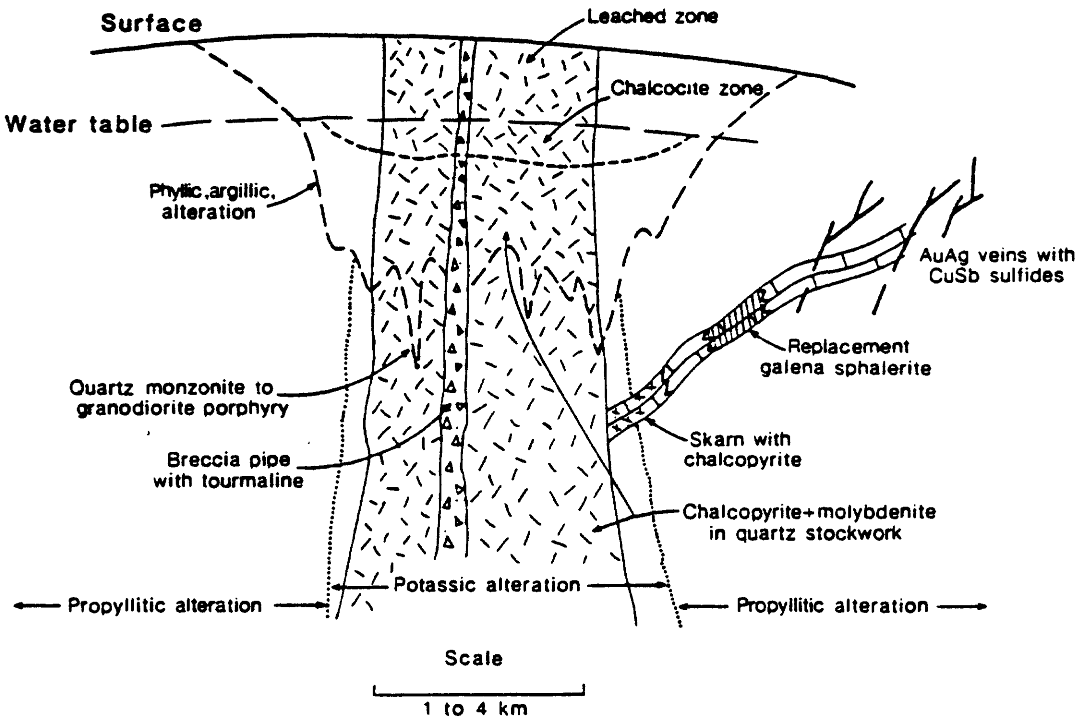
Ore Controls Veinlets and mineralized fractures are closely spaced. Favorable country rocks are calcareous sediments; diabase tonalite or diorite.

Weathering Intense leaching of surface wide areas of iron oxide stain.

Geochemical Signature: Cu+Mo±W center; Pb, Zn, au, Ag, As, Sb, Te, Mn, and Rb in outer zone.

Examples El Salvador, Chile
Silver Bell, Arizona
Highland Valley, B.C. Canada

References Gustafson and Hunt, 1975
Graybeal, 1982
McMillan, 1976



Surface
Leached zone
Chalcocite zone
Water table
Phyllic, argillic, alteration
AuAg veins with CuSb sulfides
Replacement galena sphalerite
Quartz monzonite to granodiorite porphyry
Skarn with chalcopyrite
Breccia pipe with tourmaline
Chalcopyrite+molybdenite in quartz stockwork
Potassic alteration
Propyllitic alteration
Propyllitic alteration
Scale
1 to 4 km

DEPOSIT TYPE Porphyry Cu SUBTYPE Au rich

AUTHOR Dennis P. Cox DATE December 1, 1982

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Stockwork veinlets of chalcopyrite, bornite and magnetite in porphyritic intrusions and coeval volcanic rocks.

GENERAL REFERENCE Sillitoe, 1979

GEOLOGICAL ENVIRONMENT

Rock Types Tonalite, quartz monzonite; dacite, andesite flows and tuffs coeval with intrusives. Also syenite, monzonite, and shoshonitic volcanics.

Textures Intrusive rocks are porphyritic with fine to medium grained aplitic groundmass.

Age Range Cretaceous to Quaternary.

Depositional Environment In intrusive porphyry, coeval volcanic rocks and intrusion breccia. Porphyry bodies may be as dikes.

Tectonic Setting(s) Numerous faults, large scale breccias. Evidence of volcanic center, 1 to 2 km depth of emplacement.

Associated Deposit Types Porphyry copper molybdenum; gold placers.

Metal Concentrations Cu, Au, Zn, Mo, Pb, Ag.

DEPOSIT DESCRIPTION

Ore Minerals: Chalcopyrite±bornite, gold and silver do not form minerals.

Texture/Structure Veinlets and disseminations.
Alteration Quartz+magnetite+biotite (chlorite)± K-feldspar±actinolite, center. Outer propylitic zone. Late quartz+pyrite+white mica±clay may be present.

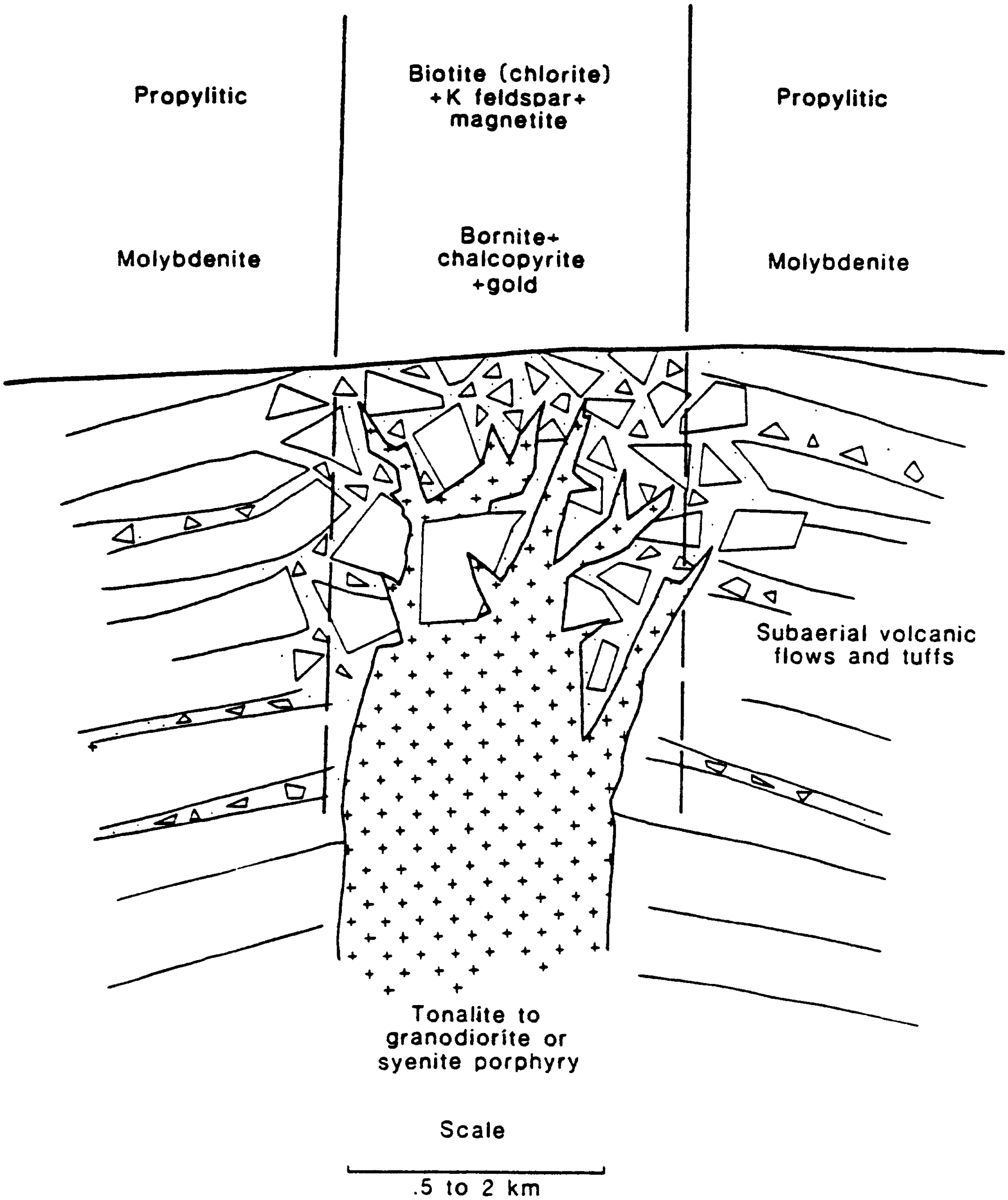
Ore Controls Veinlets and fractures of quartz, sulfides, K-feldspar magnetite, biotite, or chlorite are closely spaced.

Weathering Surface iron staining may be weak or absent if pyrite content is low in protore. Copper silicates and carbonates.

Geochemical Signature: Central Cu, Au, Ag; peripheral Mo, Pb, Zn, Mn

Examples Tanama, Puerto Rico
Dos Pobres, Arizona
Copper Mountain, B.C., Canada

References Cox, unpublished data
Langton and Williams, 1982
Fahrni, McCauley and Preto, 1976


Propylitic
Biotite (chlorite) +K feldspar+ magnetite
Propylitic
Molybdenite
Bornite+ chalcopyrite +gold
Molybdenite
Subaerial volcanic flows and tuffs
Tonalite to granodiorite or syenite porphyry
Scale
.5 to 2 km

DEPOSIT TYPE Molybdenum Porphyry SUBTYPE Climax

AUTHOR Steve Luddington DATE December 6, 1982

APPROXIMATE SYNONYM Granite molybdenite OF (REFERENCE) Mutschler and others, 1981

DESCRIPTION Stockwork of quartz and molybdenite associated with fluorite in granite porphyry.

GENERAL REFERENCE White and others, 1981.

GEOLOGICAL ENVIRONMENT

Rock Types Granite-rhyolite with >75 percent SiO_2 content. Rhyolite dikes with spessartine garnets on periphery of system.

Textures Porphyry with fine to medium-grained aplitic groundmass.

Age Range Mesozoic, Tertiary.

Depositional Environment Hypabyssal intrusions. Mainly continental interior, thick continental crust.

Tectonic Setting(s) Mainly rift zones in cratons. Less commonly in continental margin mobile belts.

Associated Deposit Types Ag-base-metal Gold veins, fluorspar deposits.

Metal Concentrations Mo, F, W, Sn, U, Be, Li and rare earths.

DEPOSIT DESCRIPTION

Ore Minerals: Molybdenite+fluorite+pyrite±wolframite±cassiterite±topaz.

Texture/Structure Disseminated and in veinlets and fractures.

Alteration Intense quartz veining, K-feldspar veining. Outer phyllic and prophylitic zones. Halo of rhodochrosite, rhodonite, spessartine.

Ore Controls Stockwork ore zone draped over small <1 km^2 cupolas.

Weathering Yellow ferrimolybdite stains.

Geochemical Signature: Outer Cu zone, peripheral Pb, U, and RE anomalies. Rb and Cs in K-feldspar altered host rocks.

Examples Climax Colorado References White and others, 1981

DEPOSIT TYPE Molybdenum porphyry SUBTYPE Low fluorine

AUTHOR Ted G. Theodore DATE December 6, 1982

APPROXIMATE SYNONYM Calc-alkaline Mo Stockwork OF (REFERENCE) Westra and Keith, 1981

DESCRIPTION Stockwork of quartz-molybdenite veinlets in felsic porphyry

GENERAL REFERENCE Westra and Keith, 1981

GEOLOGICAL ENVIRONMENT

Rock Types Tonalite granodiorite-quartz monzonite

Textures Porphyry, fine aplitic groundmass

Age Range Mesozoic-Tertiary

Depositional Environment Continental margin

Tectonic Setting(s) Numerous faults

Associated Deposit Types Vein deposits of chalcopyrite-enargite-bornite-molybdenite; or pyrite-gold; or sphalerite-galena-gold-silver

Metal Concentrations Mo, Cu, W, Ag, Au, Pb, Zn

DEPOSIT DESCRIPTION

Ore Minerals: Molybdenite+pyrite±scheelite±chalcopyrite

Texture/Structure Disseminated and in veinlets and fractures

Alteration Potassic outward to propylitic. Phyllic and argillic overprint

Ore Controls Stockwork

Weathering Yellow ferrimolybdite after molybdenite

Geochemical Signature: Zoning outward and upward from Mo+Cu to Cu, Au to Zn, Pb, Au, Ag

Examples Buckingham, Nevada — References Blake and others, 1979
USSR deposits — Pavlova and Rundquist, 1980

DEPOSIT TYPE Iron skarn

SUBTYPE

AUTHOR Dennis Cox

DATE December 8, 1982

APPROXIMATE SYNONYM

OF (REFERENCE)

DESCRIPTION Magnetite in calc silicate contact metasomatic rocks.

GENERAL REFERENCE Einaudi and Burt, 1982; Einaudi and others, 1981.

GEOLOGICAL ENVIRONMENT

Rock Types Gabbro, diorite, diabase syenite and coeval volcanic rocks.

Textures Granitic texture in intrusive rocks; granoblastic to hornfelsic.

Age Range Mainly Mesozoic and Tertiary, may be any age.

Depositional Environment Contacts of intrusion and carbonate rocks or calcareous clastic rocks.

Tectonic Setting(s) Oceanic island arc and rifted continental margin.

Associated Deposit Types

Metal Concentrations Fe, Cu, Co, Au

DEPOSIT DESCRIPTION

Ore Minerals: Magnetite±chalcopyrite±cobaltite±pyrite±pyrrhotite. Rarely cassiterite.

Texture/Structure Granoblastic with interstitial ore minerals.

Alteration Diopside-hedenbergite+grossular-andradite+epidote. Late stage amphibole±chlorite±ilvaite.

Ore Controls Carbonate rocks, calcareous rocks, igneous contacts and fracture zones near contacts.

Weathering Magnetite generally crops out or forms abundant float.

Geochemical Signature: Fe, Cu, Co, Au, possibly Sn

Examples Daiquiri, Cuba
Shinyana, Japan

References Lindgren and Ross, 1916
Uchida and Iiyama, 1982

DEPOSIT TYPE Copper skarn SUBTYPE

AUTHOR Dennis P. Cox DATE December 9, 1982

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Chalcopyrite in calc-silicate contact metasomatic rocks.

GENERAL REFERENCE Einaudi and Burt, 1982; Einaudi and others, 1981

GEOLOGICAL ENVIRONMENT

Rock Types Granodiorite to quartz monzonite intruding carbonate rocks or calcareous clastic rocks.

Textures Granitic texture, porphyry, granoblastic to hornfelsic.

Age Range Mainly Mesozoic but may be any age.

Depositional Environment Miogeoclinal sequences intruded by felsic plutons.

Tectonic Setting(s) Continental margin late orogenic magmatism.

Associated Deposit Types Porphyry Cu, zinc skarn, replacement Pb Zn

Metal Concentrations Cu, Pb, Zn, Au, Ag, Mo

DEPOSIT DESCRIPTION

Ore Minerals: Chalcopyrite+pyrite±hematite±magnetite±bornite±pyrrhotite± molybdenite±tennantite±gold and silver.

Texture/Structure Granoblastic with interstitial sulfides.

Alteration Diopside+andradite center; wollastonite outer zone; marble peripheral zone. Late stage actinolite±chlorite±montmorillonite. Igneous rocks may be altered to epidote pyroxene garnet or to potassic and phyllic assemblages.

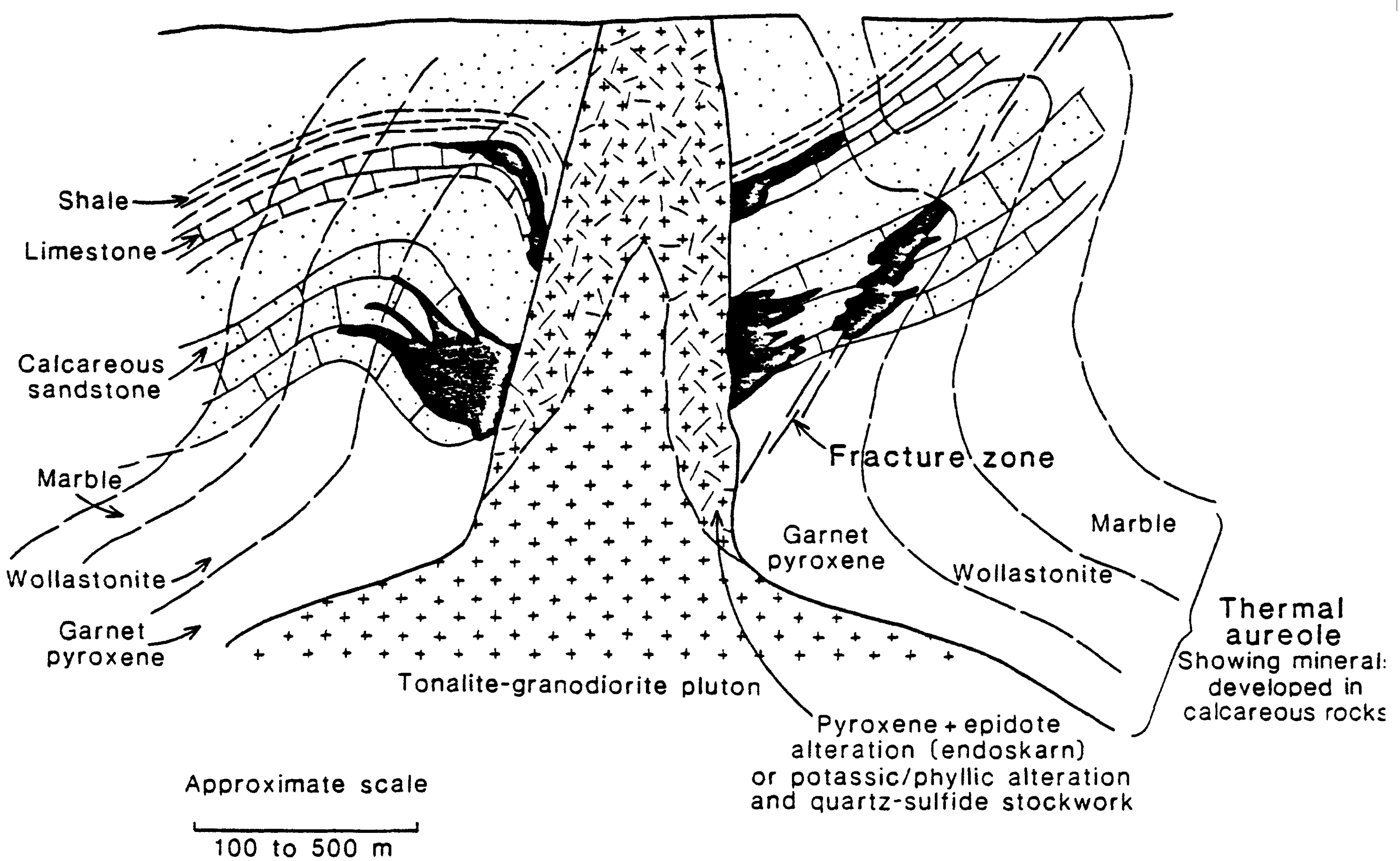
Ore Controls Carbonate rocks, calcareous rocks, igneous contacts and fracture zones near contacts.

Weathering Cu carbonates, gossan.

Geochemical Signature: Cu, Pb, Zn, Au, Ag, Mo possibly Bi.

Examples
Carr Fork, Utah
Morococha, Peru
Mina Vieja, Colombia

References
Atkinson and Einaudi, 1978
Petersen, 1965
Alberto Nunez, oral commun., 1982


Shale
Limestone
Calcareous sandstone
Marble
Wollastonite
Garnet pyroxene
Tonalite-granodiorite pluton
Fracture zone
Garnet pyroxene
Wollastonite
Marble
Thermal aureole
Showing minerals developed in calcareous rocks
Pyroxene + epidote alteration (endoskarn) or potassic/phyllic alteration and quartz-sulfide stockwork
Approximate scale
100 to 500 m

DEPOSIT TYPE Zinc-lead skarn   SUBTYPE

AUTHOR Dennis P. Cox   DATE December 9, 1982

APPROXIMATE SYNONYM   OF (REFERENCE)

DESCRIPTION Sphalerite and galena in calc silicate rocks.

GENERAL REFERENCE Einaudi and Burt, 1982; Einaudi and others, 1981

GEOLOGICAL ENVIRONMENT

Rock Types Granodiorite to granite, diorite to syenite. Carbonate rocks, calcareous clastic rocks.

Textures Granitic to porphyritic; granoblastic to hornfelsic.

Age Range Mainly Mesozoic but may be any age.

Depositional Environment Miogeoclinal sequences intruded by generally small bodies of igneous rock.

Tectonic Setting(s) Continental margin, late orogenic magmatism.

Associated Deposit Types Copper skarn.

Metal Concentrations Zn, Pb, Ag, Cu, W.

DEPOSIT DESCRIPTION

Ore Minerals: Sphalerite+galena±pyrrhotite±pyrite+magnetite±chalcopyrite± bornite±arsenopyrite±scheelite±bismuthinite±stannite±fluorite. Gold and silver do not form minerals.

Texture/Structure Granoblastic, sulfides massive to interstital.

Alteration Mn-hedenbergite±andradite±grossular±spessartine±bustamite± rhodonite. Late stage Mn-actinolite±ilvaite±chlorite±dannemorite ±rhodochrosite.

Ore Controls Carbonate rocks. Deposit may be 100's of meters from intrusive contact. Shale-limestone contacts.

Weathering Gossan.

Geochemical Signature: Zn, Pb, Cu, Co, Au, Ag, As, W, Sn, F, Mn possibly Be.

Examples	References
Ban Ban, Australia	Ashley, 1980
El Sapo, Colombia	Alberto Nunez, oral commun., 1982

DEPOSIT TYPE Tungsten skarn SUBTYPE

AUTHOR Dennis P. Cox DATE December 9, 1982

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Scheelite in calc silicate contact metasomatic rocks.

GENERAL REFERENCE Einaudi and Burt, 1982; Einaudi and others, 1981

GEOLOGICAL ENVIRONMENT

Rock Types Tonalite, granodiorite, quartz monzonite; limestone.

Textures Granitic, granoblastic.

Age Range Mainly Mesozoic, may be any age.

Depositional Environment Contacts and roof pendents of large batholith and thermal aureoles of apical zones of stocks.

Tectonic Setting(s) Continental margin. syn-late orogenic.

Associated Deposit Types Tin tungsten skarns, zinc skarns.

Metal Concentrations W, Mo, Zu, Cu.

DEPOSIT DESCRIPTION

Ore Minerals: Scheelite±molybdenite±pyrrhotite±sphalerite±chalcopyrite±bornite±arsenopyrite±pyrite±magnetite±traces of wolframite fluorite, cassiterite, and native bismuth.

Texture/Structure

Alteration Diopside-hedenbergite+grossular--andradite. Late stage spessartine+almandine. Outer barren wollastonite zone. Inner zone of massive quartz may be present.

Ore Controls Carbonate rocks in thermal aureoles of intrusions.

Weathering

Geochemical Signature: W, Mo, Zn, Cu, Sn, Bi, Be, As.

Examples Pine Creek, California
MacTung British Columbia
Strawberry, California

References Newberry, 1982
Dick and Hodgson, 1982
Nokleberg, 1981

DEPOSIT TYPE Sn-W skarn

SUBTYPE

AUTHOR Dennis P. Cox

DATE December 10, 1982

APPROXIMATE SYNONYM

OF (REFERENCE)

DESCRIPTION Tin, tungsten, beryllium minerals in skarns, veins, stockworks and greissen near granite-limestone contacts.

GENERAL REFERENCE Einaudi and Burt, 1982; Einaudi and others, 1981

GEOLOGICAL ENVIRONMENT

Rock Types Granite-rhyolite, carbonate rocks.

Textures Granitic, fine grained granitic, porphyritic aphanitic granoblastic to hornfelsic.

Age Range Mainly Mesozoic, may be any age.

Depositional Environment Late or anorogenic granites in carbonate terrain.

Tectonic Setting(s) Stable(?) continental interior.

Associated Deposit Types W skarn, Sn greissen deposits, Sn veins.

Metal Concentrations Sn, W, F, Be, Zn, Pb, Cu, Ag.

DEPOSIT DESCRIPTION

Ore Minerals: Cassiterite±scheelite±sphalerite±pyrrhotite±magnetite±pyrite±arsenopyrite±fluorite in skarn.

Texture/Structure Granoblastic skarn, stockwork veins, breccia.

Alteration Topaz tourmaline greissen. Idocrase+Mn-grossular-andradite±Sn-andradite±malayaite in skarn. Late stage amphibole+mica+chlorite and mica+touramaline+fluorite.

Ore Controls Intrusive contact with carbonte rocks. Crosscutting veins and rhyolite dikes.

Weathering

Geochemical Signature: Sn, W, F, Be, Zn, Pb, Cu, Ag, Li, Rb, Cs, Re, B.

Examples Lost River, Alaska

References Dobson, 1982

DEPOSIT TYPE Cyprus massive sulfide SUBTYPE

AUTHOR Donald Singer DATE December, 1982

APPROXIMATE SYNONYM Cupreous pyrite OF (REFERENCE)

DESCRIPTION Massive pyrite, chalcopyrite, and sphalerite in pillow basalts.

GENERAL REFERENCE Franklin, and others, 1981

GEOLOGICAL ENVIRONMENT

Rock Types Ophiolite assemblage: Tectonized dunite and harzburgite, gabbro, sheeted diabase dikes, pillow basalts, and fine-grained massive rocks such as chert and phyllite.

Textures Diabase dikes, pillow basalts, and in some cases brecciated basalt.

Age Range Archean(?) to Tertiary-majority are Ordovician or Cretaceous.

Depositional Environment Marine-believed to be ocean ridge.

Tectonic Setting(s) Local fault-controlled basins. May be adjacent to steep normal faults.

Associated Deposit Types

Metal Concentrations Mn and Fe-rich cherts regionally. Some deposits overlain by ochre (Mn-poor, Fe-rich bedded sediment containing goethite, maghemite, and quartz).

DEPOSIT DESCRIPTION

Ore Minerals: Massive: pyrite+chalcopyrite+sphalerite±marcasite±pyrrhotite. Stringer (stockwork): pyrite+pyrrhotite, minor chalcopyrite and sphalerite, (cobalt gold and silver present in minor amounts).

Texture/Structure Massive sulfides (>60 percent sulfides) with underlying sulfides stockwork or stringer zone.

Alteration Stringer zone—feldspar destruction, abundant quartz and chalcedony, abundant chlorite, some illite and calcite.

Ore Controls Pillow basalts or mafic volcanic breccias, diabase dikes below; in some cases in sediments above pillows. May be local faulting.

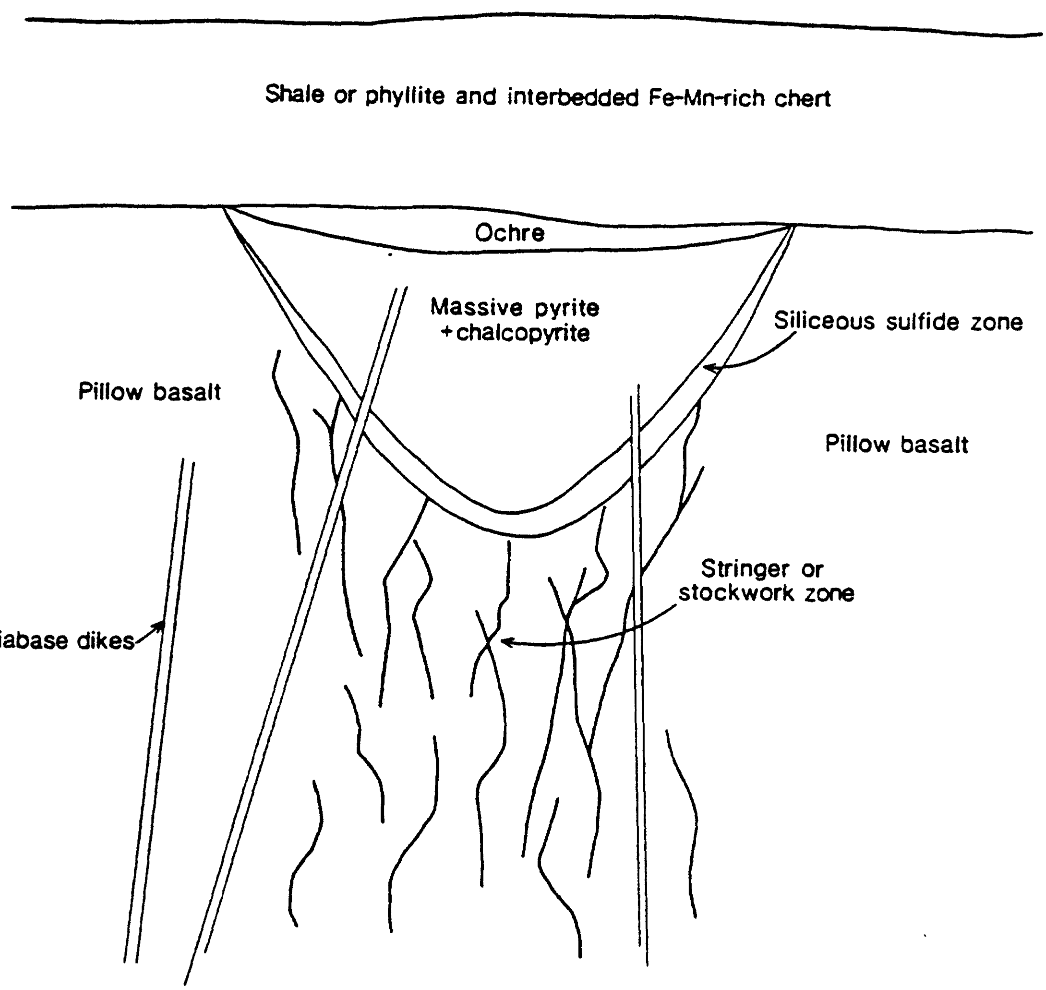
Weathering Many deposits overlain by orange-yellow to brown ochre.

Geochemical Signature: General loss of Ca and Na and introduction and redistribution of Mn and Fe in the stringer zone.

<u>Examples</u> Oxec (Guatemala) Limi, (Cyprus), York Harbor, (Canada) Turner-Albright, (USA)

<u>References</u> Petersen and Zantop, 1980

Cyprus type massive sulfide 3.1



DEPOSIT TYPE Massive sulfide in felsic to intermediate volcanics SUBTYPE

AUTHOR Donald Singer DATE December, 1982

APPROXIMATE SYNONYM Kuroko, Noranda, Volcanogenic massive sulfide OF (REFERENCE)

DESCRIPTION Copper and zinc-bearing massive sulfide deposits in marine volcanic rocks of intermediate to felsic composition.

GENERAL REFERENCE Franklin and others, 1981.

GEOLOGICAL ENVIRONMENT

Rock Types Felsic to intermediate marine volcanic rocks and associated sediments.

Textures Flows, tuffs, pyroclastics, breccias, beds, and in some cases felsic domes.

Age Range Archean through Cenozoic.

Depositional Environment Marine.

Tectonic Setting(s) Local extensional tectonic activity, faults or fractures.

Associated Deposit Types Gold-bearing quartz veins; bedded barite.

Metal Concentrations Ba, Au

DEPOSIT DESCRIPTION

Ore Minerals: Upper stratiform massive zone—pyrite+sphalerite+chalcopyrite± pyrrhotite±galena+barite; lower stratiform massive zone—pyrite+chalcopyrite± sphalerite±pyrrhotite±magnetite; Stringer (stockwork) zone—pyrite+ chalcopyrite (gold and silver).

Texture/Structure Massive (>60 percent sulfides); in some cases, an underlying stringer or disseminated sulfide zone.

Alteration Adjacent to and blanketing massive sulfide in some deposits-- zeolites, montmorillonite (and chlorite?); stringer (stockwork) zone--silica, chlorite, and sericite; below stringer-chlorite and albite.

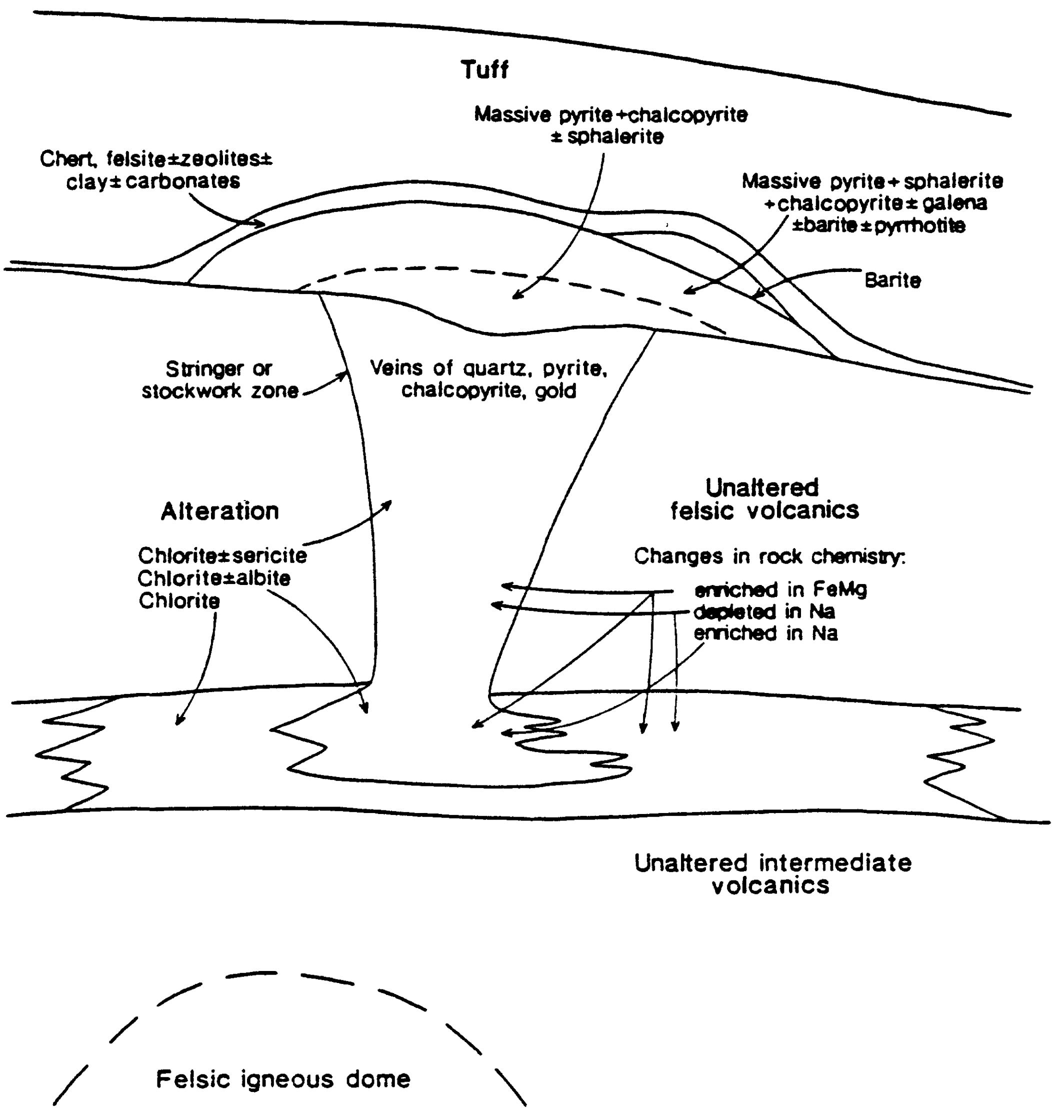
Ore Controls Towards the more felsic top of volcanic or volcanic-sedimentary rocks. Near center of felsic volcanism. May be locally brecciated and/or have felsic dome nearby.

Weathering Yellow, red, and brown gossans.

Geochemical Signature: Gossan may be high in Pb and typically Au is present. Adjacent to deposit-enriched in Mg and Zn, depleted in Na. Within deposits-Cu, Zn, Pb, Ba, As, Ag, Au, Se, Sn, Bi, Fe.

Examples Bailadores (Venezuela) — References Carlson, 1977
Kidd Creek (Canada)
Hanaoka (Japan)
Macuchi, Equador — Stoll, 1962

Massive sulfide in felsic to intermediate volcanics 3.2



DEPOSIT TYPE Volcanogenic Gold SUBTYPE

AUTHOR Byron R. Berger DATE December 1982

APPROXIMATE SYNONYM Massive sulfide gold OF (REFERENCE)

DESCRIPTION Stratabound to stratiform gold deposits in siliceous- or carbonate-iron formation in metavolcanic terrane

GENERAL REFERENCE Hutchinson and Burlington, unpublished report

GEOLOGICAL ENVIRONMENT

Rock Types Mafic or felsic metavolcanic rocks, volcaniclastic sediments, quartz porphyries, felsic plutonic rocks, banded iron formation (silica, carbonate)

Textures

Age Range Precambrian to Tertiary

Depositional Environment Active oceanic ridge spreading centers; submarine volcanic intruded by granitic stocks

Tectonic Setting(s)

Associated Deposit Types Base-metal massive sulfide deposits, iron formation, low sulfide gold quartz veins

Metal Concentrations Cu+Pb Cu+Zn Pb+Zn Cu+Pb+Zn

DEPOSIT DESCRIPTION

Ore Minerals: Native gold+pyrite+arsenopyrite+sphalerite+chalcopyrite. May get minor tetrahedrite±scheelite±wolframite±molybdenite±fluorite

Texture/Structure Narrow veins or lenses, stringers (stockworks)

Alteration Quartz+siderite and (or) ankerite+tourmaline+chlorite±magnetite in mafic volcanic terranes: chromian mica. Chlorite particularly around veins and stockworks

Ore Controls Bedded ores in chemical sediments with vein and stockworks in feeder zones to these sediments, often interlayered with flow rocks

Weathering Gossans from magnetite lateral from carbonate iron formation

Geochemical Signature: Au+As+B±Sb (+platinum-group metals in mafic volcanic terranes)

Examples Homestake, South Dakota
Passagem, Brazil
Kirkland Lake, Canada

References Rye and Rye, 1974
Fleisher and Routhier, 1973
Ridler, 1970

DEPOSIT TYPE Komatiitic Ni | SUBTYPE

AUTHOR Norman J Page | DATE 8/10/83

APPROXIMATE SYNONYM | OF (REFERENCE)

DESCRIPTION Lenticular, irregular elongate to tabular, pipelike Ni-Cu sulfides associated with komatiitic volcanic extrusive rocks.

GENERAL REFERENCE Arndt and Nisbet, (1982)

GEOLOGICAL ENVIRONMENT

Rock Types Dunite, pyroxenite, peridotite, basalt or komatiites, dunite, pyroxenite, peridotite, komatiitic basalts.
Textures Bladed olivine or pyroxene with skeletal appearance in random or parallel orientations; spinifex textures, fracture or joint patterns that resemble pillows
Age Range Archean-Proterozoic generally, some may be in Cretaceous-Tertiary.
Depositional Environment Greenstone belts with mafic to felsic rocks containing numerous volcanic events.
Tectonic Setting(s) Unstable areas.

Associated Deposit Types Dunitic Ni

Metal Concentrations Ni, Cu, Mg, PGE; Rocks contain more than 15% MgO and approach 40% MgO.

DEPOSIT DESCRIPTION

Ore Minerals: Pyrite±pyrrhotite+chalcopyrite_pentlandite, by-product PGE

Texture/Structure Sulfide amounts vary from base to top of deposit. Base contains massive sulfide grading into net-textured or matrix sulfide into disseminated sulfide.
Alteration None related to ore.
Ore Controls In lowermost flows more than 10 m thick, in zones of increased spinfex development, near feeder areas for the flows, show evidence of paleofaulting at the time the flows were deposited and have thickening and thinning of flows along strike. Ore occurs in irregularities at bottom of flows. Unit contains greater than 1,000 ppm or sulfide-bearing cherts, argillites, shales or iron carbonate sequences occur below flows.
Weathering Develop gossans, laterites.
Geochemical Signature: Gossan contain 15 to 30 ppb Pd and 5 to 10 ppb Ir over known Ni-Cu deposits where Cu and Ni are leached out of the gossan.

Examples Kambalda, Australia
Damba, Zimbabwe

References Gresham & Loftus-Hills (1981)
Williams (1979)

DEPOSIT TYPE Volcanogenic manganese SUBTYPE

AUTHOR Randolph A. Koski DATE June 8, 1983

APPROXIMATE SYNONYM Volcanogenic-sedimentary OF (REFERENCE) Roy (1981)

DESCRIPTION Lenses and stratiform bodies of manganese oxide, carbonate, and silicate in volcanic-sedimentary sequences. Genesis related to volcanic (volcanogenic) processes.

GENERAL REFERENCE Roy, Supriya, 1981, Manganese deposts: New York, Academic Press, 458 p.

GEOLOGICAL ENVIRONMENT

Rock Types Chert-shale-graywacke-tuff-basalt; chert-jasper-basalt (ophiolite); basalt-andesite-rhyolite (island-arc); basalt-limestone; conglomerate-sandstone-tuff-gypsum
Textures
Age Range Cambrian to Pliocene
Depositional Environment Seafloor hot spring, generally deep water; some shallow water marine; some may be enclosed basin
Tectonic Setting(s) Oceanic ridge, marginal basin, island arc, young rifted basin; all can be considered eugeosynclinal.
Associated Deposit Types Stratiform massive Fe-Cu-Zn sulfide deposits, stratifrom barite, ferruginous chert and limestone; gypsum.
Metal Concentrations Mn, Fe, Ba, Zn, Pb, Cu

DEPOSIT DESCRIPTION

Ore Minerals: Rhodochrosite, Mn-calcite, braunite, hausmannite, bementite, neotocite, alleghenyite, spessartine, rhodonite, Mn-opal, manganite, pyrolusite, coronadite, cryptomelane, hollandite, todorokite, amorphous MnO_2.
Texture/Structure Fine-grained massive crystalline aggregates, botryoidal, colloform in bedded and lensoid masses.
Alteration Spilitic or greenschist facies alteration of associated mafic lavas, silicification, hematitization.
Ore Controls Sufficient structure and porosity to permit subseafloor hydorthermal circulation and seafloor venting; redox potential at seafloor/seawater interface around hot spring; supergene enrichment to upgrade Mn content.
Weathering Strong development of secondary Mn oxides (todorokite, birnessite, pyrolusite, amorphous MnO_2) at the surface and along fractures.
Geochemical Signature: Although Mn is only moderately mobile and relatively abundant in most rocks, Mn minerals may incorporate many other trace elements.

Examples Olympic Peninsula
Franciscan type

References Park (1942; 1946); Sorem & Gunn (1967); Taliaferro & Hudson, (1943); Cerar and others (1982); Snyder (1978); Kuypers & Denyer (1979).

DEPOSIT TYPE Red-bed--Green-bed Cu SUBTYPE

AUTHOR D. P. Cox DATE December 14, 1982

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Stratabound, disseminated copper sulfides in reduced beds of red-bed sequences

GENERAL REFERENCE Tourtelot and Vine, 1976

GEOLOGICAL ENVIRONMENT

Rock Types Red-bed sequence containing green or gray shale, siltstone, and sandstone. Thin carbonate and evaporite beds. Local channel conglomerate.

Textures Algal mat structures, mudcrackes, deltaic cross bedding. Fossil wood in channels.

Age Range Proterozoic, Permian-Lower Mesozoic. Any Phanerozoic age.

Depositional Environment Epicontinental shallow-marine basin near paleo equator. Sabkhas. High evaporation rate. Sediments highly permeable.

Tectonic Setting(s) Intracontinental rift. Aulacogen. Failed arm of triple junction of plate spreading. Major growth faults.

Associated Deposit Types Halite, sylvite, gypsum, anhydrite. Sandstone uranium. Native copper in basaltic rocks

Metal Concentrations Cu, Ag, Mo, Pb, Zn, V, U

DEPOSIT DESCRIPTION

Ore Minerals: Chalcocite and other Cu_2S minerals+pyrite$\pm$bornite$\pm$native silver. Cu_2S replacement of early fine-grained pyrite is common. Deposits may be zoned with centers of chalcocite$\pm$bornite, rims of chalcopyrite, and peripheral galena+sphalerite.

Texture/Structure Fine disseminated, stratabound, locally stratiform

Alteration Green, white or gray (reduced) color in red beds. Regionally matmorphosed red beds may have purple color.

Ore Controls Reducing low pH environment such as fossil wood, algal mat. Abundant biogenic sulfur. Pyritic sediments. Petroleum in paleoaquifers.

Weathering Surface exposures may be completely leached. Secondary chalcocite enrichment down dip is common.

Geochemical Signature: Cu, Ag, Pb, Zn (Mo, V. U)

Examples	References
Kupferschiefer, Germany	Wedepohl, 1971
White Pine, Michigan	Brown, 1971
Western Montana (Belt)	Harrison, 1972

DEPOSIT TYPE Volcanic native Cu SUBTYPE

AUTHOR D. P. Cox DATE

APPROXIMATE SYNONYM Volcanic Red Bed Cu OF (REFERENCE) Kirkham, 1982

DESCRIPTION Disseminated native copper and copper sulfides in subaerial basalt flows and copper sulfides overlying sedimentary beds

GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types Subaerial basalt flows and breccias, red bed sandstone and conglomerate. Younger limestone and black shale

Textures Amygdules. Flow-top breccias

Age Range Proterozoic, Triassic-Jurassic, any Phanerozoic age

Depositional Environment Copper-rich (100-200 ppm) subaerial basaltic volcanism followed by shallow marine peralic basin, Near paleo equator

Tectonic Setting(s) Intracontinental rift, continental margin rift. Regional low-grade metamorphism may mobilize copper

Associated Deposit Types Copper shale, red-bed copper

Metal Concentrations Cu, Ag

DEPOSIT DESCRIPTION

Ore Minerals: Native copper, native silver±chalcosite and other Cu_2S minerals. Chalcopyrite in some deposits.

Texture/Structure Disseminated open-space filling. Stratabound and veins

Alteration Calcite-zeolite. Red coloration due to fine hematite

Ore Controls Flow top breccias, amygdules, fractures in basalt organic shale, limestone, in overlying sequence. Limestone is tidal, algal, with stromatolite fossils

Weathering Widely dispersed copper nuggets in streams

Geochemical Signature: Cu Ag

Examples Keweenaw, Michigan (White)
Wrangellia Terrane, Alaska (Bateman)
Sierra de Perija

References Maze, W. B., 1982
Champetier de Ribes and others, 1963

DEPOSIT TYPE Dolomitic copper cobalt SUBTYPE

AUTHOR D. P. Cox DATE

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Cu, Co, U in stratiform deposits in carbonates and shale

GENERAL REFERENCE Bartholome, 1974

GEOLOGICAL ENVIRONMENT

Rock Types Dolomite, limestone, shale, siliceous dolomite, carbonaceous shale

Textures Finely laminated dolomite, stromatolites, solution breccias

Age Range Proterozoic-Zaire; Devonian-Alaska

Depositional Environment Intertidal marine. Transgressive-regressive deposition. Reducing environment. Hypersaline

Tectonic Setting(s) Intracontinental rift. Passive margin rift.

Associated Deposit Types None

Metal Concentrations Cu, Co, U, V, Ge, Zn, Pb, Ga, Bi, Pt, Pd

DEPOSIT DESCRIPTION

Ore Minerals: Bornite+chalcopyrite+pyrite+carrollite±linnaeite+chalcocite± cobaltiferous pyrite. Traces of germanite, pitchblende. At Ruby Creek, assemblage includes sphalerite plus traces of galena and late tetrahedrite

Texture/Structure Finely laminated fine grained. At Ruby Creek, breccia filling

Alteration Dolomite-magnesite, relation to mineralization is not clear. Dolomite breccia with fine pyrite matrix

Ore Controls Paleoaquifers, paleo redox boundaries. At Ruby Creek, dolomite breccia with fine pyrite matrix.

Weathering Malachite, azurite, black Co oxide or pink arsenate

Geochemical Signature: Cu, Co, U, V, Ge, Ga, Pt, Pd. At Ruby Creek also Zn, Pb, As, Sb

Examples Zaire Copper Belt
Ruby Creek, Alaska
Kona Dolomite, Michigan

References

DEPOSIT TYPE Sandstone Uranium SUBTYPE Roll front, epigenetic carbonaceous

AUTHOR C. A. Hodges DATE December 15, 1982

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Concentrations of uranium oxides in localized reduced environments within medium- to coarse-grained sedimentary beds

GENERAL REFERENCE Nash and others, 1981

GEOLOGICAL ENVIRONMENT

Rock Types Feldspathic or tuffaceous sandstone, arkose, mudstone, conglomerate

Textures Permeable--medium to coarse grained; highly permeable during mineralization, subsequently restricted by cementation and alteration

Age Range Post-Silurian (<0.4 b.y.); roll-front deposits mainly Tertiary

Depositional Environment Continental--basin margins, fluvial channels, fluvial fans (especially mid-fan facies), stable coastal plain; nearby felsic plutons or felsic volcanics

Tectonic Setting(s) Stable platform or foreland-interior basin, shelf margin; adjacent major uplifts provide favorable topographic conditions

Associated Deposit Types Hydrocarbon source rocks; "red-bed Cu" deposits may be in similar host rocks and may contain U

Metal Concentrations FeS_2, Se, Mo, V

DEPOSIT DESCRIPTION

Ore Minerals: Pitchblende, coffinite, carnotite--almost invariably associated with pyrite; Se, Mo, V commonly in zonal arrangement, caused by geochemical gradient--Se generally richer in oxidized facies

Texture/Structure Stratabound deposits--tabular or roll front; disseminated mineralization

Alteration Host rocks typically contain both diagenetically reduced and oxidized facies; V ores in reduced facies (typically gray-green-white) or concentrated at interface (see diagram)

Ore Controls Permeability; adsorptive agents (humic materials, Ti oxides); reducing agents--C matter, reduced S species, "sour" gas, FeS_2; bedded sequences with low dips; felsic plutons or tuffaceous seds adjacent to or above host rock are favorable source rocks

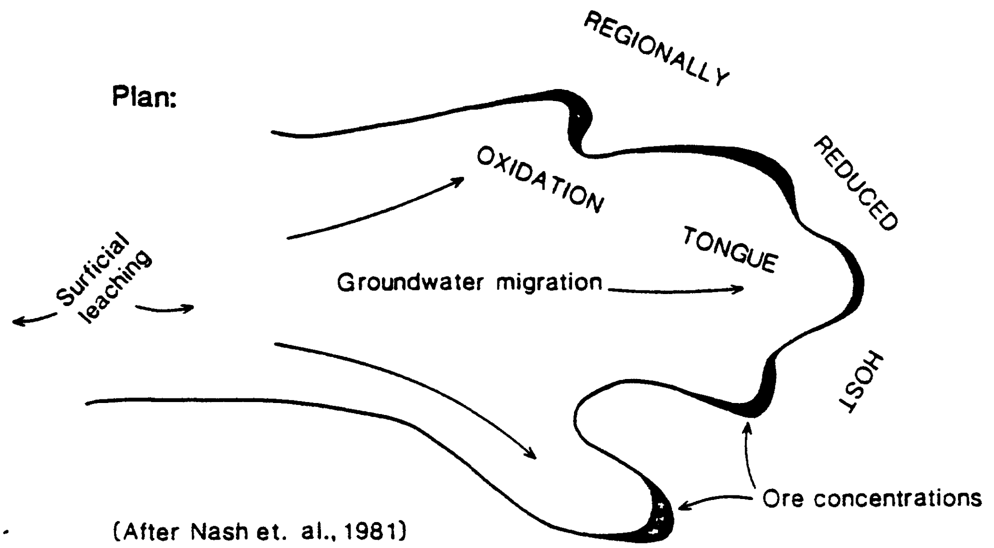
Weathering Oxidation of primary pitchblende, coffinite carnotite; little effect on ore grade or localization

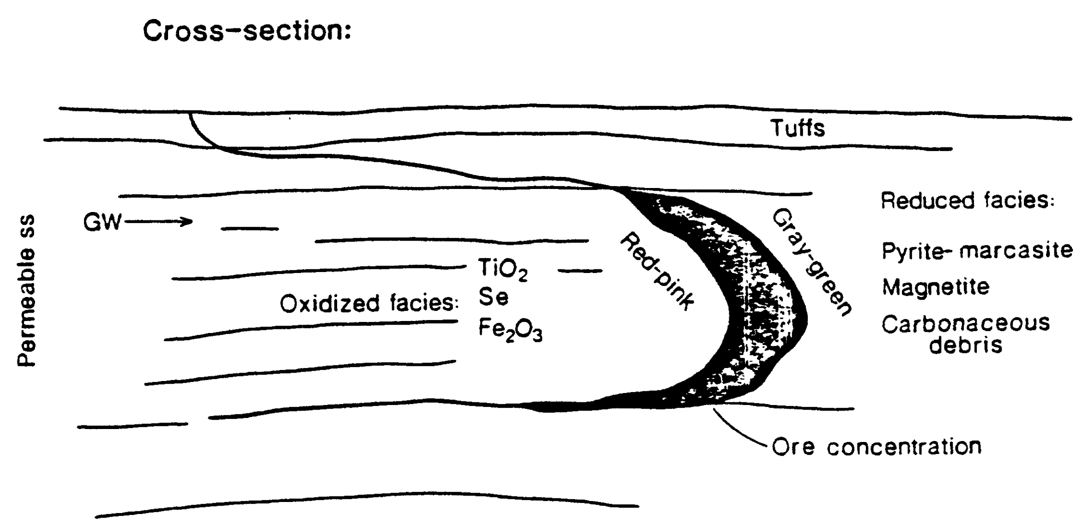
Geochemical Signature: Anomalous radioactivity (5 to 10 x normal background); low redox potential; carbonaceous material, FeS_2, other reducing agents required; Se, Mo, V, Cu commonly associated

Examples Colorado Plateau
Grants, New Mexico
Texas Gulf Coast (ross frong)

References Isachsen and Evernsen, 1956; Hilpert, 1969; Eargle and others, 1975

Roll type uranium deposit 4.4





DEPOSIT TYPE Sediment-hosted, submarine exhalative Zn-Pb **SUBTYPE**

AUTHOR Joseph A. Briskey **DATE** 12/28/82

APPROXIMATE SYNONYM Shale-hosted Zn-Pb **OF (REFERENCE)**

DESCRIPTION Stratiform basinal accumulations of sulfide and sulfate minerals interbedded with euxinitic marine sediments

GENERAL REFERENCE Large (1980)

GEOLOGICAL ENVIRONMENT

Rock Types Euxinitic sedimentary rocks including: black shale, siltstone, sandstone, chert, dolostone, and micritic limestone

Textures Contrasting sedimentary thicknesses and facies changes across hinge zones. Slump breccias and conglomerates near synsedimentary faults

Age Range Middle Proterozoic (1,700-1,400 Ma); Ordovician to Mississippian (530-300 Ma)

Depositional Environment Epicratonic marine basins or embayments, with smaller local restricted basins

Tectonic Setting(s) Epicratonic basins or embayments associated with hinge zones controlled by synsedimentary faults

Associated Deposit Types Stratiform barite deposits

Metal Concentrations Highest expected background in black shales: Pb = 500 ppm; Zn = 1,300 ppm; Cu = 750 ppm; Ba = 1,300 ppm

DEPOSIT DESCRIPTION

Ore Minerals: Pyrite, pyrrhotite, sphalerite, galena, sporadic barite, and chalcopyrite, and minor to trace amounts of marcasite, arsenopyrite, bismuthinite, molybdenite, enargite, millerite, freibergite, cobaltite, cassiterite, valleriite, and melnicovite

Texture/Structure Finely crystalline an disseminated. Metamorphosed examples are coarsely crystalline and massive

Alteration Stockwork and disseminated sulfide and alteration (silicification, tourmalization, carbonate depletion, albitization, chloritization, dolomitization) minerals representing the feeder zone of these deposits commonly present beneath or adjacent to stratiform deposits

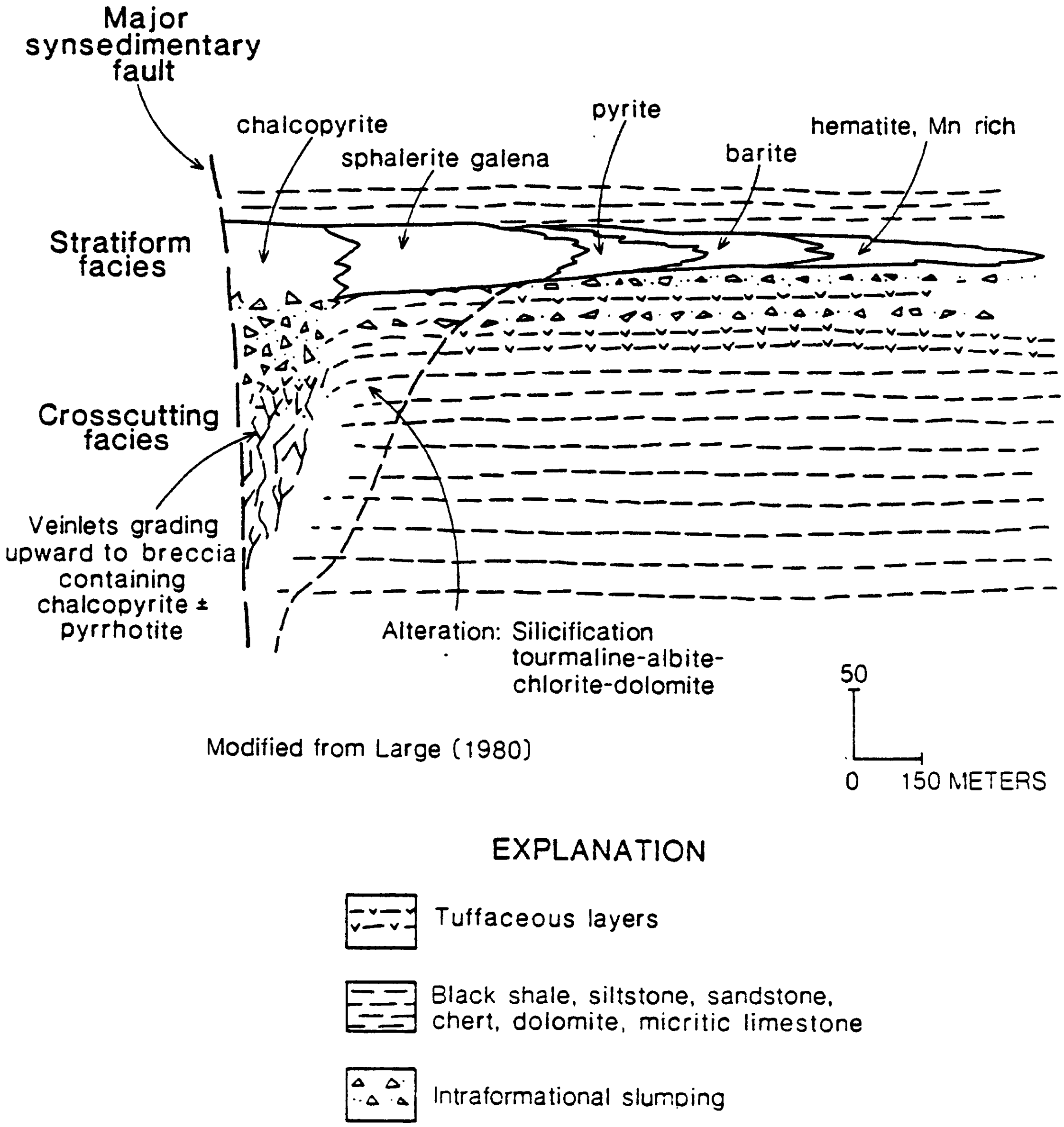
Ore Controls Within larger fault-controlled basins, small local basins form the morphological traps that contain the stratiform sulfide and sulfate minerals. The faults are synsedimentary and serve as feeders for the stratiform deposits

Weathering Surface oxidation may form large gossans containing abundant carbonates, sulfates, and silicates of lead, zinc, and copper

Geochemical Signature: Metal zoning includes lateral Cu-Pb-Zn-Ba sequence extending outward from feeder zone; or a vertical Cu-Zn-Pb-Ba sequence extending inward. Exhalative chert interbedded with stratiform sulfide and sulfate minerals. Regional Mn halos

Examples Sullivan mine, Canada References Hamilton and others (1981)

Sediment hosted submarine exhalative zinc-lead deposit 4.5



Modified from Large (1980)

DEPOSIT TYPE Stratabound Carbonate-hosted Pb-Zn SUBTYPE Southeast Missouri type

AUTHOR Joseph A. Briskey DATE 1/5/83

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Stratabound carbonate-hosted deposits of galena, sphalerite, and chalcopyrite in rocks having primary and secondary porosity, commonly related to reefs on paleotopographic highs

GENERAL REFERENCE Snyder and Gerdemann (1968)

GEOLOGICAL ENVIRONMENT

Rock Types Dolomite; locally ore bodies also occur in sandstone, conglomerate, and calcareous shales

Textures Calcarenites are most common lithology. Tidalites, stromatolite finger reefs, reef breccias, slump breccias; oolites, cross bedding, slump breccias, micrites

Age Range Cambrian to Lower Ordovician

Depositional Environment Shallow-water marine carbonate sedimentation, with prominent facies control by reefs growing on flanks of paleotopographic basement highs

Tectonic Setting(s) Stable cratonic platform

Associated Deposit Types Precmabrian deposits of magnetite-hematite, and magnetite-copper (±Co, Ni, Ba); Ba-Pb deposits occur higher in the Cambrian section

Metal Concentrations Background for carbonates: Pb = 9 ppm; Zn = 20; Cu = 4

DEPOSIT DESCRIPTION

Ore Minerals: Galena, sphalerite, chalcopyrite, pyrite, marcasite, siegenite, bornite, tennantite, barite, bravoite, digenite, covellite, arsenopyrite, fletcherite, adularia, pyrrhotite, magnetite, millerite, polydymite, vaesite, djurleite, chalcocite, anilite, and enargite in order of abundance

Texture/Structure Early fine-grained replacement; main stage coarse grained; some colloform; dissolution

Alteration Regional dolomitization; latter brown, ferroan and bitumin-rich dolomite; extensive dissolution and development of residual shales; mixed-layer illite-chlorite altered to 2M muscovite; dickite and kaolinite in vugs; very minor adularia

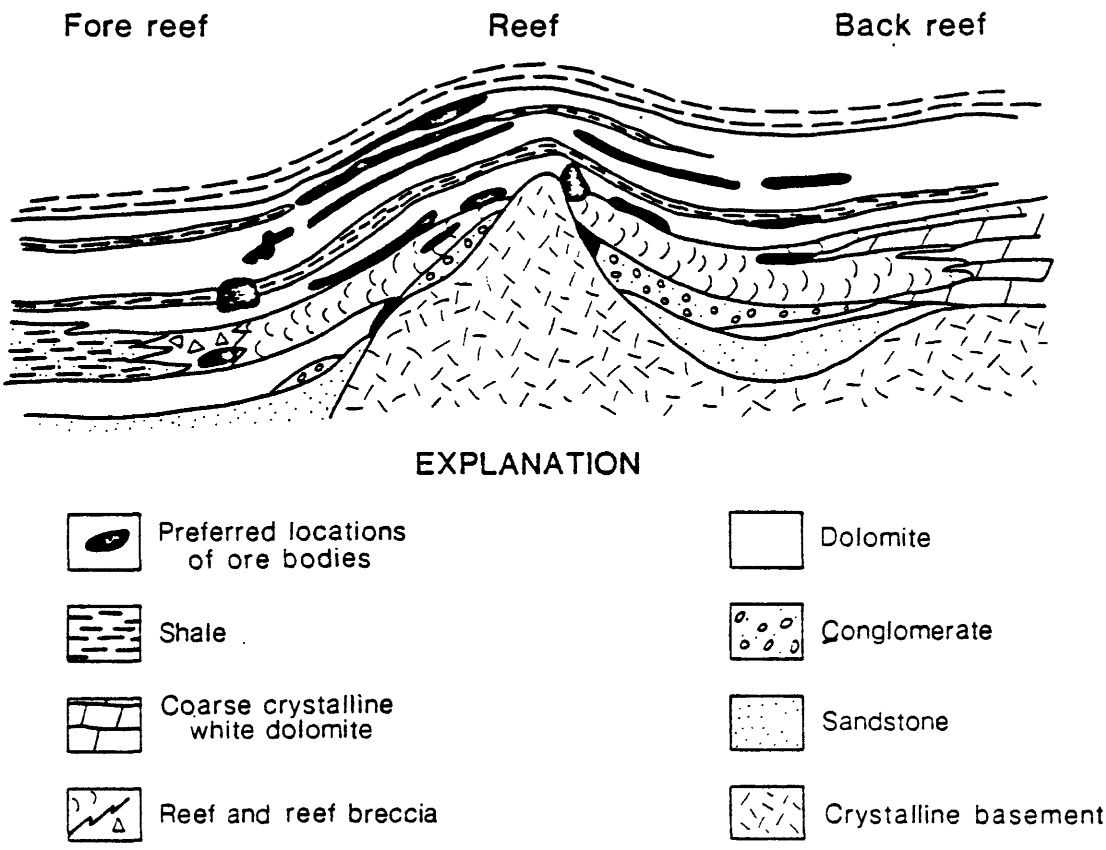
Ore Controls Numerous! Open-space filling and replacement, most commonly at the interface between gray and tan dolomite, but also in traps at any interface between permeable and impermeable units. Any porous units may host ore: sandstone pinchouts; dissolution collapse breccias; faults; permeable reefs; slump, reef, and fault breccias; coarsely crystalline dolostone; etc.

4.6 (continued)

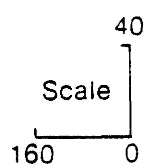
<u>Geochemical Signature:</u> Regional anomalous amounts of Pb, Zn, Cu, Mo, Ag, Co, and Ni in insoluble residues. Zoning is roughly Cu (+Ni+Co)-Pb-Zn-iron sulfide going up section; inconsistent lateral separation of metal zones

<u>Examples</u> Viburnum subdistrict <u>References</u> Heyl (1982)

Carbonate hosted lead-zinc 4.6



Generalized cross section of the Viburuum trend, S.E. Missouri. Modified from Evans, 1977



DEPOSIT TYPE Stratabound carbonate-hosted zinc-lead deposits SUBTYPE Appalachian type

AUTHOR Joseph A. Briskey DATE January 5, 1983

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Stratabound deposits of sphalerite and minor galena in primary and secondary voids in favorable beds or horizons in thick platform dolostone and limestone

GENERAL REFERENCE Hoagland (1976)

GEOLOGICAL ENVIRONMENT

Rock Types Dolostone and limestone

Textures Subtidal, intratidal, and supratidal textures are common, especially in the dolostones; limestones are commonly micritic, some with birdseye textures

Age Range Deposits occur in rocks of cambrian to middle Ordovician age.

Depositional Environment Shallow-water, tidal and subtidal marine environments

Tectonic Setting(s) Stable continental shelf

Associated Deposit Types Stratabound carbonate-hosted deposits of barite-fluorite-sphalerite, and of limonite-siderite-(±sphalerite)

Metal Concentrations Background in carbonate rocks: Zn = 20 ppm; Pb = 9 ppm

DEPOSIT DESCRIPTION

Ore Minerals: Sphalerite, with variable but subordinate pyrite and minor marcasite, and with minor barite, fluorite, gypsum, and anhydrite. Galena is usually absent or rare, but may be locally the third most abundant mineral behind sphalerite and pyrite

Texture/Structure Coarse to medium crystalline, with concentric growth banding

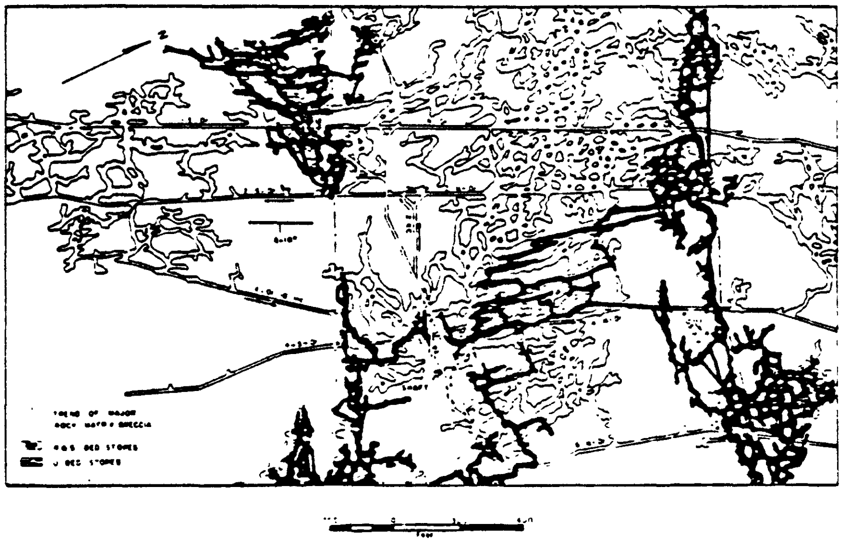
Alteration Extensive dolomitization occurs regionally and in close proximity to ore bodies. Silicification is typically closely associated with ore bodies. Extensive limestone dissolution and development of residual shales

Ore Controls Ore occurs within dissolution collapse breccias that occupy (1) readily soluble limestone beds, or (2) paleo-aquifer solution channels controlled by fractures or folds in limestone

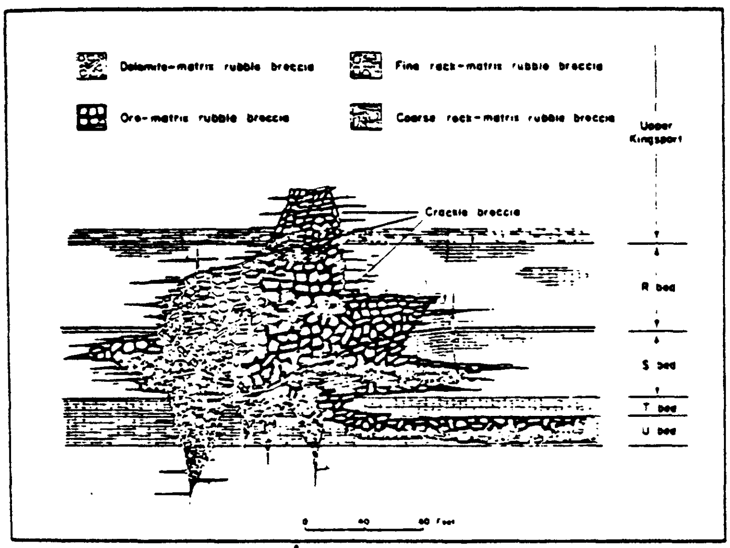
Weathering Zinc silicate and carbonate ores form in the zone of weathering and oxidation

Geochemical Signature: Oxidized sphalerite at the surface caused readily detectable zinc anomalies in residual soils and in stream sediments. Primary zinc haloes in carbonate rocks near ore are not large enough to assist in exploration

Examples East Tennessee zinc district References Crawford and Hoagland (1968)



Plan map of part of the Jefferson City mine, Jefferson City, Tennessee. After Fulweiler and McDougal, 1971.



Generalized cross section through an ore trend in the Jefferson City mine, Tennessee. After Crawford, Johnson, and Hoagland, A.D., 1968.

DEPOSIT TYPE Sandstone-hosted Pb-Zn SUBTYPE

AUTHOR Joseph A. Briskey DATE December 28, 1982

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Stratabound to stratiform galena and sphalerite in multiple, thin, sheetlike ore bodies in arenaceous sedimentary rocks

GENERAL REFERENCE Briskey (1982)

GEOLOGICAL ENVIRONMENT

Rock Types Continental, terrigenous, and marine arenaceous quartzitic and arkosic sandstones, conglomerates, grits, and siltstones

Textures Bedding, crossbedding, paleochannels, liquification structures, and intraformational slump breccias. Quartz and calcite cement

Age Range Proterozoic to Cretaceous host rocks

Depositional Environment Host rocks deposited in piedmont, lagoonal-lacustrine, lagoonal-deltaic, lagoonal-beach, and tidal channel-sand bar environments

Tectonic Setting(s) Marine platform or piedmont sedimentation associated with at least some orogenic uplift

Associated Deposit Types Sandstone-hosted copper deposits

Metal Concentrations Background in sandstone: Pb = 7 ppm; Zn = 16 ppm

DEPOSIT DESCRIPTION

Ore Minerals: Fine- to medium-crystalline galena with sporadic smaller amounts of sphalerite, pyrite, barite, and fluorite. Minor chalcopyrite, tetrahedrite-tennantite, chalcocite, freibergite, bournonite, bornite. Quartz and calcite are usual gangue minerals

Texture/Structure Clots 0.5 to several centimeters in diameter; disseminations 0.1-1 mm dia; locally massive

Alteration "Sericite" (white mica?) reported in some deposits; but may only be recrystallized sedimentary illite?

Ore Controls Intergranular porosity. Ore may be massive where localized by sedimentary structures (above), impermeable barriers, faults, joints, and fractures. Within or immediately above paleochannels or paleoridges. With organic matter.

Weathering Surface oxidation of galena to cerussite, chalcopyrite to malachite, and probably of sphalerite to smithsonite, hemimorphite, etc.

Geochemical Signature: Anomalous amounts of Pb and Zn in host rocks and derivative soils; Ba, Fl, and Ag are enriched in lowermost parts of some deposits

Examples Laisvall mine, Sweden References Rickard and others (1979)

DEPOSIT TYPE Bedded barite SUBTYPE

AUTHOR G. J. Orris DATE June 29, 1983

APPROXIMATE SYNONYM Stratiform barite OF (REFERENCE)

DESCRIPTION Stratiform basin deposits of barite interbedded with chert, shale, and limestone or dolostone.
GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types Generally dark-colored chert, shale, limestone or dolostone.

Age Range Proterozoic-Paleozoic.

Depositional Environment Epicratonic marine basins or embayments (often with smaller local restricted basins).
Tectonic Setting(s) Some deposits associated with hinge zones controlled by synsedimentary faults (sediment-hosted, submarine exhalative model).

Associated Deposit Types Sediment-hosted, submarine exhalative Zn-Pb.

Metal Concentrations Ba (peripherally Pb, Zn, Mn)

DEPOSIT DESCRIPTION

Ore Minerals: Barite±minor witherite±minor pyrite, galena, or sphalerite.

Texture/Structure Stratiform - often lensoid to poddy; ore laminated to massive with associated layers of barite nodules or rosettes; barite may exhibit primary sedimentary features.

Alteration Secondary barite veining.

Ore Controls Basins form morphological traps

Weathering Indistinct - generally resembling limestone or dolostone; occasionally weathered-out rosettes or nodules
Geochemical Signature: Ba; where peripheral to sediment-hosted Zn-Pb, may have lateral (Cu)-Pb-Zn-Ba zoning and/or regional manganese halos

Examples	References
Meggen, Germany	Krebs (1981)
Magnet Cove, Arkansas	Scull (1958)
Northumberland, Nevada	Shawe and others (1969)

DEPOSIT TYPE Sedimentary exhalative CuZn SUBTYPE

AUTHOR Dennis P. Cox DATE 10/1/83

APPROXIMATE SYNONYM Besshi Type, Kieslager OF (REFERENCE)

DESCRIPTION Thin, sheet-like bodies of massive to well-laminated pyrite and chalcopyrite within thinly laminated clastic sediments and mafic tuffs.
GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types Clastic terrigenous sedimentary rocks and tholeitic to andesitic tuffs and breccias. Locally, black shale, oxide facies iron formation, and red chert.
Textures Thinly laminated clastic rocks. All known examples are in strongly deformed metamorphic terrane. Rocks are quartzose and mafic schists.
Age Range Mainly Paleozoic and Mesozoic.

Depositional Environment Uncertain. Possibly deposition by submarine hot springs related to basaltic volcanism. Ores may be localized within permeable sediments and fractured volcanics in anoxic marine basins.
Tectonic Setting(s) Uncertain. Possibly rifted basin in island arc or back arc. Possibly spreading ridge underlying terrigenous sediment at continental slope.
Associated Deposit Types Volcanogenic chert-manganese

Metal Concentrations Cu, Ni, Co, Cr, Mn

DEPOSIT DESCRIPTION

Ore Minerals:
Pyrite+pyrrhotite+chalcopyrite+sphalerite±magnetite±valeriite±galena±bornite± tetrahedrite±cobaltite±cubanite. Quartz, carbonate, albite, white mica, chlorite, amphibole, and tourmaline.

Texture/Structure Fine-grained, massive to thinly laminated ore with colliform and framboidal pyrite. Breccia or stringer ore. Cross cutting veins contain chalcopyrite, pyrite, calcite or galena, sphalerite, calcite.
Alteration Difficult to recognize because of metamorphism.

Ore Controls Uncertain. Deposits tend to cluster in enechelon pattern.
Weathering Gossan.

Geochemical Signature: Cu, Zn, Co, Ni, Cr, Co/Ni 0.78, Au (up to 4 ppm) Ag 60 ppm.

Examples Besshi, Japan
Kieslager, Austria
Raul, Peru

References Kanehira and Tatsumi (1970)
Derkman and Klemm (1977)
Ripley and Ohmoto (1977)

DEPOSIT TYPE Replacement

SUBTYPE Limestone Replacement

AUTHOR Hal T. Morris

DATE December 15, 1982

APPROXIMATE SYNONYM Manto deposits

OF (REFERENCE) Many authors

DESCRIPTION A hydrothermal, epigenetic, sulfide mineral deposit, commonly later oxidized, that replaces limestone, dolomite, or other soluble rock.

GENERAL REFERENCE Jensen, M. L., and Bateman, A. M., 1981, p. 134-146.

GEOLOGICAL ENVIRONMENT

Rock Types: Sedimentary rocks, chiefly including limestone, dolomite, and shale, commonly overlain by volcanics and intruded by porphyritic, calc-alkaline plutons.

Textures: The textures of the replaced sedimentary rocks are not important; associated plutons typically are porphyritic.

Age Range: Not important, but many are Late Mesozoic to Early Cenozoic.

Depositional Environment: Carbonate host rocks that commonly occur in broad sedimentary basins, such as epicratonic miogeosynclines.

Tectonic Setting(s): Most deposits occur in mobile belts that have undgergone moderate deformation and have been intruded by small plutons.

Associated Deposit Types: Veins that cut the more massive igneous or sedimentary rocks, skarns, and porphyry-type disseminated copper deposits.

Metal Concentrations Over a broad area associated metals include lead, zinc, silver, copper, gold, arsenic, antimony and bismuth.

DEPOSIT DESCRIPTION

Ore Minerals: Galena, sphalerite, argentite, tetrahedrite, pyrite, enargite chalcopyrite, proustite, pyrargyrite, jamesonite, bournonite, tennantite, jordanite, stephanite, polybasite, sylvanite, calaverite, native gold, bismuthinite, marcasite, barite, quartz, rhodochrosite, calcite, and dolomite.

Texture/Structure: Ranges from massive to highly vuggy and porous.

Alteration: Typical limestone wallrocks are dolomitized and silicified; shales and igneous rocks are chloritized and commonly are argillized; where syngenetic iron oxide minerals are present, rocks are pyritized.

Ore Controls: Tabular, podlike and pipelike ore bodies are locallized by faults or vertical beds; ribbonlike or blanketlike ore bodies are locallized by bedding-plane faults or by susceptible beds.

Weathering: Near the surface, these ore bodies commonly are oxidized to ochreous masses containing cerrusite, anglesite, hemimorphite, and cerargyrite

Geochemical Signature: On a district-wide basis ore deposits commonly are zoned outward from a copper-rich central area through a through a wide lead-silver zone, to a zinc- and manganese-rich fringe.

Examples: 1. East Tintic district, Utah, USA, 2. Mexican Manto desposits, 3. Parana and Sao Paulo, Brazil

References: 1. Morris, H. T., and Lovering, T. S., 1979; 2. Prescott, Basil, 1926; 3. Melcher, G. C., 1968

DEPOSIT TYPE Carbonate-hosted gold SUBTYPE Disseminated gold

AUTHOR Byron R. Berger DATE December 1982

APPROXIMATE SYNONYM Carlin-type or invisible gold OF (REFERENCE)

DESCRIPTION Very fine grained gold and sulfides disseminated carbonaceous calcareous rocks

GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types Host rocks: thin-bedded silty or argillaceous carbonaceous limestone or dolomite often with carbonaceous shales. Intrusive rocks: felsic dikes, often porphyritic

Textures

Age Range Mainly Tertiary, but can be any age

Depositional Environment Association with intrusive. Best host rocks formed as carbonate turbidites in somewhat anoxic environments. Deposits formed where these are intruded by igneous rocks under nonmarine conditions.

Tectonic Setting(s) High-angle normal fault zones

Associated Deposit Types Tungsten-moly skarn, porphyry molybdenum, placer gold, stibnite-barite veins

Metal Concentrations Hg, Sb, As, Mo, W

DEPOSIT DESCRIPTION

Ore Minerals: Native gold (very fine grained)+pyrite+realgar+orpiment± arsenopyrite±cinnabar±fluorite±barite

Texture/Structure Silica replacement of carbonate, generally less than 1 percent fine-grained sulfides

Alteration Unoxidized ore: "jasperoid"+quartz+illite+kaolinite+calcite. Hypogene oxidized ore: kaolinite+montmorillonite+illite+jarosite+alunite

Ore Controls Selective replacement of carbonaceous carbonate rocks adjacent to and along high-angle faults or regional thrust faults

Weathering Light red gray and (or) tan oxides, light brown to reddish brown iron-oxide stained jasperoid

Geochemical Signature: Au+As+Hg+W±Mo As+Hg+Sb+Tl±F (this stage superimposed on preceding)

Examples Carlin, Nevada
Getchell, Nevada
Mercur, Utah

References Radtke, Rye and Dickson, 1980
Joralemon, 1951
Gilluly, 1932

DEPOSIT TYPE Low-sulfide quartz veins **SUBTYPE**

AUTHOR Byron R. Berger **DATE** December 1982

APPROXIMATE SYNONYM Mesothermal quartz veins **OF (REFERENCE)**

DESCRIPTION Gold in massive persistent quartz veins mainly in regionally metamorphosed volcanics and volcanic sediments

GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types Greenstone belts; oceanic sediments: graywacke, shale, quartzite, batholithic terranes

Textures

Age Range Precambrian to Tertiary

Depositional Environment Continental margin mobile belts, accreted margins

Tectonic Setting(s) Fault and joint systems

Associated Deposit Types Massive sulfide, iron formation, volcanogenic gold, skarn

Metal Concentrations Ag+Pb+Zn, Cu+Pb+Zn

DEPOSIT DESCRIPTION

Ore Minerals: Native gold+pyrite+galena+sphalerite+arsenopyrite±pyrrhotite. May get tellurides±scheelite±bismuth±molybdenite±fluorite. Productive quartz is grayish or bluish in many instances because fine-grained sulfides

Texture/Structure Saddle reefs, ribbon quartz, absence of open-space filling

Alteration Quartz+siderite and (or) ankerite±albite in veins with selvage of quartz+chlorite±biotite. Wallrock alteration is minimal, chromium mica in areas of mafic volcanism

Ore Controls Veins are persistent along regional high-angle faults, joint sets. Best deposits overall in areas with greenstones

Weathering

Geochemical Signature: Arsenic best pathfinder in general

Examples Yellowknife, Canada
Mother Lode, Grass Valley areas, Calif.
Appalachian slate belt, U.S.A.

References Boyle, 1970
Lindgren 1896, and Knopf 1929

DEPOSIT TYPE Epithermal Gold, Silver SUBTYPE Quartz-Adularia

AUTHOR Byron R. Berger DATE December, 1982

APPROXIMATE SYNONYM Precious-and base-metal veins OF (REFERENCE)

DESCRIPTION Gold in vuggy quartz veins with abundant pyrite, arsenopyrite, sphalerite and galena.

GENERAL REFERENCE Buchanon, 1980

GEOLOGICAL ENVIRONMENT

Rock Types Areas of volcanism: andesite, dacite, quartz latite, rhyodacite, rhyolite

Textures Porphyritic

Age Range Mainly Tertiary for bonanza deposits, but may be any age

Depositional Environment Centers of volcanism and associated intrusive activity for bonanza deposits; batholiths

Tectonic Setting(s) Through-going fractures systems; major normal faults, fractures related to doming, ring fracture zones, joints

Associated Deposit Types Placer gold

Metal Concentrations Ag+Pb+Zn, Ag+W+Bi+Pb+Zn

DEPOSIT DESCRIPTION

Ore Minerals: Native gold+electrum+pyrite±arsenopyrite±galena±sphalerite in high Au: Ag deposits. Native gold+electrum+tetrahedrite+pyrite+ galena+sphalerite±barite±rhodaochrosite in high Ag: Au deposits in hypogene oxidized areas of supergene zones gold+ruby silver+native silver

Texture/Structure Banded veins, open space filling, lamellar quartz, stockworks

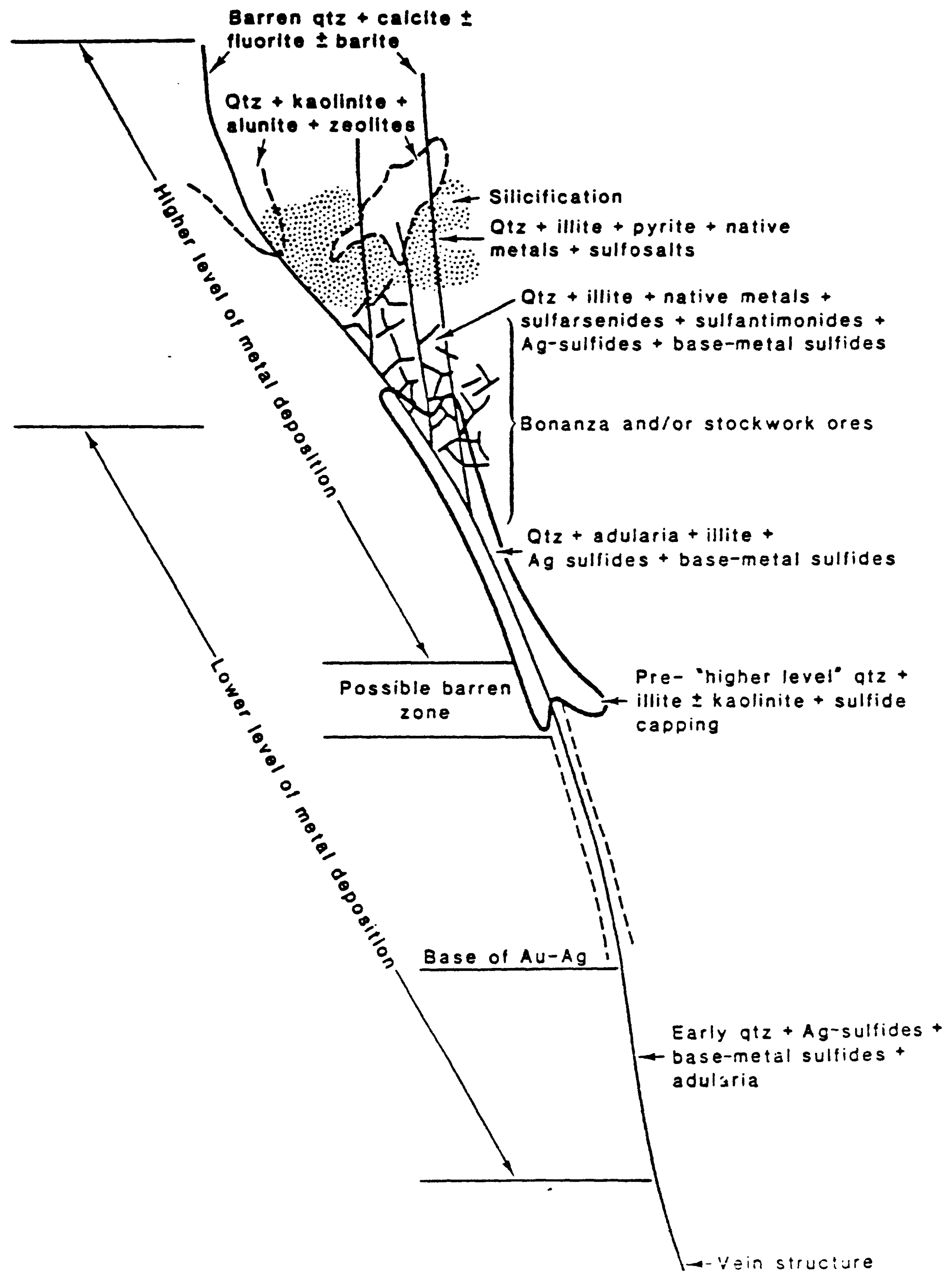
Alteration Top to bottom of system: quartz+kaolinites+montmorillenite± zeolites±barite±calcite; quartz+illite; quartz+adularia±illite; quartz+chorite presence of adularia is variable

Ore Controls Through-going, anastomosing fracture systems

Weathering Bleached country rock, goethite, jarosite, alunite--supergene processes often important factor in increasing grade of deposit

Geochemical Signature: Higher in system Au+As+Sb+Hg; Au+Ag+Pb+Zn+Cu; Ag+Pb+Zn, Cu+Pb+Zn, Base metals generally higher in deposits with silver.

Examples	References
Jarbidge, Nevada	Schrader, 1923
Comstock, Nevada	Becker, 1882
Guanajuato, Mexico	Buchanon, 1980, and Wandke and Martinez, 1928
Creede Colorado	Steven and Ratte, 1965


Barren qtz + calcite ± fluorite ± barite
Qtz + kaolinite + alunite + zeolites
Silicification
Qtz + illite + pyrite + native metals + sulfosalts
Qtz + illite + native metals + sulfarsenides + sulfantimonides + Ag-sulfides + base-metal sulfides
Bonanza and/or stockwork ores
Qtz + adularia + illite + Ag sulfides + base-metal sulfides
Higher level of metal deposition
Possible barren zone
Pre- "higher level" qtz + illite ± kaolinite + sulfide capping
Lower level of metal deposition
Base of Au-Ag
Early qtz + Ag-sulfides + base-metal sulfides + adularia
Vein structure

DEPOSIT TYPE Epithermal gold   SUBTYPE Quartz-alunite

AUTHOR Byron R. Berger   DATE December 1982

APPROXIMATE SYNONYM Acid-sulfate or enargite gold OF (REFERENCE)

DESCRIPTION Gold, pyrite and enargite in vuggy veins and breccias in zones of advanced argillic alteration related to felsic volcanism

GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types Volcanic: dacite, quartz latite, rhyodacite, rhyolite. Hypabyssal intrusions or domes

Textures Porphyritic

Age Range Generally Tertiary, but can be any age

Depositional Environment Within the volcanic edifice, ring fracture zones of calderas, or areas of igneous activity with sedimentary evaporites in basement

Tectonic Setting(s) Throughgoing fracture systems: keystone graben structures, ring fracture zones, normal faults, fractures related to doming, joint sets

Associated Deposit Types Porphyry copper, active or fossil acid-sulfate hot springs, pyrophyllite, hydrothermal clay

Metal Concentrations Copper, arsenic, antimony

DEPOSIT DESCRIPTION

Ore Minerals: Native gold+enargite+pyrite+silver-bearing sulfosalts± chalcopyrite±bornite±precious-metal tellurides±galena±sphalerite±huebnerite. May have hypogene oxidation phase with chalcocite+covellite±luzonite with late-stage native sulfur

Texture/Structure Veins; breccia pipes, pods, dikes; replacement veins often porous, vuggy

Alteration Highest temperature assemblage: quartz+alunite+pyrophyllite; may be early stage of quartz+alunite with pervasive alteration of host rock and veins of these minerals; zoned around quartz-alunite is quartz+alunite+ kaolinite+montmorillonite; pervasive propylitic alteration depends on extent of early alunitization:chlorite+calcite

Ore Controls Through-going fractures, centers of intrusive activity

Weathering Abundant yellow limonites, jarosite, goethite, white argillization with kaolinite, fine-grained white alunite veins, hematite

Geochemical Signature: Higher in system Au+As+Cu with increasing base metals at depth. Also Te, and at El Indio, W

Examples		References
	Goldfield, Nevada	Ransome, 1909
	Kasuga mine, Japan	Taneda and Mukaiyama, 1970

El Indio, Chile	Walthier and others, 1982 unpublished report)

DEPOSIT TYPE Hot Springs Gold Silver SUBTYPE

AUTHOR Byron R. Berger DATE December 1982

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Fine-grained silica and quartz in silicified breccia with gold, pyrite and Sb and As sulfides

GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types Areas of volcanic activity: rhyolite
Textures Porphyritic

Age Range Mainly Tertiary and Quaternary

Depositional Environment Rhyolitic volcanic centers, rhyolite domes

Tectonic Setting(s) Through-going fracture systems

Associated Deposit Types Quartz veins, breccia pipes

Metal Concentrations: Mo, W, Ag-sulfosalts, placer gold

DEPOSIT DESCRIPTION

Ore Minerals: Native gold+pyrite+stibnite+realgar or arsenopyrite±sphalerite±chalcopyrite±fluorite or native gold+Ag-selenide or tellurides+pyrite

Texture/Structure: Structure banded veins, stockworks, breccias (cemented or uncemented w/silica)

Alteration: Top of bottom of system: Chalcedonic sinter, massive silicification, stockworks and veins of quartz+adularia and breccias cemented w/quartz, quartz+chlorite - Veins generally chalcedonic, some opal

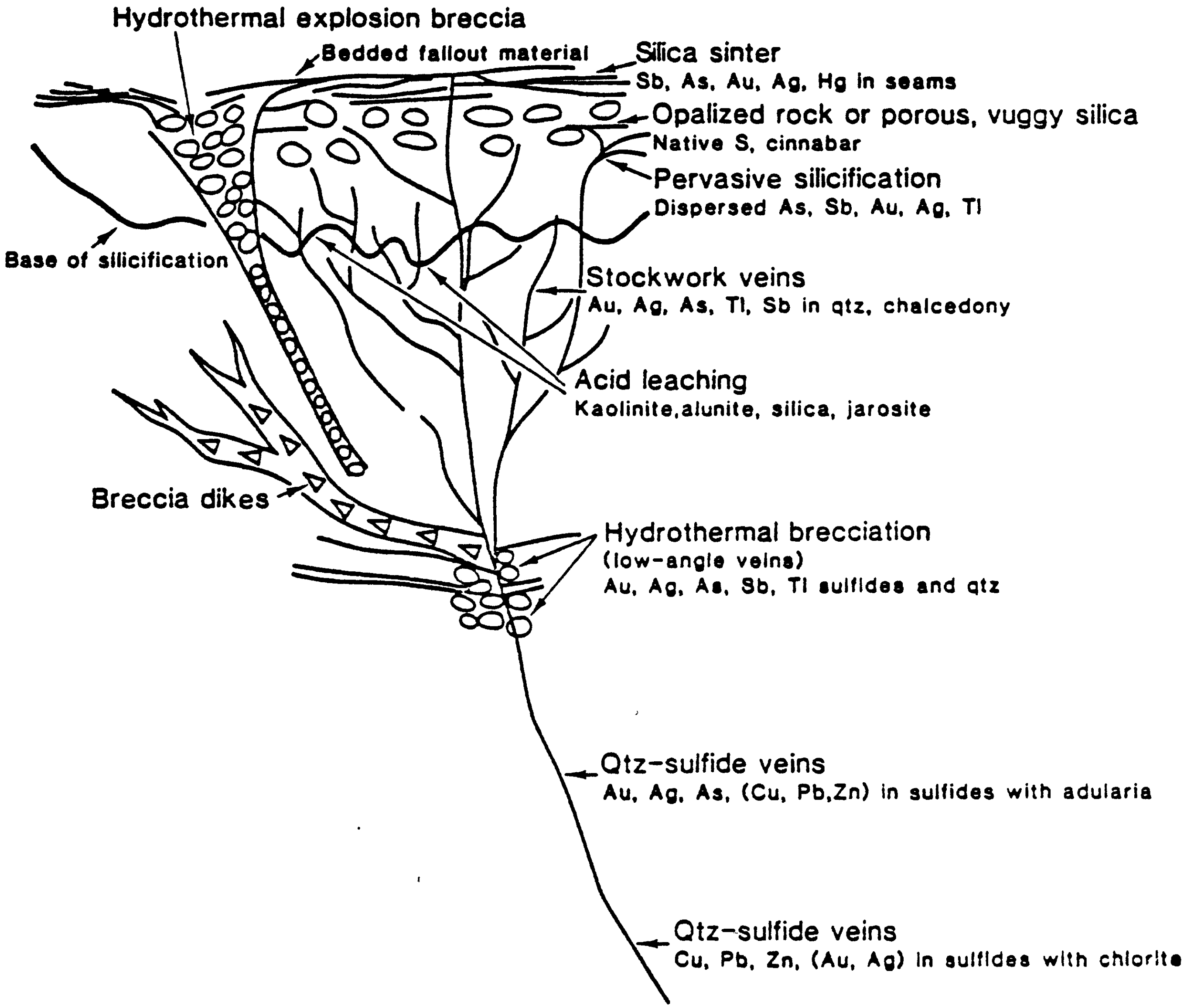
Ore Controls: Through-going fracture systems, brecciated cores of intrusive domes; cemented breccias important carrier of ore

Weathering: Bleached country rock, yellow limonites w/jarosite and fine grained alunite, hematite, goethite

Geochemical Signature: Au+As+Sb+Hg+Tl higher in system, increasing Ag w/depth, decreasing As+Sb+Tl+Hg with depth

Examples
McLaughlin, California
Round Mtn., Nevada
Delamar, Idaho

References
Averitt 1945 and Becker, 1888
Ferguson, 1921
Lindgren, 1900


Hydrothermal explosion breccia
Bedded fallout material
Silica sinter
Sb, As, Au, Ag, Hg in seams
Opalized rock or porous, vuggy silica
Native S, cinnabar
Pervasive silicification
Dispersed As, Sb, Au, Ag, Tl
Base of silicification
Stockwork veins
Au, Ag, As, Tl, Sb in qtz, chalcedony
Acid leaching
Kaolinite,alunite, silica, jarosite
Breccia dikes
Hydrothermal brecciation
(low-angle veins)
Au, Ag, As, Sb, Tl sulfides and qtz
Qtz-sulfide veins
Au, Ag, As, (Cu, Pb,Zn) in sulfides with adularia
Qtz-sulfide veins
Cu, Pb, Zn, (Au, Ag) in sulfides with chlorite

DEPOSIT TYPE Disseminated Hg SUBTYPE Aranzazu type

AUTHOR D. Cox DATE 12/1/82

APPROXIMATE SYNONYM Almaden type OF (REFERENCE)

DESCRIPTION Stratabound disseminated native mercury in volcaniclastic sedimentary rocks

GENERAL REFERENCE Saupe, 1973

GEOLOGICAL ENVIRONMENT

Rock Types Shale, graywacke, calcareous graywacke, andesitic lava and tuff, andesite dikes. Volcanic vent breccia

Textures

Age Range Cretaceous

Depositional Environment Permeable sedimentary rocks, andesite dikes possibly near volcanic center

Tectonic Setting(s) Volcanic centers along major deep-seated fault zone

Associated Deposit Types Stibnite veins

Metal Concentrations Hg As Sb

DEPOSIT DESCRIPTION

Ore Minerals: Native mercury±cinnabar+pyrite+calcite+quartz

Texture/Structure Disseminated

Alteration

Ore Controls Mineralized zone follows major fault, highest grade ore in calcareous graywacke

Weathering

Geochemical Signature: Hg As Sb

Examples Nueva Esperanza, Caldas, Colombia — References Lozano and others (1977)

Almaden, Spain — Saupe (1973)

Santa Barbara, Peru

DEPOSIT TYPE Silica-carbonate Hg SUBTYPE

AUTHOR J. Rytuba DATE January 11, 1983

APPROXIMATE SYNONYM New Almaden OF (REFERENCE)

DESCRIPTION Cinnabar at contact of serpentine and siltstone-graywacke above subduction-related thrust

GENERAL REFERENCE Bailey (1964)

GEOLOGICAL ENVIRONMENT

Rock Types Serpentine, siltstone-graywacke

Textures

Age Range Tertiary

Depositional Environment Serpentine intrusives (sill and dikes) into graywacke and siltstone, fractures in altered serpentine

Tectonic Setting(s) Deposits occur in accreted terrane above subduction-related thrust fault

Associated Deposit Types Stibnite veins

Metal Concentrations Unknown

DEPOSIT DESCRIPTION

Ore Minerals: Cinnabar, native Hg, other minor sulfides: pyrite, stibnite, chalcopyrite, sphalerite, galena, and bornite

Texture/Structure Replacement and minor veins

Alteration Replacement of serpentine by quartz and dolomite and minor hydrocarbons to form "silica-carbonate" rock

Ore Controls Contact of serpentine with siltstone especially where contact forms antiform ore primarily in silica-carbonate rock

Weathering

Geochemical Signature: Unknown, probably Hg Sb Cu Zn

Examples New Almaden, Calif. References Bailey (1964)

DEPOSIT TYPE Hot spring Hg

SUBTYPE

AUTHOR J. Rytuba

DATE January 11, 1983

APPROXIMATE SYNONYM Sulphur Bank

OF (REFERENCE) White, 1981

DESCRIPTION Cinnabar and pyrite disseminated in graywacke, shale, andesite, and basalt flows and diabase dikes

GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types Andesite-basalt flows, diabase dikes, andesitic tuffs, and tuff breccia

Textures

Age Range Tertiary

Depositional Environment Near paleo groundwater table in areas of fossil hot spring system

Tectonic Setting(s) Extensional faulting with associated small volume mafic to intermediate volcanism

Associated Deposit Types Hot Springs gold

Metal Concentrations

DEPOSIT DESCRIPTION

Ore Minerals: Cinnabar - native Hg

Texture/Structure Disseminated and coatings on fractures

Alteration Above paleo groundwater table, kaolinite-alunite-Fe oxides; below paleo groundwater table, pyrite, zeolites, potassium feldspar, chlorite, and quartz. Opal deposited at the paleo water table.

Ore Controls Paleo groundwater table within hot spring systems developed along high-angle faults

Weathering

Geochemical Signature: Hg As Sb ±Au

Examples Sulfur bank, California

References White and Roberson (1962)

DEPOSIT TYPE Emerald veins SUBTYPE

AUTHOR D. Cox DATE 2/24/83

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Emerald in plagioclase-dolomite veins in black shale

GENERAL REFERENCE Escovar, 1979

GEOLOGICAL ENVIRONMENT

Rock Types Black shale, claystone, siltstone. Minor sandstone, limestone and conglomerate. Locally coarse dolomite breccia filled by carbonates and oligoclase.

Textures Diabasic diorite dikes present but not prominent.

Age Range Cretaceous-Tertiary

Depositional Environment Thick epicontinental marine shale. Evaporites may have provided saline solutions.

Tectonic Setting(s) Major faults. Minor intrusions may have provided heat sources for fluid circulation.

Associated Deposit Types May be associated with Pb-Zn deposits

Metal Concentrations Be±Pb-Zn

DEPOSIT DESCRIPTION

Ore Minerals: Emerald+greenish berly+oligoclase+dolomite+calcite+ pyrite±fluorite±rutile±quartz

Texture/Structure Crustified banding, vuggy, coarsely crystalline

Alteration Shales altered to black hornfels, fossils replaced by oligoclase. Dolomitization

Ore Controls Major fault at intersections of minor cross faults sharp-walled veins and tabular breccia bodies

Weathering Plagioclase weathers to pockets of kaolinite

Geochemical Signature: In veins: high Be, Na, Mg; low Li, Ba, K, Mo, Pb relative to shales outside of mineralized areas

Examples Gachala District Colombia References Escobar, 1979

DEPOSIT TYPE Tin-tungsten veins SUBTYPE

AUTHOR William C. Bagby DATE February 1983

APPROXIMATE SYNONYM Dike-vein systems OF (REFERENCE)

DESCRIPTION Wolframite, cassiterite, quartz, siderite, arsenopyrite veins in metamorphic rocks above large granitic batholiths

GENERAL REFERENCE Grant, J. N., et al, 1980

GEOLOGICAL ENVIRONMENT

Rock Types Hornfels comprised of quartzites and shales; schists with volumetrically minor granitic intrusions

Textures Fine-grained sediments metamorphosed to schists and hornfels.

Age Range Mesozoic and younger

Depositional Environment Open fracture filling in country rocks above massive granitic intrusions

Tectonic Setting(s) Andean arc farthest from trench

Associated Deposit Types Sn-W placer deposits. Veins may grade into porphyry tin deposits with depth.

Metal Concentrations As, Sn, Be, Sb, Pb, Zn, Cu

DEPOSIT DESCRIPTION

Ore Minerals: Wolframite (ferberite, hubnerite) and cassiterite are major ore minerals accompanied by quartz, siderite, arsenopyrite, tourmaline, apatite, pyrrhotite, pyrite, vivianite, chalcopyrite, and sphalerite. See cartoon for zoning

Texture/Structure Veins are massive quartz siderite with Sn/W ore minerals

Alteration Quartz+tourmaline is intense at deposit center. This grades outward through sericite+pyrite to propylitic (calcite+pyrite)

Ore Controls Open fractures in shear zones and breccia pipes above diffentiating granitic batholiths. Temperatures are high (390°C for Chicote Grande)

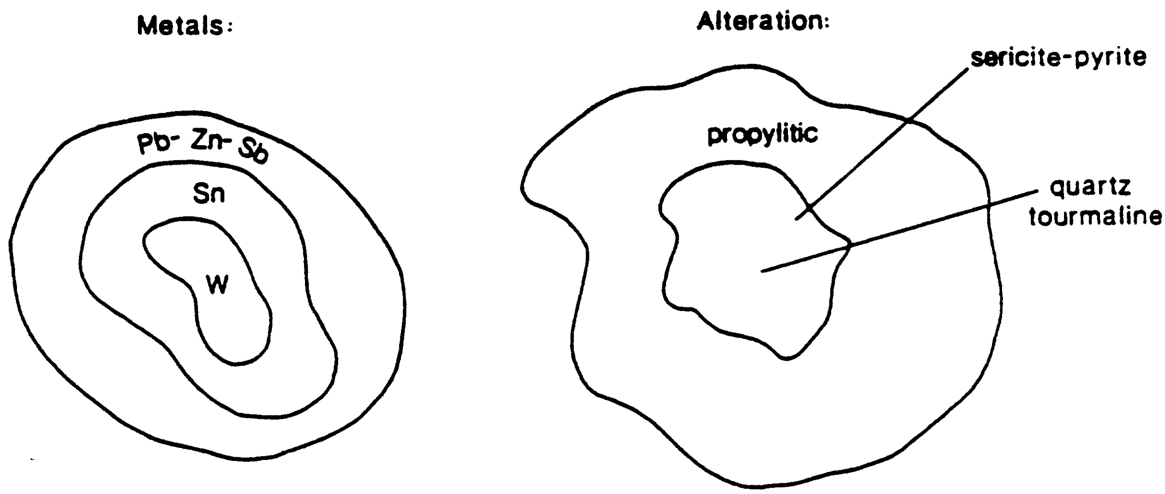
Weathering Weathering of arsenopyrite results in jarosite-rich deposits which are easily eroded creating placer deposits of wolfranite and cassiterite

Geochemical Signature: As and Sb are anomalously high

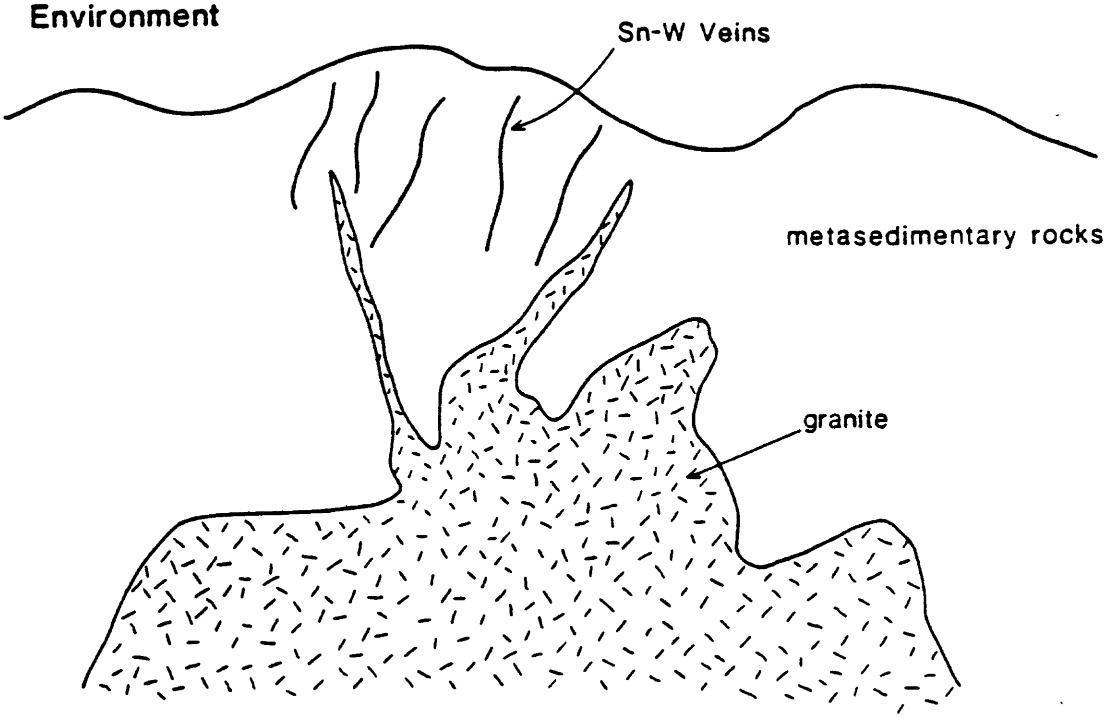
Examples
Isla de Pinos, Cuba
Chicote Grande Bolivia
Huanuni, Bolivia

References
Page L. R., and McAllister, J. F., 1944
Personal Visit
Grant, J. N., et al, 1980

Zoning Patterns



Depositional Environment



From Grant, J.N. and others 1980

DEPOSIT TYPE Volcanogenic Uranium **SUBTYPE**

AUTHOR William C. Bagby **DATE** February 14, 1983

APPROXIMATE SYNONYM **OF (REFERENCE)**

DESCRIPTION Uranium mineralization in epithermal veins comprised of quartz fluorite, and iron, arsenic, and molybdenum sulfides

GENERAL REFERENCE Nash, J. T., 1981

GEOLOGICAL ENVIRONMENT

Rock Types High silica alkali rhyolite and potash trachytes. Both peralkaline and peraluminous rhyolite, host ore

Textures Porphyritic to aphyric vesicular flows and shallow intrusives

Age Range Pre-Cambrian to Tertiary

Depositional Environment Subaerial to subaqueous volcanic complexes. Near-surface environment, association with shallow intrusives is important

Tectonic Setting(s) Continental rifts and associated calderas

Associated Deposit Types Roll front uranium in volcaniclastic sediments

Metal Concentrations Hg, Li, Be, Mo, ±B, ±REE

DEPOSIT DESCRIPTION

Ore Minerals: Coffinite, uraninite, brannerite are most common uranium minerals. Other minerals include pyrite, realgar/orpiment, jordisite, leuroxene, fluorite, quartz, adularia, and barite. Gold is present in some deposits. Deposits associated with alkaline complexes may contain bastnaesite.

Texture/Structure Open-space filling in breccias. Uraninite commonly encapsulated in silica.

Alteration Kaolinite, montmorillonite, and alunite are common. Silicification, accompanied by adularia, affects wall rocks spatially most closely associated with ore.

Ore Controls Through-going fractures and breccias formed along the margins of shallow intrusives. Vugs in surface flows are of minor importance

Weathering Near surface oxidation produces a variety of secondary uranium minerals. Supergene uranium enrichment is generally not important.

Geochemical Signature: Li and Hg are zoned away from the ore. High anomalous As, Sb, F, Mo, ±W occur near and with the ore. Mo is deep. Hg is shallow. REE maybe highly anomalous.

Examples Marysvale, Utah
Autota prospect, Oregon
Rexspar British Columbia

References Kerr, P. F., et al 1957
Roper, M. W., Wallace, A. B., 1981
Joubin, F. R., and James, D. G., 1957

DEPOSIT TYPE Subaerial volcanogenic manganese SUBTYPE

AUTHOR D. L. Mosier DATE July 1983

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Manganese mineralization in epithermal veins filling faults and fractures in subaerial volcanic rocks.
GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types Flows, tuffs, breccias, and agglomerates of rhyolitic, dacitic, andesitic or basaltic composition.
Textures

Age Range Tertiary
Depositional Environment Volcanic centers

Tectonic Setting(s) Through-going fracture systems

Associated Deposit Types Epithermal gold-silver

Metal Concentrations Mn, Fe, P, (Pb, Ag, Au, Cu)

DEPOSIT DESCRIPTION

Ore Minerals: Psilomelane, pyrolusite, braunite, wad, manganite, rhodochrosite, cryptomelane, hollandite, coronadite, Fe oxides, manganocalcite, calcite, quartz chalcedony, barite, zeolites.
Texture/Structure Veins, bunches, stringers, nodular masses, disseminations.
Alteration Kaolinitization

Ore Controls Through-going faults and fractures; brecciated volcanic rocks.

Weathering Oxidized zone contains abundant manganese and iron oxides and kaolinite.
Geochemical Signature:

Examples Talamantes, Mexico
Gloryana, New Mexico
Sardegna, Italy

References Rocha and Wilson (1948)
Farnham (1961)
Burckhardt and Falini (1956)

DEPOSIT TYPE Carbonate-hosted manganese replacement SUBTYPE

AUTHOR D. L. Mosier DATE July 1983

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Manganese mineralization occurs as epigenetic veins or cavity-fillings in limestone, dolomite, or marble, which may be associated with intrusive complexes.

GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types Limestone, dolomite, marble, and associated sedimentary rocks; granite and granodiorite plutons.

Textures

Age Range Mainly Paleozoic and Mesozoic, but may be any age.

Depositional Environment Miogeosynclinal sequences intruded by small plutons.

Tectonic Setting(s) Continental margin, late orogenic magmatism.

Associated Deposit Types Silver-bearing replacement vein deposit; skarn deposits; replacement lead-zinc.

Metal Concentrations Mn, Fe, P, Cu, Ag, Au, Pb, Zn

DEPOSIT DESCRIPTION

Ore Minerals:
Psilomelane+pyrolusite+rhodochrosite+wad±manganite±rhodonite±braunite+calcite+quartz±barite±fluorite±jasper±manganocalcite±pyrite±chalcopyrite±galena±sphalerite.

Texture/Structure Tabular veins, irregular open space fillings, lenticular pods, pipes, chimneys.

Alteration

Ore Controls Open space filling in carbonate rocks. May be near intrusive contact.

Weathering Limonite and kalolinite.

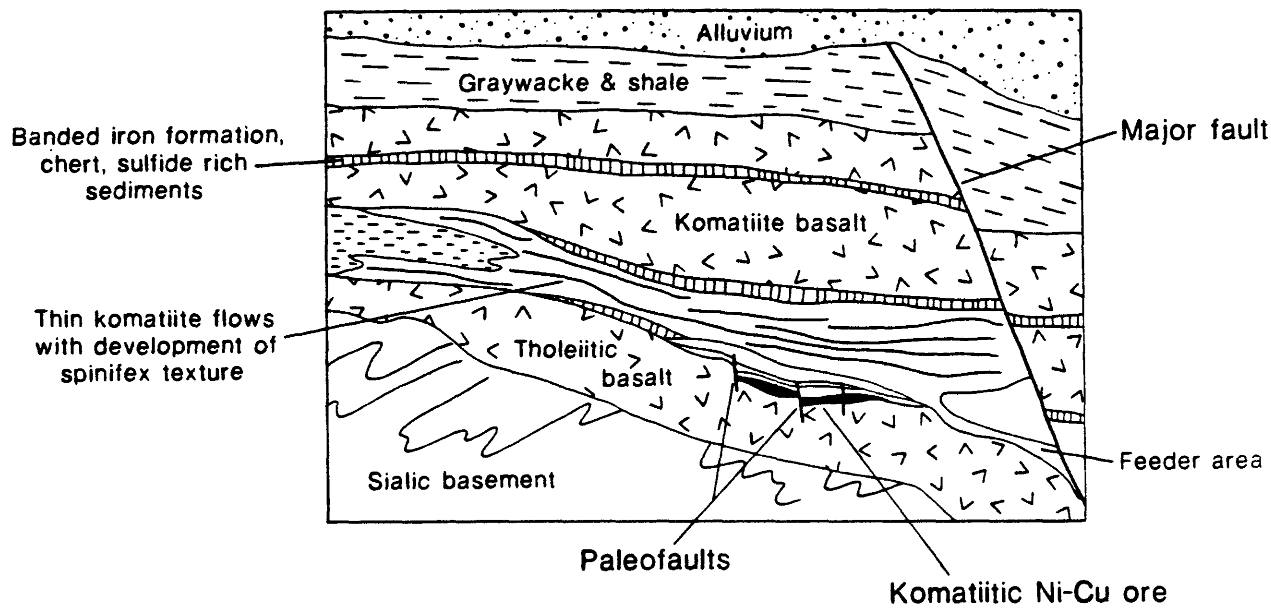
Geochemical Signature:

Examples Lake Valley, New Mexico
Philipsburg, Montana
Lammereck, Austria

References Farnham (1961)
Prinz (1963)
Lechner and Plochinger (1956)

CARTOON CROSS-SECTION

Modified from Marsten, et al. (1981)



DEPOSIT TYPE Volcanic hosted massive replacement SUBTYPE

AUTHOR Dennis Cox DATE 5/20/83

APPROXIMATE SYNONYM Enargite massive sulfide OF (REFERENCE) Silitoe, 1983

DESCRIPTION Stratbound massive copper sulfosalt deposits in volcanic flows, breccias and tuffs near porphyry systems.

GENERAL REFERENCE Sillitoe, 1983

GEOLOGICAL ENVIRONMENT

Rock Types Andesite, dacite, flows, breccias and tuffs

Textures Fine grained, porphyritic, brecciated

Age Range Mainly Tertiary

Depositional Environment Volcanic terrane, uppermost levels of intrusive systems

Tectonic Setting(s) Continental margins and island arcs

Associated Deposit Types Porphyry Cu-Mo

Metal Concentrations Cu, Ag, As, Sb, Zn, Mo

DEPOSIT DESCRIPTION

Ore Minerals: All contain pyrite. In addition, enargite+luzonite+tennantite (Lepanto), enargite+covellite+chalcocite+bornite+chalcopyrite (Bor), enargite+luzonite+tetrahedrite (Resck), tetrahedrite+sphalerite+chalcopyrite+arsenopyrite (Sam Goosly). Most contain a few ppm Au, Sam Goosly is Ag-rich.
Texture/Structure Breccia filling, replacement of clasts by sulfides

Alteration Chalcedony, alunite, pyrophyllite, diaspore, dickite andalusite dumortierite, tourmaline, barite, and scorzalite.

Ore Controls Tuff-breccias or breccia pipes are the channel ways for ore solutions originating from younger porphyry copper systems.

Weathering

Geochemical Signature: As, Sb, Cu, Zn, Ag, Au, Sn (Lepanto), W (Sam Goosely).

Examples Lepanto, Philippines
Recsk, Hungary; Bor, Yugoslavia
Sam Goosly (Equity Silver), B.C. Canada

References Gonzales (1956)
Sillitoe (1983)
Schroeter (1980)

DEPOSIT TYPE Quartz pebble conglomerate Au-U-Os-Ir SUBTYPE

AUTHOR D. Cox DATE 8/9/83

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION

GENERAL REFERENCE Pretorius (1981)

GEOLOGICAL ENVIRONMENT

Rock Types Conglomerate and sandstone deposited on Archean granite-greenstone. Basal volcanic rocks. Sequence grades upward to fine then to coarse sediments.
Textures Clast supported conglomerate. Well rounded, well packed pebbles of vein quartz, chert and, locally, pyrite. Matrix is quartz, mica, chlorite, pyrite and fuchsite.
Age Range Major deposits are Archean to L. Proterozoic 3,100-2,200 m.y. Tarkwa is 1900 m.y.
Depositional Environment Elongate basins or half-graben. Middle and basal reaches of alluvial fans deposited on steeper side of basins.

Tectonic Setting(s) Moderate uplift and erosion of Archean granite-greenstone terrane and cover rocks so as to remove Phanerozoic strata and retain lower Proterozoic rocks.
Associated Deposit Types Recent gold placer deposits. Low-sulfide gold quartz veins and massive sulfide in underlying basement rocks.

Metal Concentrations

DEPOSIT DESCRIPTION

Ore Minerals: Gold, pyrite, uraninite, brannerite, osmium-iridium alloys, isoferro platinum and sperrylite. By-product Ag. Middle Proterozic and Phanerozoic occurrences have only traces of pyrite.

Texture/Structure Pyrite may occur as rounded grains and pebbles.

Alteration

Ore Controls Alluvial fans, trough-cross bedding, current- or wave winnowed bedding surfaces. Carbonaceous layers derived from algal mats deposited at low-energy base of fan contain U and fine Au.
Weathering
Geochemical Signature:

Examples Witwatersrand, S. Africa
Elliot Lake, Ontario
Jacobina, Brazil
Tarkawa, Ghana

References Pretorius (1981); Feather (1976); Roscoe (1969); Gross (1968); Cox (1967); Sestini (1973)

DEPOSIT TYPE Diamond placers (and pipes) SUBTYPE

AUTHOR Dennis Cox DATE 5/13/83

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Diamonds in kimberlite diatremes and in sedimentary rocks and alluvial- and beach-sediments derived from them.

GENERAL REFERENCE Orlov (1973), Lampietti and Sutherland (1978)

GEOLOGICAL ENVIRONMENT

Rock Types Kimberlite diatremes. Conglomerate beds may contain paleoplacers. Modern placers may be derived from Kimberlites or conglomerate.
Textures Pipes: porphyritic igneous texture. Breccias with inclusions of many rocks from mantle, basement and overlying sequences.
Age Range Most productive pipes are 80-100, 250, and 1,000-1,100 m.y. in age
Depositional Environment Alluvial deposits may be 1,000 km from source in sandstone, conglomerate or modern river and beach sediment
Tectonic Setting(s) Some pipes occur at intersections of regional zones of weakness visible in LANDSAT or SLAR
Associated Deposit Types Placer Au, PGE

Metal Concentrations

DEPOSIT DESCRIPTION

Ore Minerals: Diamond, bort or carbonado (polycrystalline generally dark colored) ballas (spherulitic polycrystalline) and amorphous carbonado. Diamonds derived from sedimentary rocks may retain sand grains cemented to grooves or indentations in the crystal.
Texture/Structure

Alteration Diamonds may have patches of greenish coloration which, on heating above 400° turn brown. Therefore brown patches indicate derivation from metamorphosed sediment rather than kimberlite.
Ore Controls Both pipe and placer deposits are heterogeneous in their diamond distribution. Alluvial diamonds decrease in size but increase in quality with distance from source.
Weathering

Geochemical Signature: Anomalous Ni, Nb, and heavy minerals such as pyrope garnet, and Mg-ilmenite indicate nearby pipes.

Examples African Placer deposits
Venezuela placer deposits

References Sutherland (1982)
Fairbairn (1971) and Reid and Bisque (1975)

DEPOSIT TYPE Placer Au, PGE (high energy) SUBTYPE

AUTHOR Warren Yeend DATE 8/12/83

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Elemental gold and platinum-group alloys in grains and (rarely) nuggets in gravel, sand, silt, and clay, and their consolidated equivalents, in alluvial, beach, aeolin, and (rarely) glacial deposits.
GENERAL REFERENCE Boyle (1979), Wells (1973)

GEOLOGICAL ENVIRONMENT

Rock Types Alluvial gravel and conglomerate with white quartz clasts, and heavy minerals indicative of low-grade metamorphic terrane. Sands and sandstones of secondary importance.
Textures Coarse clastic

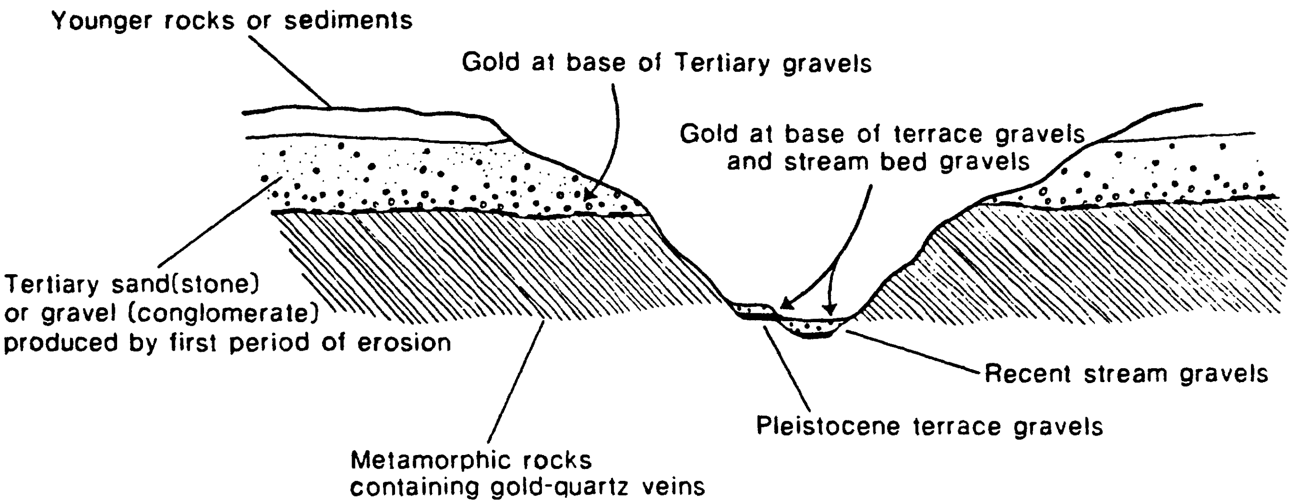
Age Range Cenozoic (see attached sketch showing multic-cycle placer gold)

Depositional Environment High energy alluvial where gradients flatten, and river velocities lessen as inside of meanders, below rapids and falls, beneath boulders, vegetation mats; raised, present, and submerged beaches.
Tectonic Setting(s) Tertiary conglomerates along major fault zones, shield areas where erosion has proceeded for a long time producing multicycle sediments; high-level terrace gravels.
Associated Deposit Types Black sands (magnetite, ilmenite, chromite), garnet, zircon, monazite (yellow) sands; low grade metamorphic rock terrains--slate, phyllite, schist with abundant quartz veins and pods; secondary pyrite; serpentine.
Metal Concentrations As, Ag, Sb, Cu, Hg, Cr, Ni

DEPOSIT DESCRIPTION

Ore Minerals: Au, platinum-iron alloys, osmium alloys; gold commonly with attached quartz, magnetite and/or ilmenite.
Texture/Structure Flattened, rounded edges, flaky, flour gold extremely fine grained flakes; very rarely equidimensional nuggets.
Alteration
Ore Controls See depositional environment above; gold "traps" as natural riffles in floor of river or stream as fractured bedrock, slates, schists, phyllites, dikes, bedding planes, all structures trending transverse to direction of water flow; for PGE, ophiolite or zoned "Alaskan type" ultramafic complexes as source rocks.
Weathering
Geochemical Signature: Anomalous high amounts of Ag, As, Hg, Sb, Cu, Fe, S, and heavy minerals-magnetite, chromite, ilmenite, hematite, pyrite, zircon, garnet, rutile
Examples The Choco, Colombia
Nevada, California
Victoria, Australia

References Emmons (1937); Meyer Sierra (1941); Lindgren (1911); Yeend (1974); Knight (1975)


Younger rocks or sediments
Gold at base of Tertiary gravels
Gold at base of terrace gravels
and stream bed gravels
Tertiary sand(stone)
or gravel (conglomerate)
produced by first period of erosion
Recent stream gravels
Pleistocene terrace gravels
Metamorphic rocks
containing gold-quartz veins

DEPOSIT TYPE Placer (medium to low energy) SUBTYPE

AUTHOR Warren Yeend DATE 8/16/83

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Elemental gold and platinum-group alloys and certain heavy minerals in eluvium, alluvial, beach, and aeolin sands and silts.

GENERAL REFERENCE Wells (1973); Jenkins (1964)

GEOLOGICAL ENVIRONMENT

Rock Types Beach sands (raised, modern and submerged), eluvium, alluvial sands and fine-grained gravels, aeolin.

Textures Medium clastic

Age Range Recent, Quaternary, rarely Tertiary

Depositional Environment Marine (near shore), rivers and streams (medium to low gradient), desert (aeolin) sand dunes, in-place weathering.

Tectonic Setting(s) Within and adjacent to modern and ancient plate margin mountain systems.

Associated Deposit Types Black sands, both high and low grade metamorphic terrains, plutonic igneous rock terrains both felsic and mafic; ophiolite and ultramafic terranes, tin granites.

Metal Concentrations As, Ag, Sb, Cu, Hg, Cr, Sn, Pb, Cr

DEPOSIT DESCRIPTION

Ore Minerals: Au, PGE, monazite, rutile, magnetite, ilmenite, cassiterite, garnet, zircon, chromite, spinel

Texture/Structure Stream tin (cassiterite) and spinel as rolled pebbles; zircon and garnet as rounded grains; magnetite, ilmenite, chromite as equidimensional grains, gold and platinum-iron alloys as flattened grains, osmium alloys as irregular sometimes hexagonal grains.

Alteration

Ore Controls See depositional environment above; gold "traps" as natural riffles in floor of river or stream as fractured bedrock, slates, schists, phyllites, dikes, bedding planes, all structures trending transverse to direction of water flow. For PGE, ophiolite or zoned "Alaskan" type complexes as source rocks.

Weathering

Geochemical Signature: Anomalous high amounts of Ag, As, Hg, Sb, Cu, Fe, S, Cr

Examples Netherlands Indies References Westerveld (1937)

DEPOSIT TYPE Sedimentary manganese SUBTYPE

AUTHOR Cannon, W. F., and Force, E. R. DATE 5/19/83

APPROXIMATE SYNONYM Bath tub-ring Mn OF (REFERENCE) Cannon & Force (1983)

DESCRIPTION Shallow marine (non-volcanogenic) sedimentary Mn deposits formed around rims of anoxic basins during transgression.

GENERAL REFERENCE Cannon and Force (1983)

GEOLOGICAL ENVIRONMENT

Rock Types Shallow marine sediments, most commonly carbonates, clays, and glauconitic sands, commonly with shellbeds, in transgressive sequences associated with anoxic basins.

Textures

Age Range Mostly in "Anoxic events," narrow time periods within the lower Paleozoic, Jurassic, and mid-Cretaceous, but may be in rocks of any age associated with anoxic basins.
Depositional Environment Shallow (50-300 m) marine, commonly in sheltered sites around Paleo-islands.

Tectonic Setting(s) Cratonic or nearly so.

Associated Deposit Types Locally, sedimentary phosporites

Metal Concentrations Mn

DEPOSIT DESCRIPTION

Ore Minerals: Wide variety of Mn carbonates (mostly basinward) and oxides (mostly landward).

Texture/Structure Commonly as oolites, pisolites, laminae, and shell replacements.
Alteration Supergene alteration to high grade ore is common.

Ore Controls Oxidation-reduction interface (involves age, paleobasin reconstruction, paleodepth of site) and lack of clastic dilution.

Weathering Mn carbonates may weather to brown, nondescript rock. Black secondary oxides are common.
Geochemical Signature: none known.

Examples Molango, Mexico (Jurassic) References
Nikopol, USSR (Oligocene)
Groote Eylanot, Australia (Cretaceous)

DEPOSIT TYPE Marine phosphate-upwelling type   SUBTYPE

AUTHOR D. L. Mosier   DATE 10/3/83

APPROXIMATE SYNONYM   OF (REFERENCE)

DESCRIPTION Phosphorite sediments form a major stratigraphic unit within a sequence of marine sediments in basins with good connection to the open sea and upwelling areas.

GENERAL REFERENCE Slansky (1980); Sheldon (1964)

GEOLOGICAL ENVIRONMENT

Rock Types Phosphorites, marls, shales, cherts, limestones, dolomites, and volcanic materials.

Textures

Age Range Precambrian through Miocene.

Depositional Environment Marine sedimentary basins with good connection to the open sea and upwelling, areas highly productive of plankton. Deposition occurs mostly in warm latitudes, mostlly between the 40th parallels.
Tectonic Setting(s) Intra-plate shelf, platform, miogeosynclines, and eugeosynclines.
Associated Deposit Types Sedimentary manganese.

Metal Concentrations

DEPOSIT DESCRIPTION

Ore Minerals: Apatite+fluorapatite+dolomite+calcite+quartz+clays (montmorillonite or illite)±halite±gypsum±iron oxides±siderite± pyrite±carnotite

Texture/Structure Pellets, nodules, phosphatized shell and bone material.

Alteration

Ore Controls Basins, or parts of basins, favorable for the accumulation of organic rich sediments and for their evolution into phosphorites. Individual beds may be several feet thick and may extend over hundreds of square miles.
Weathering Limonite an goethite.
Geochemical Signature: P, N, F, C, and U.

Examples	References
Southeast Idaho, Idaho	Gulbrandsen and Krier (1980)
Meskala, Morocco	British Sulphur Corp. Ltd. (1980)
Stra Quertane, Tunisia	British Sulphur Corp. Ltd. (1980)

DEPOSIT TYPE Marine phosphate-warm current type

SUBTYPE

AUTHOR D. L. Mosier

DATE 10/3/83

APPROXIMATE SYNONYM

OF (REFERENCE)

DESCRIPTION Phosphorites formed in warm currents along the eastern coasts of continents -- consist of phosphatic limestones or sandstone.

GENERAL REFERENCE Cathcart and Gulbrandsen (1973); Sheldon (1964); Zellers-Williams, Inc. (1978)

GEOLOGICAL ENVIRONMENT

Rock Types Phosphatic limestone and sandstone; chert and diatomaceous material may be present.

Textures

Age Range Lower Cretaceous through Pliocene.

Depositional Environment Basins of structural lows on the flanks of rising domes, at the mouths of rivers and estuaries. Deposition occurs in warm latitudes, mostly between the 40th parallels. Deposits are formed by dynamic upwelling or by the cool counter current associated with warm density current.

Tectonic Setting(s) Continental shelf; may be associated with eugeosynclinal rocks.

Associated Deposit Types

Metal Concentrations

DEPOSIT DESCRIPTION

Ore Minerals:
Fluorapatite+quartz+dolomite+montmorillonite+kaolinite+calcite±wavellite±crandallite±illite±clinoptilolite±altapulgite±smectite±collophane

Texture/Structure Phosphatic pellets and fossils fragments with a carbonate matrix.

Alteration

Ore Controls Stratigraphic phosphatic horizons within embayments and estuarine environments in proximity to the open seas. Basins on flanks of structural highs (domes, arches, anticlines) are important controls for phosphate deposition.

Weathering Geothite

Geochemical Signature: P, C, U, N, F

Examples	References
Paulista, Brazil	British Sulphur Corp. Ltd. (1980); Zellers-Williams Inc. (1978)
East North, and South Florida	
Offshore Savannah, Georgia	Zellers-Williams Inc. (1978)

DEPOSIT TYPE Cauca Valley Bauxite SUBTYPE

AUTHOR Dennis P. Cox DATE December 6, 1982

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Bauxite in weathered fluvio lacustrine deposits.

GENERAL REFERENCE

GEOLOGICAL ENVIRONMENT

Rock Types Andesitic tuffs, flows and agglomerate overlain by fine grained fluvio lacustrine sediments.

Textures

Age Range Plio-Pleistocene.

Depositional Environment Lake beds weathered in humid tropical environment.

Tectonic Setting(s) Horizontal beds.

Associated Deposit Types

Metal Concentrations

DEPOSIT DESCRIPTION

Ore Minerals: Cliachite, gibbsite, clay.

Texture/Structure Coarse gibbsite aggregates in clay matrix.

Alteration

Ore Controls Uppermost lake beds.

Weathering

Geochemical Signature:

Examples Upper Cauca Valley, Colombia References Rosas, 1978; oral commun., 1982

DEPOSIT TYPE Nickel laterite SUBTYPE Oxide & Silicate type

AUTHOR Donald Singer and M. P. Foose DATE 6/83

APPROXIMATE SYNONYM OF (REFERENCE)

DESCRIPTION Nickel-rich in situ lateritic weathering products developed from peridotites. Ni silicates predominate in some deposits, Ni rich iron oxides in others

GENERAL REFERENCE Evans and others (1979)

GEOLOGICAL ENVIRONMENT

Rock Types Ultramafic rocks-particularily peridotites, dunites, and serpentenized peridotites.

Textures Pisolitic soils

Age Range Precambrian to Tertiary source rocks, typically Cenozoic weathering.

Depositional Environment Relatively high rates of chemical weathering (warm-humid climates) and relatively low rates of physical erosion.
Tectonic Setting(s) Unstable tectonic areas.

Associated Deposit Types Podiform chromite, PGE placers

Metal Concentrations Co, Cr, Mn

DEPOSIT DESCRIPTION

Ore Minerals: Garnierite, hydrous silicates, nickeliferous quartz, and goethite. In oxide type, Ni goethite is abundant.

Texture/Structure Red-brown pisolitic soils.
Alteration Zoned-from top: (1) Red, yellow, and brown limonite soils; (2) saprolites--continuous transition from soft saprolite below soils through hard saprolite and saprolitized peridotite to fresh peridotite. Boxwork of chalcedony and garnierite.
Ore Controls Upper limonite zone containing 1-2 percent Ni in oxides is more common in the oxide type; lower saprolite and boxwork zone contain 2-3 percent Ni in hydrous silicates. The oxide and silicate types are end members with most deposits inbetween.
Weathering Red-brown pisolitic soils representing the products of leached ultramafics.
Geochemical Signature: Enriched in Ni, Co, Cr; depleted in MgO relative to fresh peridotite (i.e. less than 40 percent MgO)

Examples	References
Poro, Tiebaghi, New Caledonia	Troly and others (1979)
Cerro Matoso, Colombia	Gomez and others (1979)
Nickel Mountain, Oregon USA	Chase and others (1969)
Greenvale, Queensland, Australia	Burger (1979)

REFERENCES

Arndt, N. T., and Nesbet, E. G., 1982, Komatiites: George Allen and Un win, London, 526 p.

Ashley, P. M., 1980, Geology of the Ban Ban Zinc deposit, a sulfide bearing skarn deposit, southeast Queensland, Australia: Economic Geology v. 75, p. 15-29.

Atkinson, W. W., Jr., and Einaudi, M. T., 1978, Skarn formation and mineralization in the contact aureole at Carr Fork, Bingham, Utah: Economic Geology, v. 73, p. 1326-1365.

Avevitt, P., 1945, Quicksilver deposits of the Knoxville district, Napa, Yolo, and Lake Counties, California: California Journal of Mines and Geology, v. 41, no. 2, p. 65-89.

Bailey, Edgar, 1964, Geology and quicksilver deposits of the New Almaden district, California: U.S. Geological Survey Professional Paper 360, 206 p.

Barton, P. B., Jr., Bethke, P. M., and Roedder, E., 1977, Environment of ore deposition in the Creede mining district, San Juan Mountains, Colorado: Part III. Progress toward the interpretation of the chemistry of the ore-forming fluid for the OH vein: Economic Geology, v. 71, p. 1-24.

Becker, G., 1888, Quicksilver deposits of the Pacific slope: U.S. Geological Survey Mon. 13.

Becker, G. F., 1882, Geology of the Comstock Lode and the Washoe District: U.S. Geological Survey, Mon. 3, 422 p.

Bichan, R., 1969, Chromite seams in the Hantley Complex of the Great Dike of Rhodesia in Magmatic Ore Deposits ed., H. D. B. Wilson, Economic Geology Monograph 4, p. 95-113.

Blake, D. W., Theodore, T. G., Batchelder, J. N., and Krestchmer, E. L., 1979, Structural relations of igneous rocks and mineralization in the Battle Mountain mining district Lander County, Nevada in Ridge, J. D., ed., Papers on mineral deposits of western North America: Nevada Bureau of Mines Geological Report 33, p 87-99.

Boyd, R., and Mathiesen, C. O., 1979, The nickel mineralization of the Rana Mafic Intrusion, Nordland, Norway: The Canadian Mineralogist, v. 17, p. 287-298.

Boyle, R. W., 1979, The geochemistry of gold and its deposits: Geological Survey Canada Bull. 280, 584 p.

Briskey, J. A., 1982, Summary of the general geologic characteristics of sandstone-hosted lead-zinc deposits in Characteristics of Mineral Deposit Occurrences: U.S. Geological Survey Open-File Report 82-795, p. 183-185.

British Sulphur Corporation Ltd., 1980, World Survey of phosphate deposits: London, 4th edition, 1980, 238 p.

Brown, A. C., 1971, Zoning in the White Pine copper deposit, Ontonagan County, Michigan: Economic Geology, v. 66, p. 543-573.

Buchanon, L. J., 1980, Ore controls of vertically stacked deposits, Guanajuato, Mexico: American Institute of Mining Engineers, Preprint 80-82, 26 p.

Burchkhardt, C. E., and Falini, Filippo, 1956, Memoria suigiacimenti Italiani di Manganese, in Reyna, J. G., ed., Symposium sobre yacimientos de Manganese: International Geology Congress, v. 20, Mexico, V-Europe, p. 221-272.

Burger, P. A., 1979, The Greenvale nickel laterite orebody: in Evans and others, eds., International Laterites Symposium: New Orleans, 1979: Society of Mining Engineers, AIME, p. 24-37.

Burt, D. R. L., and Sheppy, N. R., 1975, Mount Keith Nickel Sulfide Deposit in Knight, C. L., ed., Economic geology of Australia and Papua New Guinea, I. Metals: Melbourne, Australasian Inst. Mining Metallurgy Mon 5, p. 159-168.

Cameron, E. N., and Desborough, G. A., 1969, Occurrence and characteristics of chromite deposits--Eastern Bushveld Complex in Magmatic Ore Deposits, ed., H. D. B., Wilson, Economic Geology Monograph 4, p. 95-113.

Cannon, W. F., and Force, E. R., 1983, Potential for high-grade shallow-marine manganese deposits in North America: in press.

Cathcart, J. B., and Gulbrandsen, R. A., 1973, Phosphate deposits, in Brobst, D. A., and Pratt, W. P., eds., United States Mineral Resources: U.S. Geological Survey Professional Paper 820, p. 515-525.

Carlson, G. G., 1977, Geology of the Bailadores, Venezuela, Massive sulfide deposit: Economic Geology, v. 72, p. 1131-1140.

Cerar, D. A., Namson, Jay, Chyi, M. S., Williams, Loretta, and Feigenson, M. D., 1982, Manganiferous cherts of the Franciscan Assemblage: I. General Geology, ancient and modern analogues, and implications for hydrothermal convection at oceanic spreading centers: Economic Geology, v. 77, p. 519-540.

Chace, F. M., Umberlidge, J. T., Cameron, W. L., and Von Nort, S. D., 1969, Applied geology at the Nickel Mountain mine, Riddle Canyon: Economic Geology, v. 64, no. 1, p. 1-16.

Champetier de Ribes, G., Pagnacco, P., Radelli, L., Weeckstein, G., 1963, Geologia y mineralizaciones cupriferas de la Serrania de Perija entre Becerril y Villanueva (Guajira, magdalena) Bol. Geol. v. 11, p. 133-138.

Cox, D. P., ed., 1983, U.S. Geological Survey - INGEOMINAS mineral resource assessment of Colombia: Ore deposit models: U.S. Geological Survey open-file report 83-423, 65 p.

Crawford, Johnson, and Hoagland, A. D., 1968, The mascott-Jefferson City zinc district, Tennessee in Ridge, J. D., ed., Ore deposits of the United States 1933-1967, New York, AIME, p. 242-256.

Derkman K., and Klemm, D. D., 1977, Strata-bound kies ore deposit in ophiolitic rocks of the "Tavern fenster" (eastern Alps, Austria/Italy), in Klemm D. D., and Schneider H. J., eds., Time and strabound ore deposits: New York Spriner-Verlag, p. 305-313.

Dick, L. A., and Hodgson, C. T., 1982, The MacTung W-Cu (Zn) contact metasomatic and related deposits of the northeastern Canadian Cordillera: Economic Geology, v. 77, p. 845-867.

Dickey, J. S., Jr., 1975, A hypothesis of origin for podiform chromite deposits: Geochimica Cosmochimica Acta, v. 39, p. 1061-1074.

Dobson, D. C., 1982, Geology and alteration of the Lost River tin-tungsten-fluorine deposit, Alaska: Economic Geology, v. 77, p. 1033-1052.

Duparc, L., and Tikonovitch, M., 1920, Le platine et les gites platiniferes de loural et du Monde: Geneve Impr. et lith "Sonor" s.a., 542 p.

Eargle, D. H., Dickinson, K. A., and Davis, B. O., 1975, South Texas uranium deposits: Bulletin of the American Association of Petroleum Geologists, v. 59, p. 766-779.

Einaudi, M. T., and Burt, D. M., 1982, Introduction--terminology, classification, and composition of skarn deposits: Economic Geology, v. 77, p. 745-754.

Einaudi, M. T., Meinert, L. D., and Newberry, R. J., 1981, Skarn deposits: Economic Geology, 75th Anniversary volumne, p. 317-391.

Emmons, S. F., 1937, Gold deposits of the world: McGraw-Hill Book Company Inc., New York, 562 p.

Escovar, Ricardo, 1979, Geologia y geoquimica de las minas de esmeraldas de Gachala, Cundinamarca: INGEOMINAS, Bol. Geol., v. 22, p. 119-153.

Evans, D. J. I., Shoemaker, R. S., and Veltman, H., eds., 1979, International Laterite Symposium: New Orleans, 1979: Society of Mining Engineers, AIME, 688 p.

Evans, L. L., 1977, Geology of the Brushy Creek mine, Viburnum trend, southeast Missouri: Economic Geology, v. 77, p. 381-390.

Fahrni, K. C., McCauley, T. N., and Preto, V. A., 1976, Copper Mountain and Ingerbelle in Sutherland Brown, A., ed., Porphyry Deposits of the Canadian Cordillera, Special V. 15, p. 368-375.

Farnham, L. L., 1961, Manganese deposits of New Mexico: U.S. Bureau of Mines Inf. Circular 8030, 176 p.

Fairbairn, W. C., 1971, Diamonds in Venezuela: Mining Magazine, v. 125, p. 349-353.

Feather, C. E., 1976, Mineralogy of platinum-group minerals in the Witwatersrand, South Africa: Economic Geology, v. 71, p. 1399-1428.

Ferguson, H. G., 1921, The Round Mountain district, Nevada: U.S. Geological Survey Bulletin 725, p. 383-406.

Fleischer, Ronald and Routhier, Pierre, 1973, The "consanguineous" origin of a tourmaline-bearing gold deposit: Passagem de Mariana (Brazil): Economic Geology, v. 68, p. 11-22.

Franklin, J. M., Sangster, D. M., and Lydon, J. W., 1981, Volcanic-associated massive sulfide deposits: Economic Geology 75th Anniversary Volumne, p. 485-627.

Fulweiler, R. E., and McDougal, S. E., 1971, Bedded-ore structures, Jefferson City mine, Jefferson City, Tennessee: Economic Geology, v. 66, p. 763-769.

Gilluly, J., 1932, Geology and ore deposits of the Stockton and Fairfield quadrangles, Utah: U.S. Geological Survey Professional Paper 173, 171 p.

Gomez, R., Ogryzlo, C. T., and Dor, A. A., 1979, The Cerro Matoso Nickel Project: in Evans and others, eds., International Laterite Symposium: New Orleans, 1979: Society of Mining Engineers, AIME, p. 412-458.

Gonzales, A., 1956, Geology of the Lepanto Copper mine, Mankayan, Mountain Province in Kinkel, A. R. Jr., and others, eds., Copper deposits of the Philippines: Philippines Bureau of Mines Special Projects Series, Publication 16, p. 17-50.

Grant, J. N., Halls, C., Sheppard, F. M. S., and Avila, W., 1980, Evaluation of the porphyry tin deposits of Bolivia: in Granitic magmatism and related mineralization, S. Ishihara and S. Takenouchi, eds., Mining Geology Special Issue, no. 8, The Society of Mining Geologists of Japan, 247 p.

Graybeal, F. T., 1982, Geology of the El Tiro area, Silver Bell mining district Pima County, Arizona: in Titley, S. R., ed., Advances in Geology of the Porphyry Copper Deposits; southwestern North America: Tucson, University of Arizona Press, p. 487-506.

Gresham, J. J., and Loftus-Hills, G. D., 1981, The Geology of the Rambalda Nickel Field Western Australia: Economic Geology, v. 76, p. 1373-1417.

Green, A. H., and Naldrett, A. J., 1981, The Langmuir volcanic peridotite-associated nickel deposits: Canadian equivalents of the western Australia occurrences: Economic Geology, v. 76, p. 1503-1523.

Gross, W. 1968, Evidence for a modified placer origin for auriferous conglomerate, Canavieras mine, Jacobina, Brazil: Economic Geology, v. 63, p. 271-276.

Gulbrandsen, R. A., and Krier, D. J., 1980, Large and rich phosphorus resources in the Phosphoria Formation in the Soda Springs area, southeastern Idaho: U.S. Geological Survey Bulletin 1496, 25 p.

Gustafson, L. B., and Hunt, J. P., 1975, The porphyry copper deposit at El Salvador, Chile: Economic Geology, v. 70, p. 857-912.

Hamilton, J. M., Hauser, R. L., and Ransome, P. W., 1981, The Sullivan ore body in Thompson R. I., and Cook, D. G., eds., Field guides to geology and mineral deposits: Geological Association of Canada.

Harrison, J. E., 1972, Precambrian Belt basin of northwestern United States: It's geometry, sedimentation, and copper occurrences: Geological Society of America Bulletin, v. 83, p. 1215-1240.

Heyl, A. V., 1982, Mineral deposit occurrence model for the Viburnum trend subregion of the southeast Missouri base metal and barite district in Characteristics of Mineral Deposit Occurrences: U.S. Geological Survey Open-File Report 82-795, p. 158-171.

Hilpert, L. S., 1969, Uranium resources of northwestern New Mexico: U.S. Geological Survey Professional Paper 603, 166 p.

Hoagland, A. D., 1976, Appalachian zinc-lead deposits in Wolf, K. H., ed., Handbook of stratabound and stratiform ore deposits: Amsterdam, Elsevier Scientific Publishing Company, p. 495-534.

Isachsen, Y. W., and Evensen, C. G., 1956, Geology of uranium deposits of the Shinarump and Chinle Foramtions on the Colorado Plateau: U.S. Geological Survey Professional Paper 300, p. 263-280.

Irvine, T. N., 1974, Petrology of the Duke Island ultramafic complex southeastern Alaska: Geological Society America Memoir 138, 240 p.

Jackson, E. D., 1969, Chemical variation in coexisting chromite and olivine in chromite zones of the Stillwater Complex in Magmatic Ore Deposits ed., H. D. B. Wilson, Economic Geology Monograph p. 41-71.

Jenkins, O. 1964, Geology of placer deposits: Mines Information Service, California Division of Mines, Geology, v. 17.

Jensen, M. L., and Bateman, A. M., 1981, Economic Mineral Deposits, 3rd ed. John Wiley & Sons, New York, 593 p.

Jorakemon, P., 1951, The occurrence of gold at the Getchell mine, Nevada: Economic Geology, v. 46, p. 267-310.

Joubin, F. RF., and James, D. G., 1957, Rexspar uranium deposits: in Structural geology of Canadian ore deposits, LIM, Congress volume, p. 85-88.

Kanehira, K., and Tatsumi, T., 1970, Bedded cupriferous iron sulfide deposits in Japan, a review, in Tatsumi T., ed., Volcanism and ore genesis: Tokyo, University of Tokyo Press, p. 51-76.

Kerr, P. F., Brophy, G. P., Dahl, H. M., Green, J., and Woolard, L. E., 1957, Marysvale, Utah, uranium alea; geology, volcanic relations, and hydrothermal alteration: Geological Society of America Special Paper 64, 212 p.

Kirkham, R. V., 1982, Volcanic red bed copper deposits-environments of formation and distribution in accreted terrains of North America in Rocks and Ores of the Middle Ages: Geological Association of Canada, Cordilleran Section Programs and Abstracts, February 18-19, 1982.

Klau, W., and Large, D. E., 1980, Submarine exhalative Cu-Pb-Zn deposits: a discussion of their classification and metallogenesis: Geological Jahrbuch sec. D, no. 40, p. 13-58.

Knight, C. L., ed., 1975, Economic geology of Australia and Papua, New Guinea: The Australasian Institute of Mining and Metallurgy, 1126 p.

Knopf, Adolph, 1929, The Mother Lode System of California: U.S. Geological Survey Professional Paper 73, 226 p.

Krebs, Wolfgang, 1981, The geology of the Meggen ore deposit in Wolf, K. H., ed., Handbook of strata-bound and stratiform ore deposits, Part III: Elsevier Scientific Publishing Company, p. 509-549.

Kuypers, E. P., and Denyer, P., 1979, Volcanic exhalative manganese deposits of the Nicoya ophiolite complex, Costa Rica: Economic Geology, v. 74, p. 672-678.

Lampietti, F. M. J., and Sutherland, D. G., 1978, Prospecting for diamonds, some current aspects: Mining Magazine, v. 132, p. 117-123.

Langton, J. M., and Williams, S. A., 1982, Structural petrological and mineralogical controls for the Dos Pobres ore body in Titley, S. R., ed., Advances in Geology of the Porphyry Copper deposits; southwestern North America: Tucson, Univ. Arizona Press, p. 335-352.

Large, D. E., 1980, Geologic parameters associated with sediment-hosted, submarine exhalative Pb-Zn deposits: an emprical model for mineral exploration, in Stratiform Cu-Pb-Zn deposits: Geologisches Jahrbuch, Reine D., Heft 40, p. 59-129.

Lechner, K., and Plochinger, B., 1956, Die manganerzlagerstatten Osterreichs, in Reyna, J. G., ed., Symposium sobre yacimiento de manganeso: Intern. Geol. Congress, 20, Mexico, Tomo V-Europo, p. 299-313.

______1896, The gold-quartz veins of Nevada City and Grass Valley districts, California: U.S. Geological Survey 17th Annual Report, pt. 2, p. 1-262.

Lindgren, W., 1900, The gold and silver veins of Silver City, DeLamar and other mining districts in Idaho Twentieth Annual Report: U.S. Geological Survey, pt. 3, p. 67-255.

______1911, The Tertiary gravels of the Sierra Nevada of California: U.S. Geological Survey Professional Paper 73, 226 p.

Lindgren, W., and Ross, C. P., 1916, The iron deposits of Daiquiri Cuba: American Institute of Mining Engineers Transactions, v. 53, p. 40-46.

Lozano, H., Perez, H., and Vesga, C. J., 1977, Prospeccion geoquimica y genesis del mercurio en ele flanco occidental de la Cordillera Central Municipios de Aranzazu, Salamina y Pacora Departamento de Caldas: INGEOMINAS unpublished report.

Marston, R. J., Groves, D. I., Hudson, D. R., and Ross, J. R., 1981, Nickel sulfide deposits in western Australia: a review: Economic Geology, v. 76, p. 1330-1336.

Martin, J. E., and Allchurch, P. D., 1975, Perseverance nickel deposit, Agnew, in Knights, C. L., ed., Economic geology of Australia and Papua New Guinea, I. Metals: Melbourne, The Australasian Institute of Mining and Metallurgy Proceeding Mon 5, p. 149-155.

Maze, W. B., 1982, Geology and copper mineralization of the Jurassic La Quinta Formation in the Sierra de Perija, northwestern Venezuela: Transaction 9th Caribbean Geological Congress, Santo Domingo, 1980, p. 283-294.

Meyer, A., 1941, In the Choco Colombia: Engineering and Mining Journal, v. 142, no. 9, p. 35-39.

McMillan, W. J., 1976, Geology and genesis of the Highland Valley ore deposits and the Guichon Creek Batholith: Chapter 11 in Sutherland Brown, A., ed., Porphyry Deposits of the Canadian Cordilleran, Canadian Institute of Mining and Metallurgy, Special Volume 15, p. 85-104.

Molyneux, T. G., 1969, The geology of the area in the vicinity of Magnet Heights, Eastern Transvaal, with special reference to Magnetic Iron Ore Symposium ore Bushveld Igneous Complex and other Intrusions: Geological Society of South Africa Special Publication no. 1, p. 228-241.

Morris, H. T., and Lovering, T. S., General geology and mines of the East Tintic mining district, Utah and Juab Counties, Utah: U.S. Geological Survey Professional Paper 1024, 203 p.

Mutschler, F. E., Wright, E. G., Ludington, Steve, and Abbott, J. T., 1981, Granitic molybdenite systems: Economic Geology, v. 76, p. 874-897.

Nash, J. T., 1981, Geology and genesis of major world hardrock uranium deposits--An overview: U.S. Geological Survey Open-File Report 81-166, 123 p.

Nash, J. T., Granger, H. C., and Adams, S. S., 1981, Geology and concepts of genesis of important types of uranium deposits: Economic Geology, 75th Anniversary volume, p. 63-116.

Newberry, R. J., 1982, Tungsten-bearing skarns in the Sierra Nevada. I. The Pine Creek mine, California: Economic Geology, v. 77, p. 823-844.

Nokleberg, W. J., 1981, Geologic setting, petrology, and geochemistry of zoned tungsten-bearing skarns at the Strawberry mine, central Sierra Nevada, California: Economic Geology, v. 26, p. 111-133.

Orlov, Y. L., 1973, The mineralogy of the diamond: Translation from Izdatel'stva Nauka, Wiley and Sons, New York, 235 p.

Page, L. R., and McAllister, J. F., 1944, Tungsten deposits, Isla de Pinos, Cuba: U.S. Geological Survey Bulletin 935-D, 246 p.

Page, N. J., 1977, Stillwaters complex, Montana: Rock succession, metamorphism and structure of the complex and adjacent rocks: U.S. Geological Survey Professional Paper 999.

Park, C. F., 1942, Manganese resources of the Olympic Peninsula, Washington: U.S. Geological Survey Bulletin 931-R, p. 435-457.

Park, C. F., 1946, The spilite and manganese problems of the Olympic Peninsula, Washington: American Journal of Science, v. 244, no. 5, p. 305-323.

Paulova, I. G., and Rundquist, D. V., 1980, Zoning of ores and hydrothermal rocks of molybdenum-copper-porphyry deposits under different conditions of formation in Ridge, J. D., ed., Proceedings of the Fifth Quadrennial IAGOD Symposium, Stuttgart, E., Schweizer bart'sche, p. 113-124.

Peredery, W. V., 1979, Relationship of ultramafic amphibolites to metavolcanic rocks and serpentinites in the Thompson belt, Manitoba: Canadian Mineralogist, v. 17, p. 187-200.

Peterson, E. U., 1965, Regional geology and major ore deposits of central Peru: Economic Geology, v. 60, p. 407-476.

Peterson, E. U., and Zantop, Half, 1980, The Oxec deposit, Guatemala: an ophiolite copper occurrence: Economic Geology, v. 75, p. 1053-1065.

Prescott, Basil, 1926, The underlying principles of the limestone replacement deposits of the Mexican province: Engineering and Mining Journal, v. 122, p. 246-253 and 289-296.

Pretorius, D. A., 1981, Gold and uranium in quartz-pebble conglomerate: Economic Geology 75th Anniversary Volume, p. 117-138.

Prinz, W. C., 1963, Manganese in Mineral and water resources of Montana: U.S. Government Printing Office, Washington, p. 83-86.

Radtke, A. S., Rye, R. O., and Dickson, F. W., 1980, Geology and stable isotope studies of the Carlin gold deposit, Nevada: Economic Geology, v. 75, p. 641-672.

Ransome, F. L., 1909, Geology and ore deposits of Goldfield, Nevada: U.S. Geological Survey Professional Paper 66, 258 p.

Reid, A. R. and Bisque, R. E., 1975, Stratigraphy of the diamond-bearing Roraima Group, Estado Bolivar, Venezuela: Quarterly of the Colorado School of Mines, v. 70, no. 1, p. 61-82.

Rickard, D. T., Willden, M. Y., Marinder, N. E., and Donnelly, T. H., 1979, Studies on the genesis of the Laisvall sandstone lead-zinc deposits, Sweden: Economic Geology, v. 74, p. 1255-1285.

Ridler, R. H., 1970, Relationship of mineralization to volcanic stratigraphy in the Kirkland-Larder Lakes Area Ontario: Geological Association of Canada, v. 21, p. 33-42.

Riordan, P. H., 1957, The structural environment of the Thetford-Black Lake Asbestos Deposit: Geological Association of Canada Proceedings, v. 9, p. 83-93.

Ripley, E. M., and Ohmoto, Hiroshi, 1977, Mineralogic, sulfuric isotope and fluid inclusion studies of the stratabound copper deposits at the Raul mine, Peru: Economic Geology, v. 72, p. 1017-1041.

Rocha, V. S., and Wilson, I. F., 1948, Los yacimientos de manganeso de Talamantes, Municipio de Allende, estado de Chihuahua: Mexico, Comite Directivo Para la Investigacion de Los Recursos Minerales de Mexico, Bol. 18, 39 p..

Roper, M. W., and Wallace, A. B., 1981, Geology of the Aurora uranium prospect, Malheur County, Oregon: in P. C. Goodell and A. C. Waters, eds., Uranium in volcanic and volcaniclastic rocks: American Association of Petroleum Geologists Studies in Geology, no. 13, p. 81-88.

Roscoe, S. M., 1969, Huronian rocks and uraniferous conglomerates in the Canadian Shield: Geological Survey of Canada Paper 68-90, 205 p.

Ross J. R., and Travis, G. L., 1981, The nickel sulfide deposits of Western Australia in global perspective: Econ. Geol., v. 76, p. 1291-1329.

Rye, D. M., and Rye, R. O., 1974, Homestake gold mine, South Dakota: I. Stable Isotope Studies: Economic Geology, v. 69, p. 293-317.

Saupe, Fancis, 1973, La Geologie du gisements de mercure d'Almaden: Science de la Terre, Memoir 29, p. 7-341.

Schrader, F. C., 1923, The Jarbidge mining district, Nevada, with a note on the Charleston district: U.S. Geological Survey Bulletin 741, 86 p.

Schroeter, T. G., 1980, West central and northwest British Columbia, Selected mineral property examinations: B.C. Ministry of Energy, Mines, and Petrology Resources, Paper 1980-1, p. 123-125.

Scull, B. J., 1958, Origin and occurrence of barite in Arkansas: Arkansas Geological and Conservation Commission Information Circular 18, 101 p.

Sestini, G., 1973, Sedimentology of a paleoplacer: The gold-bearing Tarkwaian of Ghana: in Amstutz G. C., and Bernard, A. J., eds., Ores in sediments: Heidelberg, Springer-Verlag, p. 275-305.

Shawe, D. R., Poole, F. G., and Brobst, D. A., 1969, Newly discovered bedded barite deposits in East Northumberland Canyon, Nye County, Nevada: Economic Geology, v. 64, p. 245-254.

Sheldon, R. P., 1964, Paleolatitudinal and paleogeographic distribution of phosphorite: U.S. Geological Survey Professional Paper 501-C, p. C106-C113.

Shride, A. F., 1973, Asbestos in Brobst, D. A., and Pratt, W. P., eds., United States Mineral Resources: U.S. Geological Survey Professional Paper 820, p. 63-74.

Sillitoe, R. H., 1979, Some thoughts on gold-rich porphyry copper deposits: Mineralium Deposita, v. 14, p. 161-174.

_____ 1983, Enargite-bearing massive sulfide deposits, high in porphyry copper systems: Economic Geology, v. 78, p. 348-352.
Singer, D. A., and Mosier, D.L., eds., 1983a, Mineral deposit grade-tonnage models: U. S. Geological Survey Open-File Report 83-623, 100 p.
Singer, D. A., and Mosier, D. L., eds., 1983b, Mineral deposit grade-tonnage models II: U. S. Geological Survey Open-File Report 83-902, 101 p.
Slansky, Maurice, 1980, Ancient Upwelling models--Upper Cretaceous and Eocene phosphorite deposits around west Africa in Sheldon, R. P., and Burnett, W. C., eds., Fertilizer mineral potential in Asia and the Pacific: Honolulu, Hawaii, East-West Resource Systems Institute, Proceedings of the Fertilizer Raw Materials Resources Workshop, August 20-24, 1979, p. 145-158.
Snyder, F. G., and Gerdemann, P. E., 1968, Geology of the southeast Missouri lead district, in Ridge, J. D., ed., Ore deposits of the United States, 1933-1967: New York, American Institute of Mining Engineers, p. 326-358.
Snyder, W. S., 1978, Manganese deposited by submarine hot springs in chert-greenstone complexes, western United States: Geology, v. 6, p. 741-744.
Sorem, R. K., and Gunn, D. W., 1967, Mineralogy of manganese deposits, Olympic Peninsula, Washington: Economic Geology, v. 62, p. 22-56.
Steven, T. A., and Ratte, J. C., 1965, Geology and structural control of ore deposition in the Creede district, San Juan Mountains, Colorado: U.S. Geological Survey Professional Paper 487, 90 p.
Steven, T. A., and Eaton, G. P., 1975, Environment of ore deposition in the Creede Mining District, San Juan Mountains, Colorado: Part I. Geologic, hydrologic, and geophysical setting: Economic Geology, v. 70, p. 1023-1037.
Stoll, W. C., 1962, Notes on the mineral resources of Equador: Economic Geology, v. 57, p. 799-808.
Sutherland, D. G., 1982, The transport and sorting of diamonds by fluvial and marine processes: Economic Geology, v. 77, p. 1613-1620.
Taliaferro, N. L., and Hudson, F. S., 1943, Genesis of the manganese deposits of the Coast Ranges of California, in Manganese in California: California Division of Mines Bulletin 125, p. 217-275.
Taneda, S., and Mukaiyama, H., 1970, Gold depositss and Quaternary volcanoes in the southern Kyushu: Guidebook II, Excursion B8, International Association on the Genesis of Ore Deposits, Tokyo-Kyoto Meeting, 1970.
Taylor, H. P., Jr., 1967, The zoned ultramafic complexes of southeastern Alaska, in P. J., Wyllie, ed., Ultramafic and related rocks: New York, John Wiley & Sons, Inc., p. 96-118.
Thayer, T. P., 1964, Principal features and origin of podiform chromite deposits and some observations on the Guliman-Soridag district, Turkey: Economic Geology, v. 59, p. 1497-1524.
Thornett, J. R., 1981, The Sally Malay deposit: gabbroid associated nickel copper sulfide mineralization in Halls Creek Mobile zone, Western Australia: Economic Geology, v. 76, p. 1565-1580.
Titley, S. R., 1982, The style and progress of mineralization and alteration in porphyry copper systems in Titley, S. R., ed., Advances in Geology of the Porphyry Copper Deposits; southwestern North America: Tucson, University of Arzona Press, p. 487-506.
Todd, S. G., Keith, D. W., Lekoy, L. W., Schissel, D. J., Maun, E. L., and Irvine, T. N., 1982, The JM platinum-palladium reef of the Stillwater Complex, Montana: Stratigraphy and Petrology: Economic Geology, v. 77, p. 1454-1480.

Tourtelot, E. B., and Vine, J. D., 1976, Copper deposits in sedimentary and volcanogenic rocks. U.S. Geological Survey Professional Paper 907-C, 34 p.

Troly, G., Esterle, M., Pelletier, B. G., and Reibell, W., 1979, Nickel deposits in New Caldonia--some factors influencing their formation: in Evans and others, eds., International Laterite Symposium: New Orleans, 1979: Society of Mining Engineers, AIME, p. 85-120.

Uchida, Etsuo, and Iiyana, J. T., 1982, Physicochemical study of skarn formation at the Shinyama iron-copper ore deposits of the Kamaishi mine, northeastern Japan: Economic Geology, v. 77, p. 809-822.

Vermaak, C. F., and Hendricks, L. P., 1976, A review of the mineralogy of the Merensky Reef, with specific reference to new data on the precious metal Mineralogy: Economic Geology, v. 71, p. 1244-1269.

Wandke, Alfred, and Martinez, Juan, 1928, The Guanajuato mining district, Guanajuato, Mexico: Economic Geology, v. 23, p. 1-44.

Wells, F. G., Cater, F. W., Jr., and Rynearson, G. A., 1946, Chromite deposits of Del Norte County, California: California Division of Mines and Geology Bulletin 134, p. 1-76.

Wells, J. H., 1973, Placer examination-principles and practice: U.S. Department of Interior Bureau of Land Management, Bulletin 4, 204 p.

Wedepohl, K. H., 1971, "Kupferschiefer" as a prototype of syngenetic sedimentary ore deposits: International Association on Genesis of Ore Deposits, Tokyo Kyoto, 1970, Proc. Special Issue 3, p. 268-273.

Westerveld, J., 1937, Tin Ores of the Dutch East Indies, Economic Geology, v. 32, p. 1019-1041.

Westra, Gerhard, and Keith, S. B., 1981, Classification and genesis of stockwork molybdenum deposits: Economic Geology, v. 76, p. 844-873.

White, D., and Roberson, C. E., 1962, Sulfur Bank, California, a major hot spring quicksilver deposit: Geological Society of America, Buddington volume, p. 397-428.

White, D., 1982, Active geothermal systems and hydrothermal ore deposits: Economic Geology, 75th Anniversary volumne, p. 392-423.

White, W. H., Bookstrom, A. A., Kamili, R. J., Ganster, M. W., Smith, R. P., Ranta, D. E., and Steininger, R. C., 1981, Character and origin of climax type molybdenum deposits: Economic Geology, 75th Anniversary volume, p. 270-316.

Williams, D. A. C., 1979, The association of some nickel sulfide deposits with komatiitic volcanism in Rhodesia: Canadian Mineralogist, v. 17, p. 337-349.

Williams, J., 1969, The vanadiferous magnetic iron ore of the Bushveld igneous complex in Magmatic Ore Deposits ed H. D. B. Wilson, Economic Geology Monograph 4, p. 187-208.

Wokittel, R., 1961, Geologia economico del Choco, Colombia: INGEOMINAS, Bol. Geol., v. 7, p. 119-162.

Yeend, W. E., 1974, Gold-bearing gravels of the Ancestral Yuba River, Sierra Nevada, California: U.S. Geological Survey Professional Paper 772, 44 p.

Zellars-Williams, Inc., 1978, Evaluation of the phosphate deposits of Florida using the minerals availability system-final report: Prepared for the Department of the Interior, Bureau of Mines Contract No. J0377000, 196 p.

U.S. GEOLOGICAL SURVEY--INGEOMINAS

MINERAL RESOURCE ASSESSMENT OF COLOMBIA

Appendix B: MINERAL DEPOSIT GRADE-TONNAGE MODELS

By

D. A. Singer and D. L. Mosier Editors

TABLE OF CONTENTS

Page

INTRODUCTION

This compendium of 37 grade-tonnage models is presented as an aid in mineral resource assessments. These models should be used in conjunction with the descriptive ore deposit models assembled by D. P. Cox (appendix A). Both the descriptive and the grade-tonnage models were prepared for an assessment of the country of Colombia, but the models are generalized and applicable elsewhere.

The descriptive and the grade-tonnage models have been published separately (Cox, 1983a, 1983b; Singer, 1983a, 1983b). A second podiform chromite model based primarily on Turkish deposits is provided in order to provide an alternative model for regions where the larger variety of podiform deposit is appropriate. Grade-tonnage models of Superior-Algoma iron, skarn copper associated with porphyry copper, and general porphyry copper do not yet have associated descriptive models.

Estimated premining tonnages and average grades of well-explored prototype deposits of each type were used to construct the grade-tonnage models. Where several different estimates were available for a deposit, the estimated tonnage and average grades associated with the lowest cutoff grade were used. Stratiform deposits such as sedimentary manganese and marine phosphate could have substantially larger tonnages and corresponding lower grades if consistent information on thickness and cutoff grades were available. Grades not available were treated as zero. Because over 2,800 deposits were employed constructing these models, references are only provided to data sources where one or two sources were used.

The grade-tonnage models are presented in graphical form in order to make it easy to compare deposit types and to display the data. All plots of the same commodity or tonnage are presented on the same scale on the x-axis, while the y-axis is always the cumulative proportion of deposits. Deposits, plotted as dots, are cumulated from the lowest tonnage or grade to the highest. All original tonnage and grade units were transformed, if necessary, so that they would plot on a single page; a logarithmic transformation was used for tonnage, nickel, platinum group elements, and copper grade, whereas a square root transformation was used for other grades. Values on the x-axis were transformed back to the original units and rounded to two significant places. The curve through the plotted deposits was hand drawn to provide a general guideline. Connected to this curve are lines representing the 90th, 50th, and 10th percentiles and the associated values of the observed frequency. The number of deposits employed for each model is given on the upper right of each plot. Correlations among grades and tonnages are reported in the text when significant.

DEPOSIT TYPE Podiform chromite I   MODEL NUMBER 1.1

AUTHOR D. A. Singer

DATA REFERENCES Singer and others, 1980; Calkins and others, 1978.

COMMENTS All deposits are from California and Oregon. The two largest tonnage deposits are actually districts rather than individual deposits. The majority of the grades represent shipping grades. Grades less than 35 percent typically represent in place "ore". The mixture of shipping grades and in place grades may explain the significant negative correlation (r = -0.22) between grade and tonnage.

DEPOSITS

Name	Country	Name	Country
Ace of Spades	USCA	Black Chrome	USCA
Adobe Canyon Gp.	USCA	Black Diamond	USOR
Alice Mine	USCA	Black Diamond (Grey Eagle Gp.)	USCA
Allan (Johnson)	USCA	Black Hawk	USOR
Alta Hill	USCA	Black Otter	USOR
Althouse	USOR	Black Rock Chrome	USCA
Alyce and Blue Jay	USCA	Black Streak	USOR
American Asbestos	USCA	Black Warrior	USOR
Anti Axis	USCA	Blue Brush	USCA
Apex (Del Norte Co.)	USCA	Blue Creek Tunnel	USCA
Apex (El Dorado Co.)	USCA	Blue Sky (Lucky Strike)	USCA
Applegate	USOR	Boiler Pit	USCA
Associated Chromite	USOR	Booker Lease	USCA
Babcock	USOR	Bonanza	USCA
Babyfoot	USOR	Bowden Prospect	USCA
Beat	USCA	Bowie Estate	USCA
Big Bear	USOR	Bowser	USOR
Binder No. 1	USCA	Bragdor	USCA
Big Bend	USCA	Briggs Creek	USOR
Big Chief	USOR	Brown Scratch	USOR
Big Dipper (Robr)	USCA	Bunker	USCA
Big Four	USOR	Burned Cabin	USOR
Big Pine Claim	USCA	Butler Claims	USCA
Big Yank No. 1	USOR	Butler, Estate Chrome, etc.	USCA
Black Bart (Great Western)	USCA	Buttercup Chrome	USCA
Black Bart Claim (Avery)	USCA	Camden Mine	USCA
Black Bart Group	USCA	Camptonville area	USCA
Black Bear	USCA	Castro Mine	USCA
Black Beauty	USOR	Cattle Springs	USCA
Black Boy	USOR	Cavyell Horse C	USOR

(continued on next page)

DEPOSIT TYPE Podiform chromite I

MODEL NUMBER 1.1

DEPOSITS (continued)

Name	Country	Name	Country	Name	Country
Cavyell Horse Mountain	USOR	Eden	USCA	Harp and Sons Ranch	USCA
Cedar Creek	USOR	Eggling and Williams	USCA	Hawks Rest View	USOR
Challange area	USCA	El Primero	USCA	Hayden and Hilt	USCA
Chicago	USCA	Elder Claim	USCA	Helemar	USCA
Christain Place	USCA	Elder Creek	USCA	Hendricks No. 2	USCA
Chrome Camp	USCA	Elder Creek Gp.	USCA	High Dome	USCA
Chrome Gulch	USCA	Elk Creek Claim	USCA	High Plateau	USCA
Chrome Hill	USCA	Elkhorn Chromite	USOR	Hill-Top Chrome	USCA
Chrome King	USOR	Ellingwood	USCA	Hodge Ranch	USCA
Chrome King	USOR	Ellis	USCA	Hoff	USCA
Chrome No. 3	USOR	Esterly Chrome	USOR	Holbrook and McGuire	USCA
Chrome Ridge	USOR	Esther and Phyllis	USCA	Holseman (and others)	USCA
Clara H	USCA	Fairview	USCA	Holston (Vaughn)	USCA
Clary and Langford	USCA	Fiddler's Green	USCA	Horseshoe	USCA
Cleopatra	USOR	Fields and Stoker	USCA	Horseshoe Chrome	USOR
Clover Leaf	USCA	Finan	USCA	Houser & Burges	USOR
Codd Prospect	USCA	Forest Queen	USCA	Hudson (Fuller Claims)	USCA
Coggins	USCA	Foster	USOR	I-Wonder	USCA
Collard Mine	USOR	Four Point	USOR	Illinois River	USOR
Commander	USCA	Fourth of July	USCA	Independence	USOR
Coon Mt. Nos. 1-3	USCA	French Hill	USCA	Irene Chromite	USOR
Copper Creek (Low Divide)	USCA	Friday	USOR	Iron Mountain	USOR
Courtwright	USCA	Gallagher	USOR	Jack Forth	USCA
Courtwright (Daggett)	USCA	Gardner Mine	USOR	Jack Sprat Gp.	USCA
Crouch	USOR	Gas Canyon	USCA	Jackson	USOR
Crow Creek Gp.	USCA	Geach	USCA	Jim Bus	USOR
Crown	USOR	Bibsonville	USCA	Johns	USOR
Cyclone Gap	USCA	Glory Ho	USOR	Josephine	USCA
Cynthia	USOR	Griffin Chromite	USOR	Josephine No. 4	USOR
Daisy (Aldelabron)	USCA	Gill (Gill Ranch)	USCA	Judy (Hicks)	USCA
Dark Star	USOR	Gillan	USCA	Julian	USCA
Darrington	USCA	Gillis Prospect	USCA	Kangaroo Court Mine	USCA
Deep Gorge Chrome	USOR	Golconda Fraction	USCA	Kleinsorge Gp.	USCA
Detert	USCA	Gold Bug Claim	USCA	Kremmel and Froelich	USCA
Diamond	USCA	Goncolda	USOR	Lacey	USCA
Dickerson	USCA	Gray Boy	USOR	Lambert	USCA
Dickey and Drisbach	USCA	Gray Buck Gp.	USOR	Langley Chrome	USOR
Dirty Face	USOR	Green (Americus)	USCA	Lassic Peak	USCA
Doe Flat	USCA	Green Mine	USCA	Last Chance	USOR
Don Pedro	USCA	Green Ridge	USCA	Last Chance	USOR
Dorriss	USCA	Green's Capco Leases	USCA	Laton	USCA
Dozier	USCA	Gunn Claims	USCA	Letty	USCA
Earl Smith	USCA	Half Chrome	USCA	Liberty	USCA
Early Sunrise	USOR	Hanscum	USOR	Liberty Bond Claim	USCA
Edeline	USCA	Happy Go Lucky	USCA	Linda Marie	USOR

(continued on next page)

DEPOSIT TYPE Podiform chromite I MODEL NUMBER 1.1

DEPOSITS (continued)

Name	Country	Name	Country
Little Boy	USOR	Mountain View Gp.	USCA
Little Castle Creek	USCA	Mulcahy Prospect	USCA
Little Hope	USCA	Mule Creek	USCA
Little Rock Mine	USCA	Mum and Alice June Claim	USCA
Little Siberia	USOR	MuNaly	USCA
Lone Gravel	USCA	Murphy	USCA
Long Ledge Gp.	USCA	Muzzleloader (Stevens No. 1)	USCA
Lost Lee	USOR	New Hope	USCA
Lotty	USCA	New Hope Claim	USOR
Lucky Boy	USCA	Newman	USCA
Lucky Friday	USOR	Nichelini Mine	USCA
Lucky Girl	USCA	Nickel Mountain	USOR
Lucky Hunch	USOR	Nickel Ridge	USOR
Lucky L. & R.	USOR	No. 5	USCA
Lucky Nine Gp.	USOR	Noble Electric Co.	USCA
Lucky Star	USOR	Norcross	USCA
Lucky Strike	USCA	North End, West End, Spotted Fawn	USCA
Lucky Strike	USCA	North Fork Chrome	USCA
Lucky Strike	USOR	North Star	USOR
Lucky Strike	USOR	North Star (Red Mtn)	USCA
Mackay	USCA	Oak Ridge	USCA
Madeira	USCA	Olive B.	USOR
Madrid	USCA	Olsen	USCA
Manchester	USCA	Onion Springs	USOR
Maralls Capro Leases	USCA	Oregon Chrome	USOR
Mary Jane	USCA	Oxford	USCA
Mary Walker	USOR	P. U. P. (Zenith)	USCA
Maxwell	USCA	Paradise No. 1	USOR
Mayflower	USCA	Paradise No. 2	USOR
McCaleb's Sourdough	USOR	Park's Ranch	USCA
McCarty	USCA	Parker	USCA
McCormick	USCA	Parkeson	USCA
McGuffy Creek Gp.	USCA	Pearsoll Peak	USOR
McMurty	USCA	Peewan	USCA
Meeker (Sonoma Chrome)	USCA	Peg Leg (Lambert)	USCA
Merrifield	USCA	Pennington Butte	USOR
Mighty Joe	USOR	Perconi Ranch	USCA
Milton	USCA	Pillikin	USCA
Mockingbird	USOR	Pine Mountain Claim	USCA
Moffett Creek Gp.	USCA	Pines	USOR
Mohawk Claim	USOR	Pleasant No. 1 & 2	USOR
Moore	USCA	Poco Tiempo Quartz	USCA
Moscatelli	USCA	Poodle Dog	USCA
Moscatelli No. 2	USCA	Pony Shoe	USCA
Mountain View	USCA	Porter Property	USCA

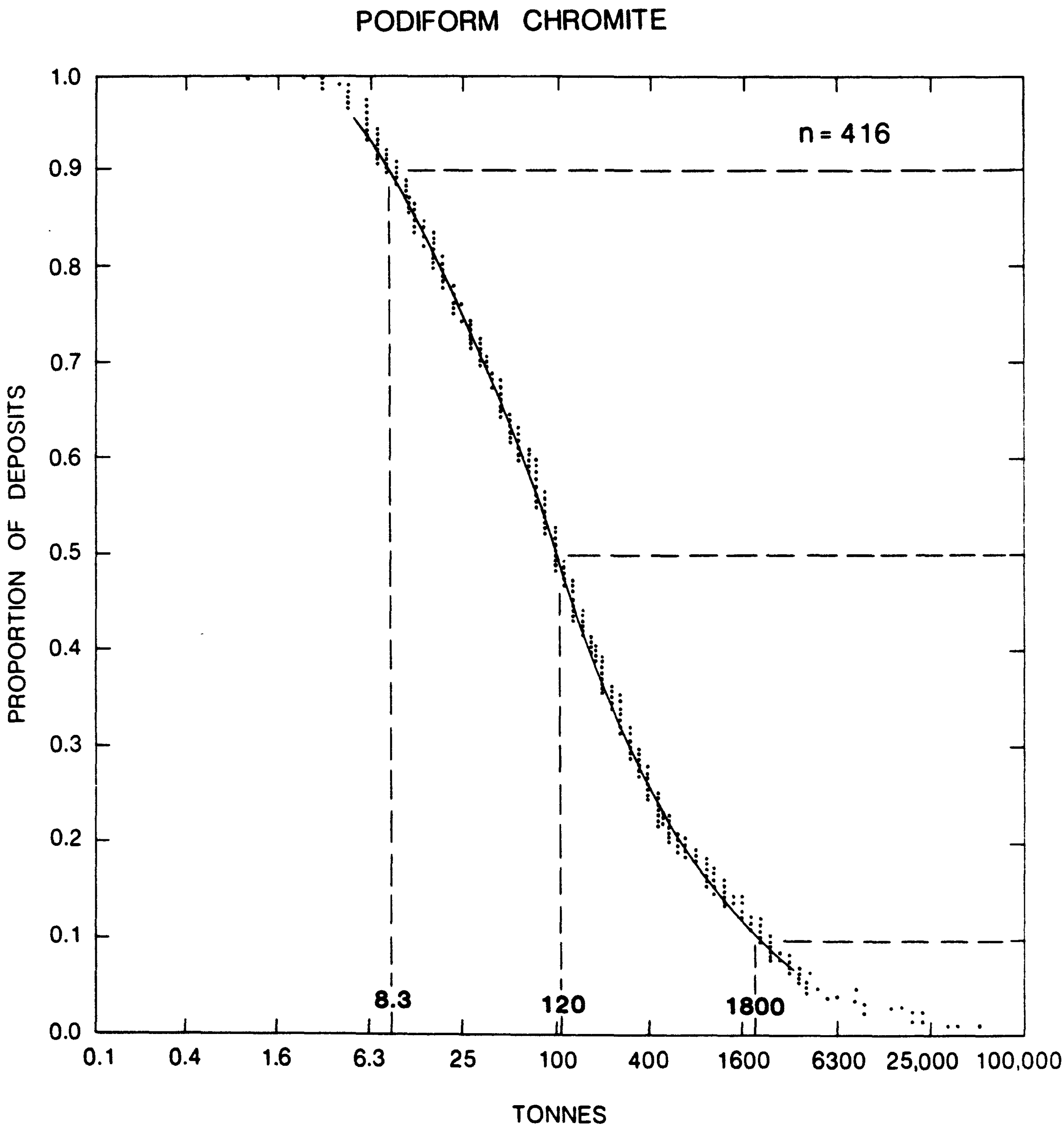
(continued on next page)

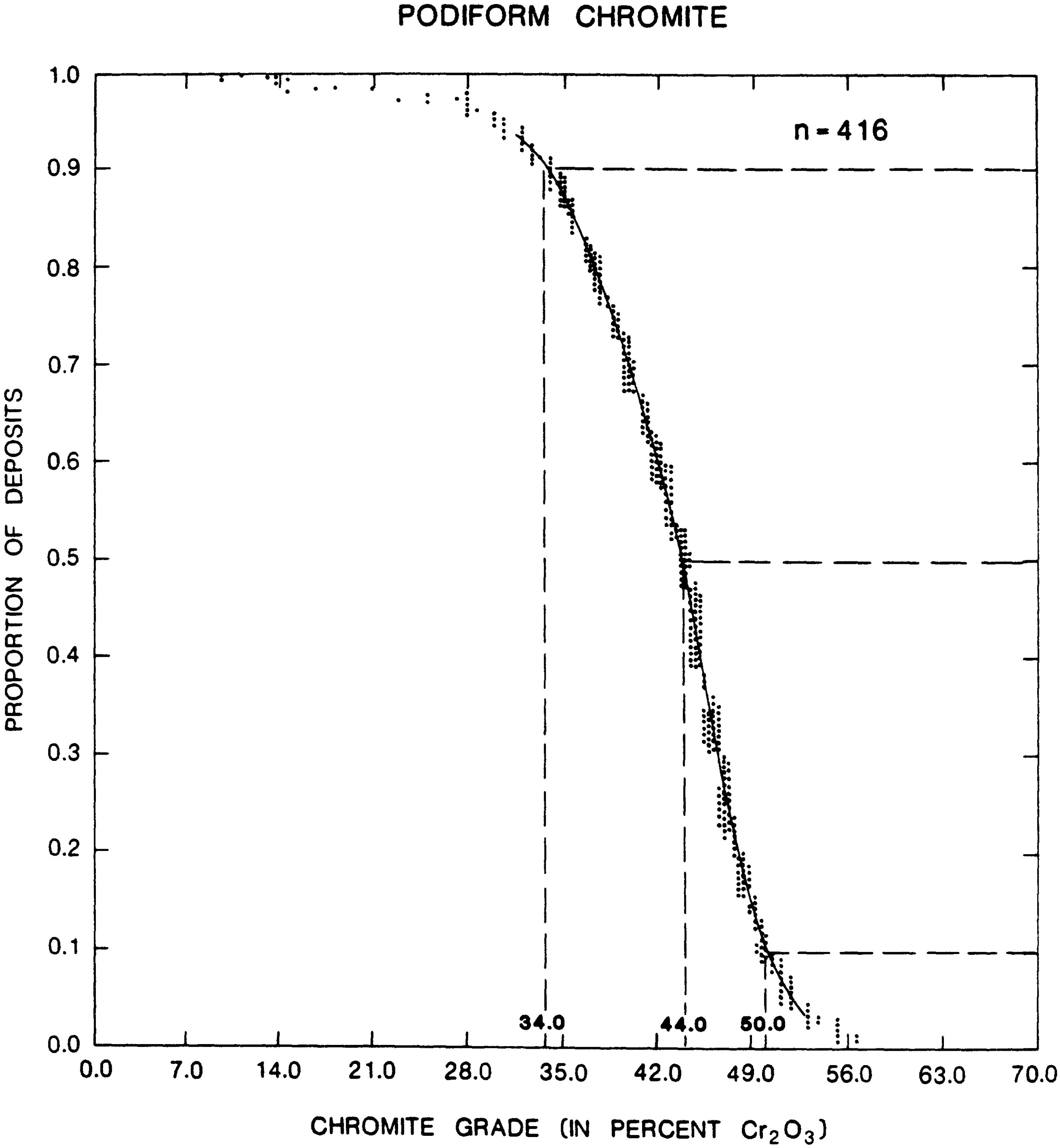
DEPOSIT TYPE Podiform chromite I

MODEL NUMBER 1.1

DEPOSITS (continued)

Name	Country
Prater	USOR
Pyramid	USCA
Quigg	USCA
Rainbow	USOR
Rainy Day	USOR
Rancherie	USOR
Randall	USCA
Rattlesnake Mountain	USCA
Red Ledge	USCA
Red Mountain	USOR
Red Slide Gp.	USCA
Redskin	USCA
Richards	USCA
Richey, U.S. & S.J.	USCA
Robt. E.	USOR
Rock Creek	USOR
Rock Wren Mine	USCA
Rose Claim	USCA
Rosie Claim	USOR
Round Bottom	USCA
Roupe	USCA
Sad Sack	USOR
Saddle Chrome	USOR
Saint	USCA
St. Patrick (Camp 8)	USCA
Sally Ann	USOR
Salt Rock	USOR
Saturday Anne	USOR
Schmid	USOR
Seiad Creek (Mt. View)	USCA
September Morn	USCA
Sexton Mountain	USOR
Shade Chromite	USOR
Shady Cove	USOR
Shafer Lease	USCA
Shamrock	USCA
Shelly	USCA
Sheppard Mine	USCA
Shotgun Creek	USCA
Simmons	USCA
Simon	USCA
Sims	USCA
Six-Mile	USOR
Skyline Mine	USCA
Skyline No. 1	USCA
Skyline No. 2	USCA
Snakehead (Jumbo)	USCA
Snowy Ridge	USCA
Snowy Ridge	USOR
Snyder	USCA
Sour Dough	USOR
Sousa Ranch	USCA
Southern Pacific Property	USCA
Spot	USCA
Spring Hill	USCA
Stafford	USCA
Stark Bee	USCA
State School	USCA
Stevens-Miller	USOR
Stewart	USCA
Store Gulch	USOR
Stray Dog	USOR
Sullivan and Kahl	USCA
Sunnyslope	USCA
Sunrise	USCA
Sunset	USCA
Sunset	USCA
Sunshine	USCA
Sutro Mine	USCA
Suzy Bell (Lucky Strike)	USCA
Swayne	USCA
Sweetwater	USCA
Tangle Blue Divide	USCA
Tennessee Chrome	USOR
Tennessee Pass	USOR
Thompson Gp.	USOR
Toujours Gai	USCA
Trinidad	USCA
Twin Cedars	USOR
Twin Valley	USOR
Tomkin	USCA
Uncle Sam	USOR
Unamed	USCA
Unknown	USOR
Unknown	USOR
Unknown	USOR
Unknown	USOR
Unknown	USOR
Unknown	USOR
Unknown	USOR
Unknown	USOR
Unknown	USOR
Unknown	USOR
Unknown	USOR
Unknown	USOR
Unknown	USOR
Unknown	USOR
Unknown	USOR
Unknown	USOR
Unknown	USOR
Unknown	USOR
Valen Prospect	USOR
Valenti	USCA
Victory No. 3	USCA
Violet	USOR
Vogelgesang	USCA
Wait	USCA
Waite	USCA
Walker	USCA
War Bond	USCA
War Eagle-Miller	USCA
Ward and Lyons	USCA
Washout	USCA
Welch Prospect	USCA
West Chrome	USCA
Western Magnesite	USCA
White Bear	USCA
White Cedar	USCA
White Feather	USCA
White Pine Mine	USCA
Wild Cat Claim	USOR
Wilder (Fish Creek)	USCA
Windy Point	USOR
Wolf Creek	USCA
Wolf Creek area	USCA
Wonder	USOR
Wonder Gp.	USOR
Yellow Pine	USCA
Young	USOR
Young's Mine	USOR
Zerfirg Ranch	USCA


PODIFORM CHROMITE
n = 416
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
8.3
120
1800
0.1
0.4
1.6
6.3
25
100
400
1600
6300
25,000
100,000
TONNES



PODIFORM CHROMITE
n = 416
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PROPORTION OF DEPOSITS
34.0
44.0
50.0
0.0
7.0
14.0
21.0
28.0
35.0
42.0
49.0
56.0
63.0
70.0
CHROMITE GRADE (IN PERCENT Cr_2O_3)

DEPOSIT TYPE Podiform chromite II

MODEL NUMBER 1.1

AUTHOR D. A. Singer, N. J Page, and B. R. Lipin

COMMENTS This model is provided as an alternative to the podiform chromite model based on California and Oregon deposits.

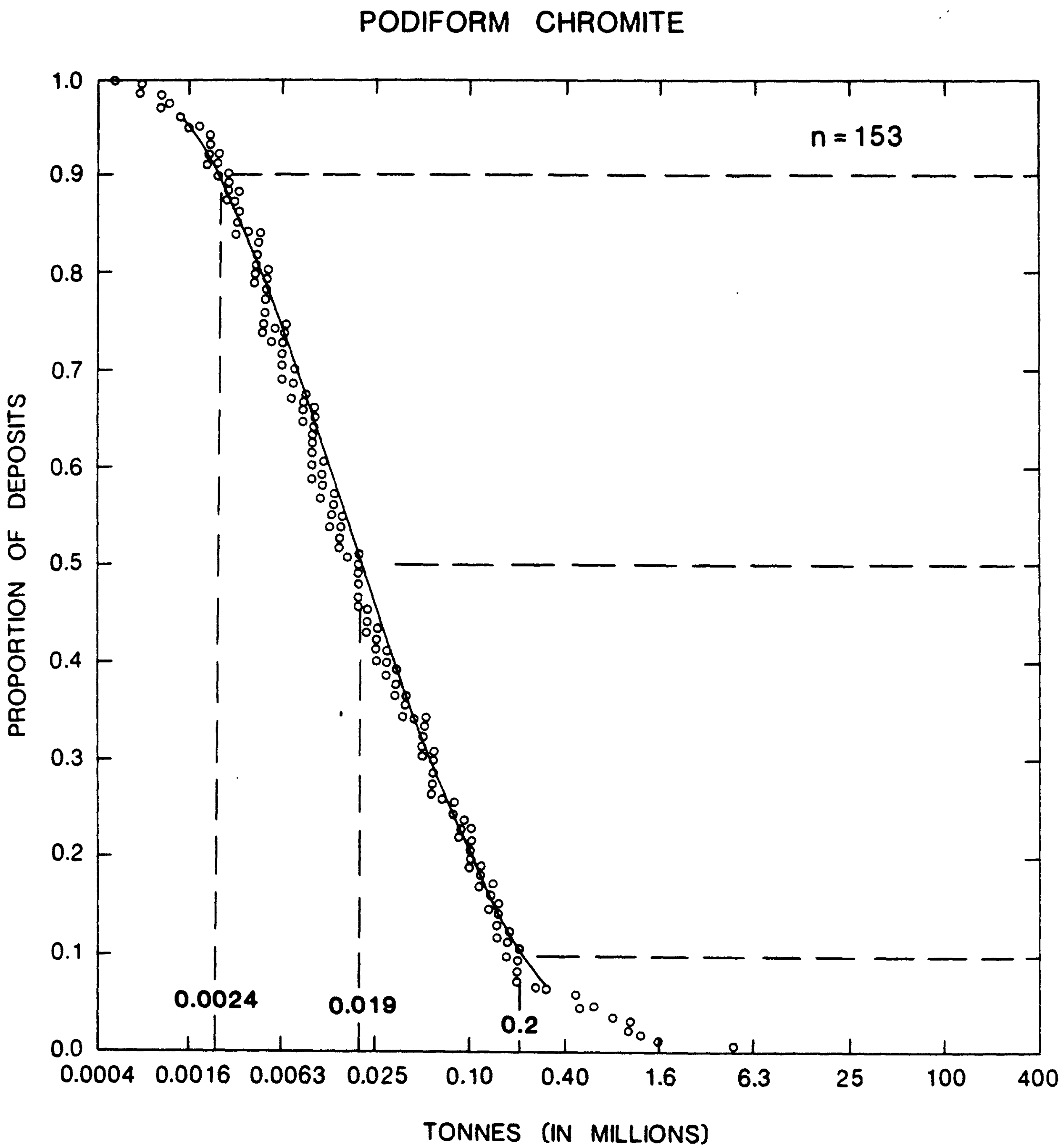
DEPOSITS

Name	Country	Name	Country
Abdasht	IRAN	Cezni	TRKY
Akarca	TRKY	Chagrin	NCAL
Akcabuk	TRKY	Child Harold	NCAL
Akkoya	TRKY	Consolation	NCAL
Alice Louise	NCAL	Cosan	TRKY
Alpha	NCAL	Coto	PLPN
Altindag	TRKY	Cromita	CUBA
Amores	CUBA	Dagardi	TRKY
Andizlik	TRKY	Dagkuplu	TRKY
Anna Madeleine	NCAL	Danacik	TRKY
Asagi Zorkum	TRKY	Dcev 7	NCAL
Aventura	CUBA	Delta	CUBA
Avsar	TRKY	Demirli	TRKY
Bagin	TRKY	Dinagat	PLPN
Bagirsakdire	TRKY	Dogu Ezan	TRKY
Balcicakiri	TRKY	Dogu Kef	TRKY
Batikef	TRKY	Domuzburnu II	TRKY
Bati-N. Yarma	TRKY	Dovis	IRAN
Bati-Taban	TRKY	East Ore Body	PLPN
Bati- W. Yarma	TRKY	El Cid	CUBA
Bellacoscia	NCAL	Eldirek	TRKY
Bellevue	NCAL	Ermenis	TRKY
Bereket	TRKY	Fanroche	NCAL
Bezkere-Bulurlii	TRKY	Findikli	TRKY
Bicir-Cakir	TRKY	Findikli #301	TRKY
Bicir-Gul	TRKY	Findikli #306-307	TRKY
Bonsecours	NCAL	Findikli #326	TRKY
Bozkonus	TRKY	General Gallieni	NCAL
Bozotluk-No. 551	TRKY	Gerdag	TRKY
Bugugan	TRKY	Golalan	TRKY
Buyiik Gurleyen	TRKY	Gorunur	TRKY
Buyiik Karamanli	TRKY	Govniikbelen	TRKY
Caledonia	CUBA	Gr2h	NCAL
Camaguey	CUBA	Guillermina	CUBA
Catak	TRKY	Gunliik Basi	TRKY
Catak-Koraalan	TRKY	Herpit Yayla	TRKY
Catolsinir I	TRKY	Igdeli Payas	TRKY
Catolsinir II	TRKY	Ikisulu-Gercek	TRKY
Cenger	TRKY	Jose	CUBA
Cenger-Adatepe	TRKY	Kagit Octu	TRKY
Cenger-Demirk	TRKY	Kandira	TRKY
Cenger-Domuza	TRKY	Kapin	TRKY

DEPOSIT TYPE Podiform Chromite II MODEL NUMBER 1.1

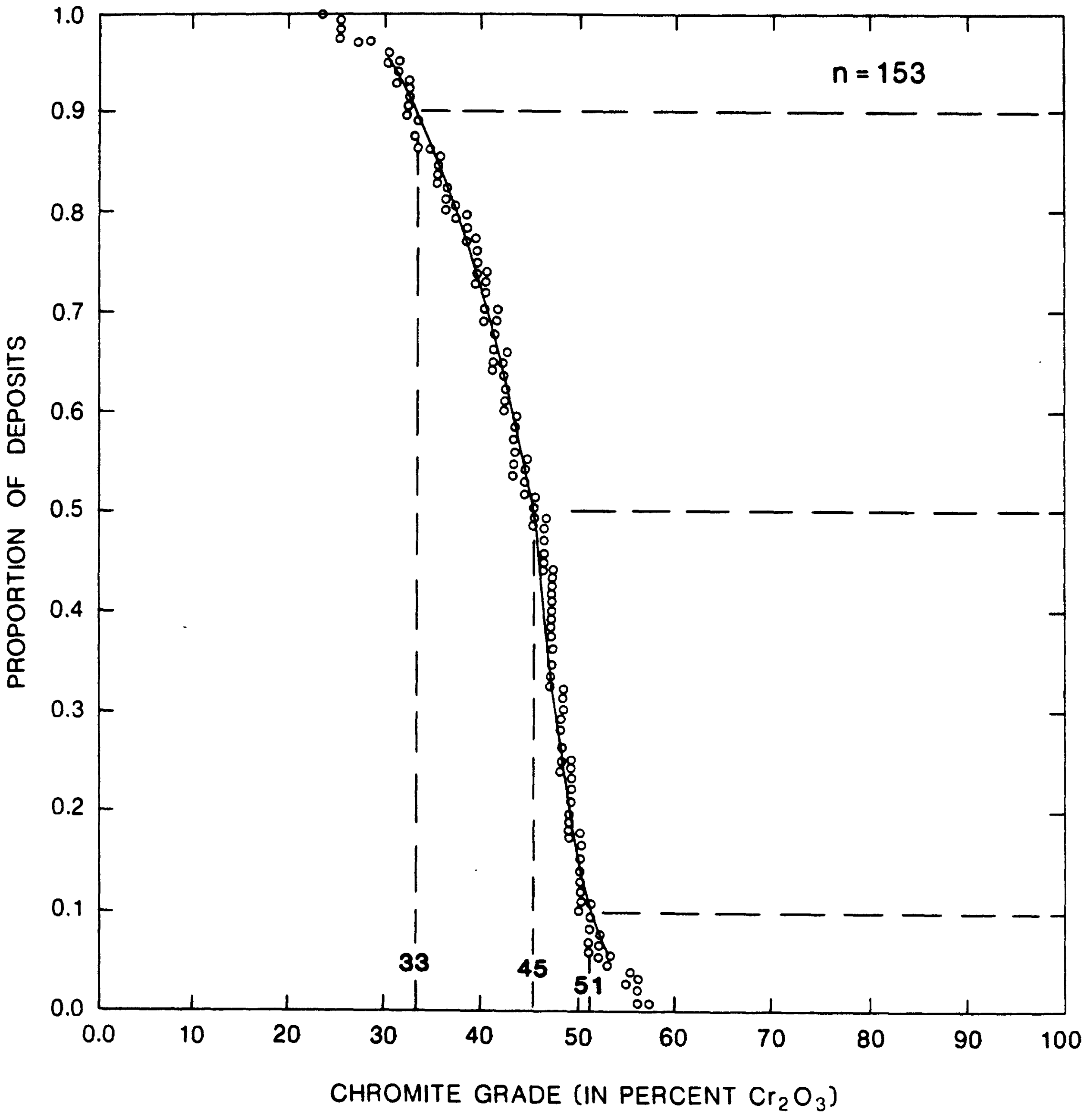
DEPOSITS (continued)

Name	Country	Name	Country
Karaculha	TRKY	P. B.	NCAL
Karageban	TRKY	Pergini	TRKY
Karakcali	TRKY	Potosi	CUBA
Karani	TRKY	Ruff Claim No. 32	PLPN
Karaninar	TRKY	Saka	TRKY
Karasivri	TRKY	Salur	TRKY
Karatas-Kumocak	TRKY	Sarialan	TRKY
Kartalkoyu	TRKY	Sarikaya	TRKY
Kauakdere	TRKY	Saysin	TRKY
Kazadere-Kandil	TRKY	Sekioren	TRKY
Kefdag-East	TRKY	Shahin	IRAN
Kemikli Inbasi	TRKY	Sicankale	TRKY
Kilic-Kafasi 1	TRKY	Sirac	TRKY
Kilic-Kafasi 2	TRKY	Sofulu	TRKY
Kiranocak	TRKY	Sogham	IRAN
Koca	TRKY	Sta. Cruz	PLPN
Komek	TRKY	Stephane	NCAL
Koycegiz-Curukcu	TRKY	Suluiyeh	IRAN
Koycegiz-Kurardi	TRKY	Sulu	TRKY
Koycegiz-Orta	TRKY	Suluk	TRKY
Kuldoden	TRKY	Sutpinar	TRKY
Kundikan-Keluskdere	TRKY	Suzanne	NCAL
Kundikan-Kelusktepe	TRKY	Tekneli	TRKY
Kurudere	TRKY	Tepebasi	TRKY
Kuyuluk Isletmesi	TRKY	Terlik	TRKY
Kuzkavak	TRKY	Tiebaghi	NCAL
La Caridid	CUBA	Tilkim-Karanlik	TRKY
Lagonoy	PLPN	Togobomar	PLPN
La Victoria	CUBA	Tosin	TRKY
Lolita	CUBA	Toparlar-Alacik	TRKY
Marais Kiki	NCAL	Tuzlakaya	TRKY
Meululter	TRKY	Uckopru	TRKY
Middle Ore Body	PLPN	Vieille Montagne 1	NCAL
Mirandag Koru	TRKY	Vieille Montagne 2	NCAL
Mirandag Mevki	TRKY	West Ore Body	PLPN
Morrachini	NCAL	Yanikara	TRKY
Musa Danisman	TRKY	Yaprakli	TRKY
Narciso	CUBA	Yayca Boyna	TRKY
Ni Te Ocutes	CUBA	Yilmaz Ocagi	TRKY
Ochanocagi	TRKY	Yukari Zorkum	TRKY
Ofelia	CUBA	Yunus Yayla	TRKY
Orta Ezan	TRKY	Yurtlak	TRKY
Otmanlar-Harpuzlu	TRKY	Zambales Ch	PLPN
Otmanlar-Mesebuku	TRKY	Zimparalik	TRKY
Panamana-An	PLPN		



PODIFORM CHROMITE
n = 153
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PROPORTION OF DEPOSITS
0.0024
0.019
0.2
0.0004
0.0016
0.0063
0.025
0.10
0.40
1.6
6.3
25
100
400
TONNES (IN MILLIONS)

PODIFORM CHROMITE



DEPOSIT TYPE Synvolcanic - synorogenic nickel MODEL NUMBER 1.7

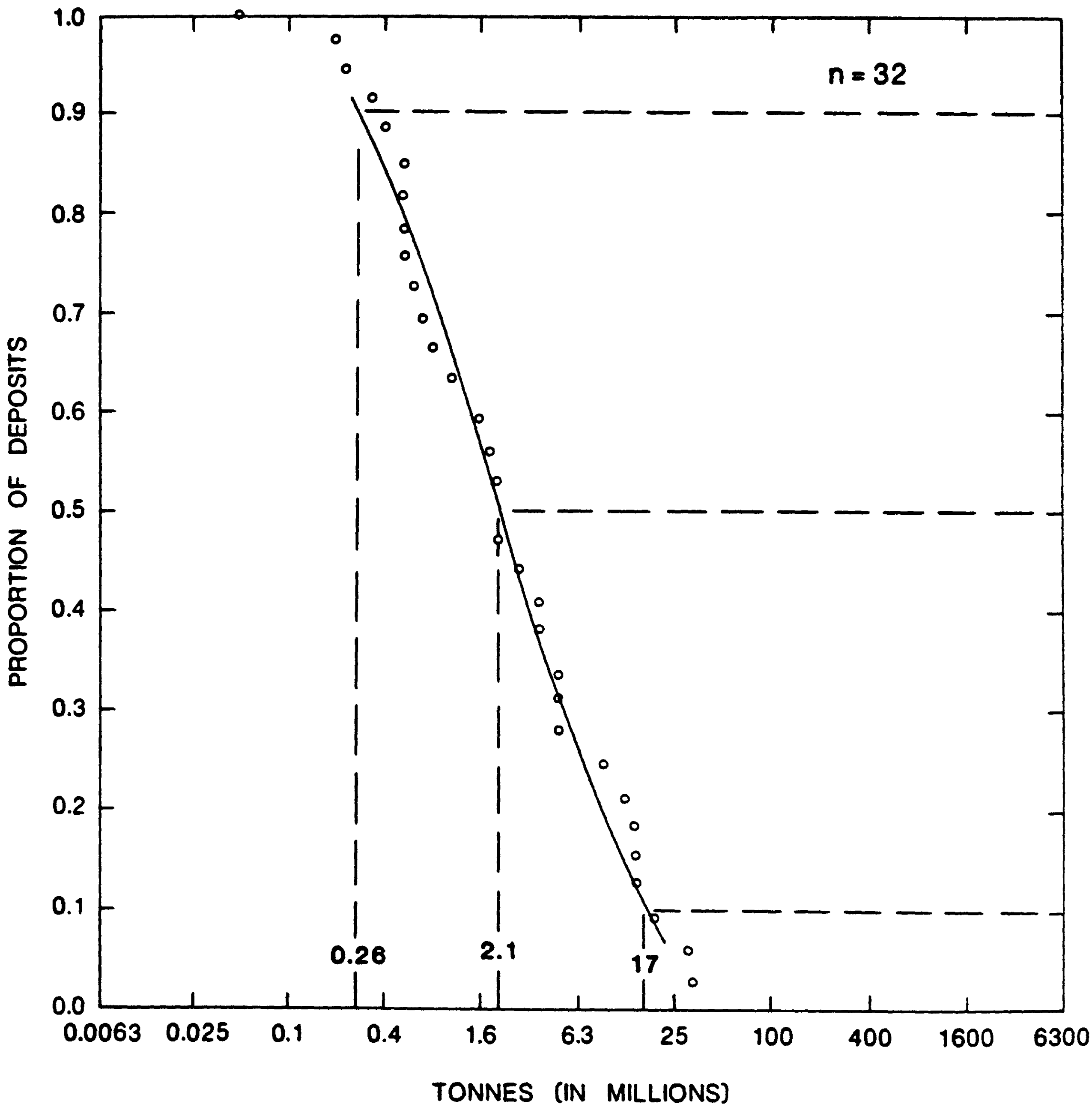
AUTHOR D. A. Singer, N. J Page, and W. D. Menzie

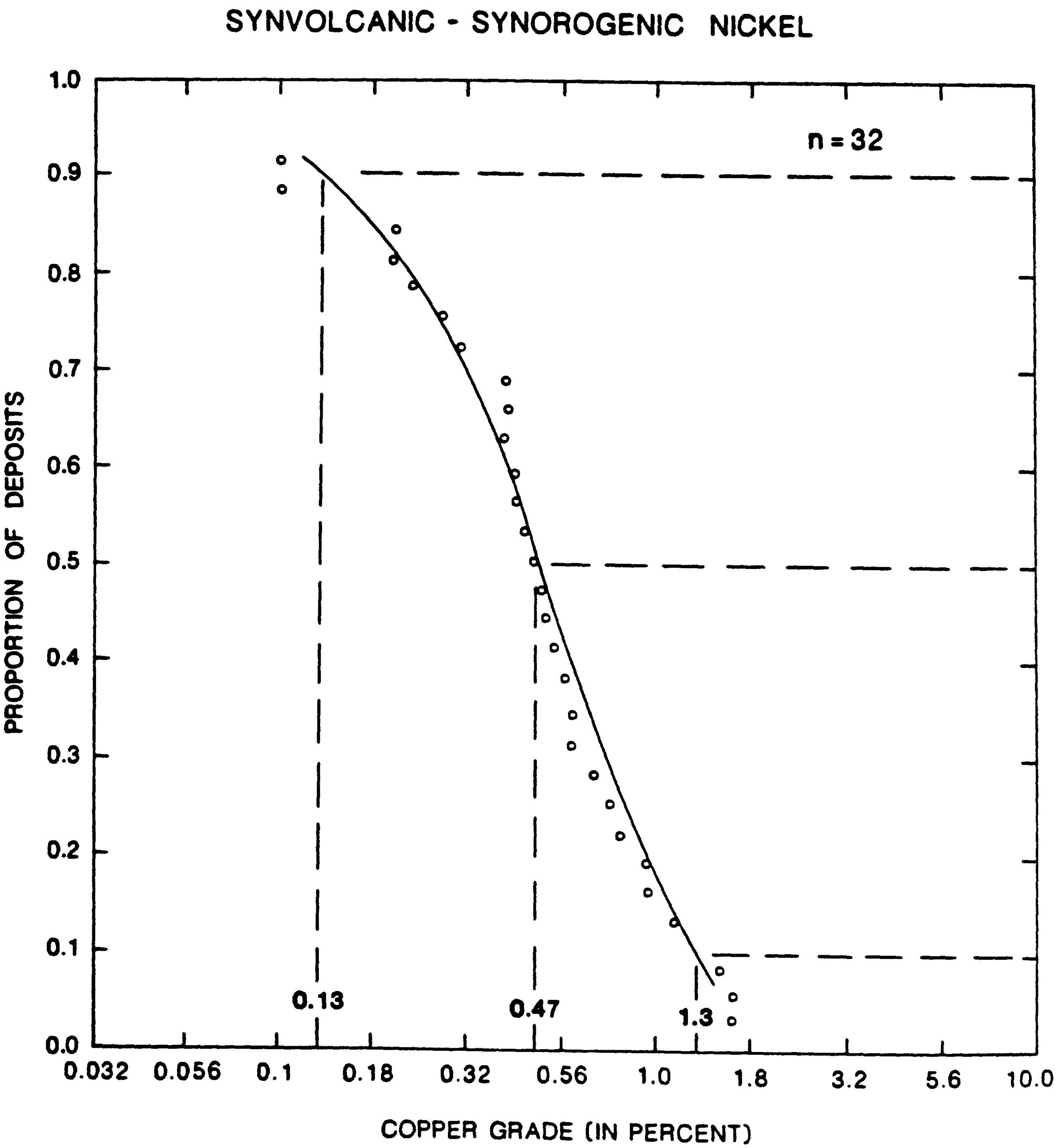
COMMENTS

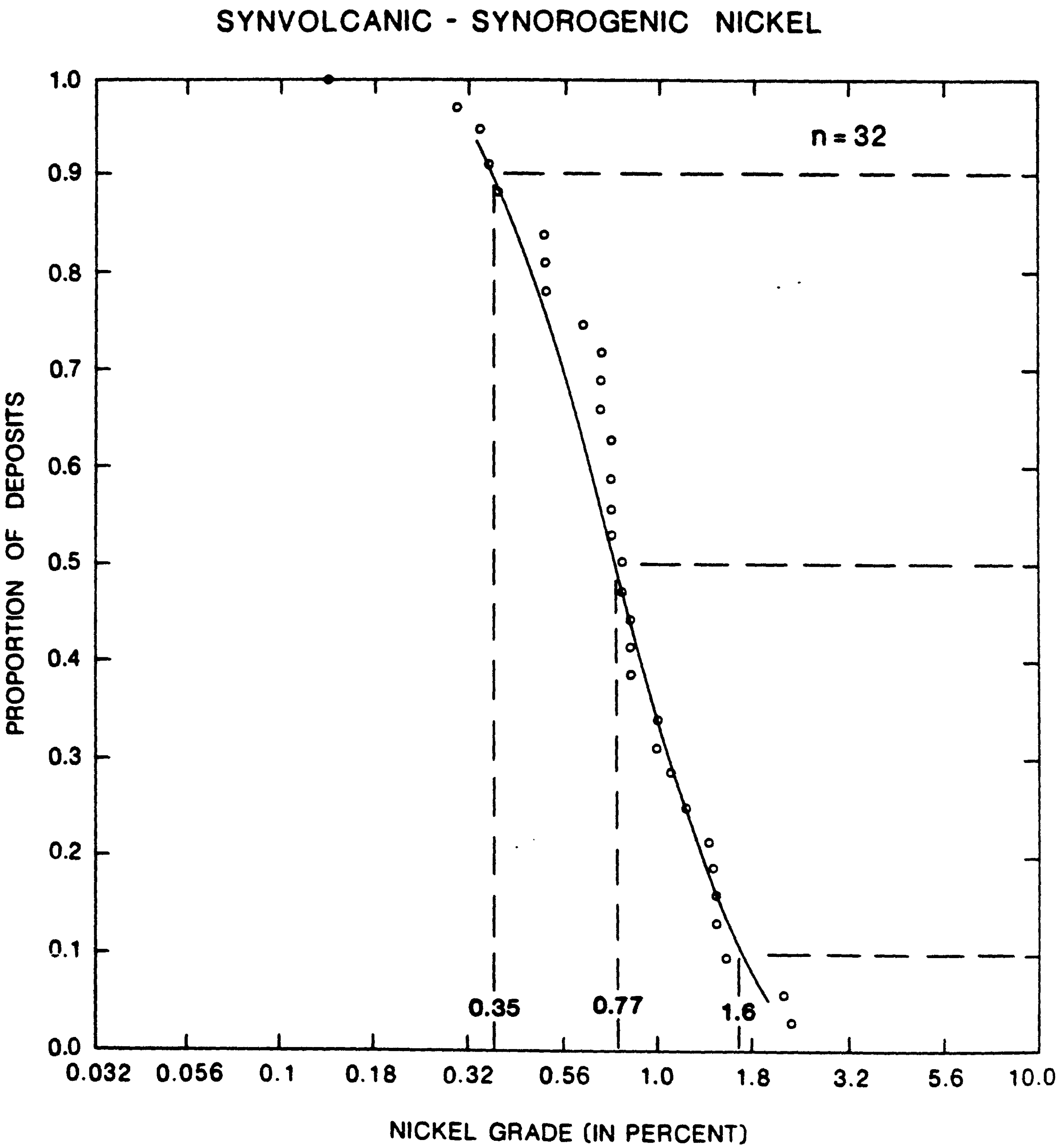
DEPOSITS

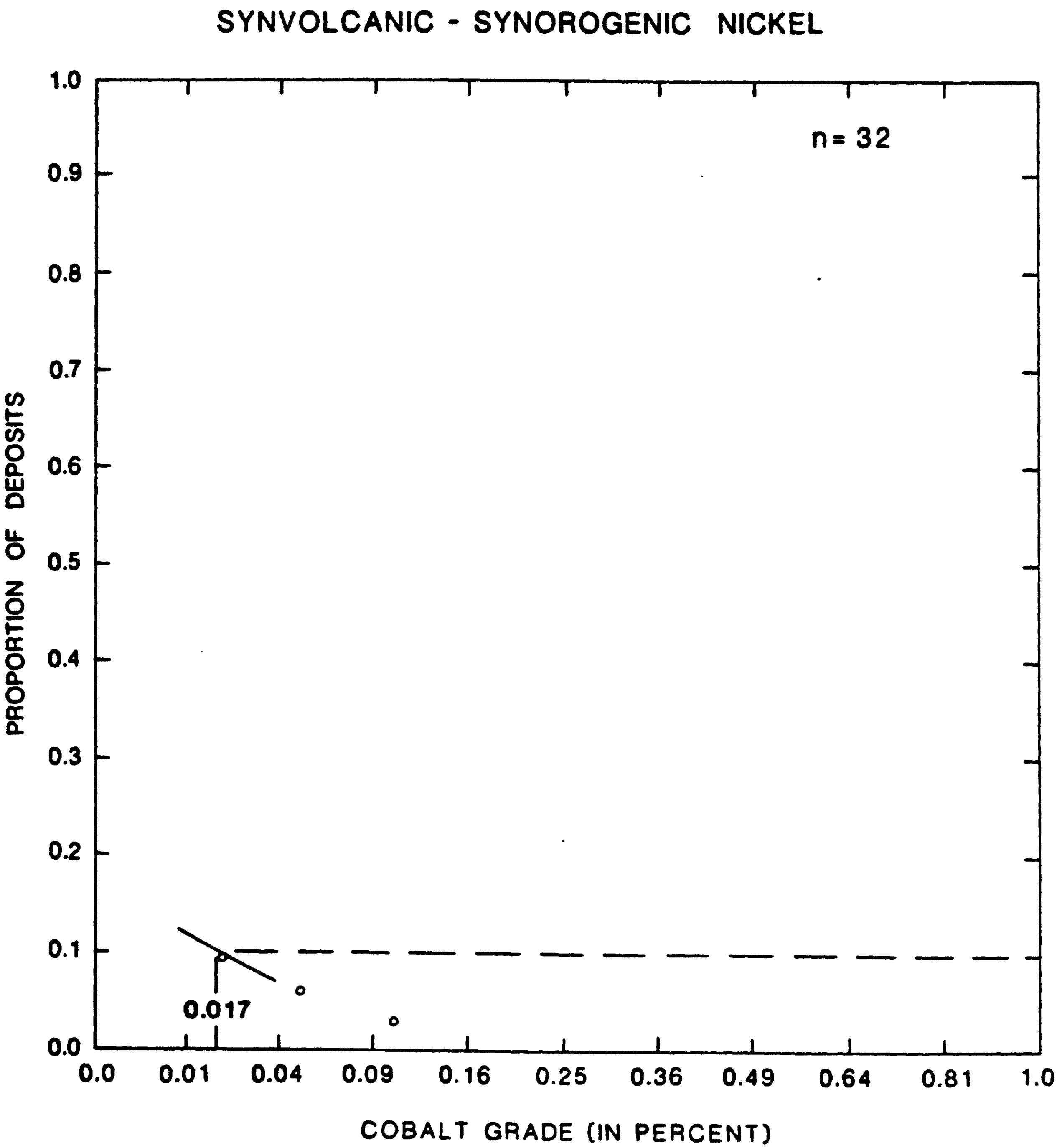
Name	Country	Name	Country
Bamble	NRWY	Makola	FNLD
Carr Boyd	AUWA	Mjodvattnet	SWDN
Empress	ZIMB	Montcalm	CNON
Flaat	NRWY	Mt. Sholl	AUWA
Funter Bay	USAK	Phoenix	BOTS
Gap	USPA	Pikwe	BOTS
Giant Mascot	CNBC	Renzy	CNQU
Hosanger	NRWY	Risliden	SWDN
Kenbridge	CNON	Selebi	BOTS
Kylmakoski	FNLD	Selebi N.	BOTS
Lainijaur	SWDN	Selkirk	BOTS
Lappuattnet	SWDN	Tekwane	BOTS
Laukunkawges	FNLD	Thierry	CNON
Lorraine	CNQU	Vakkerlien	NRWY
Lynn Lake	CNMN	Vammala	FNLD
Madziwa	ZIMB	Yakobi Island	USAK

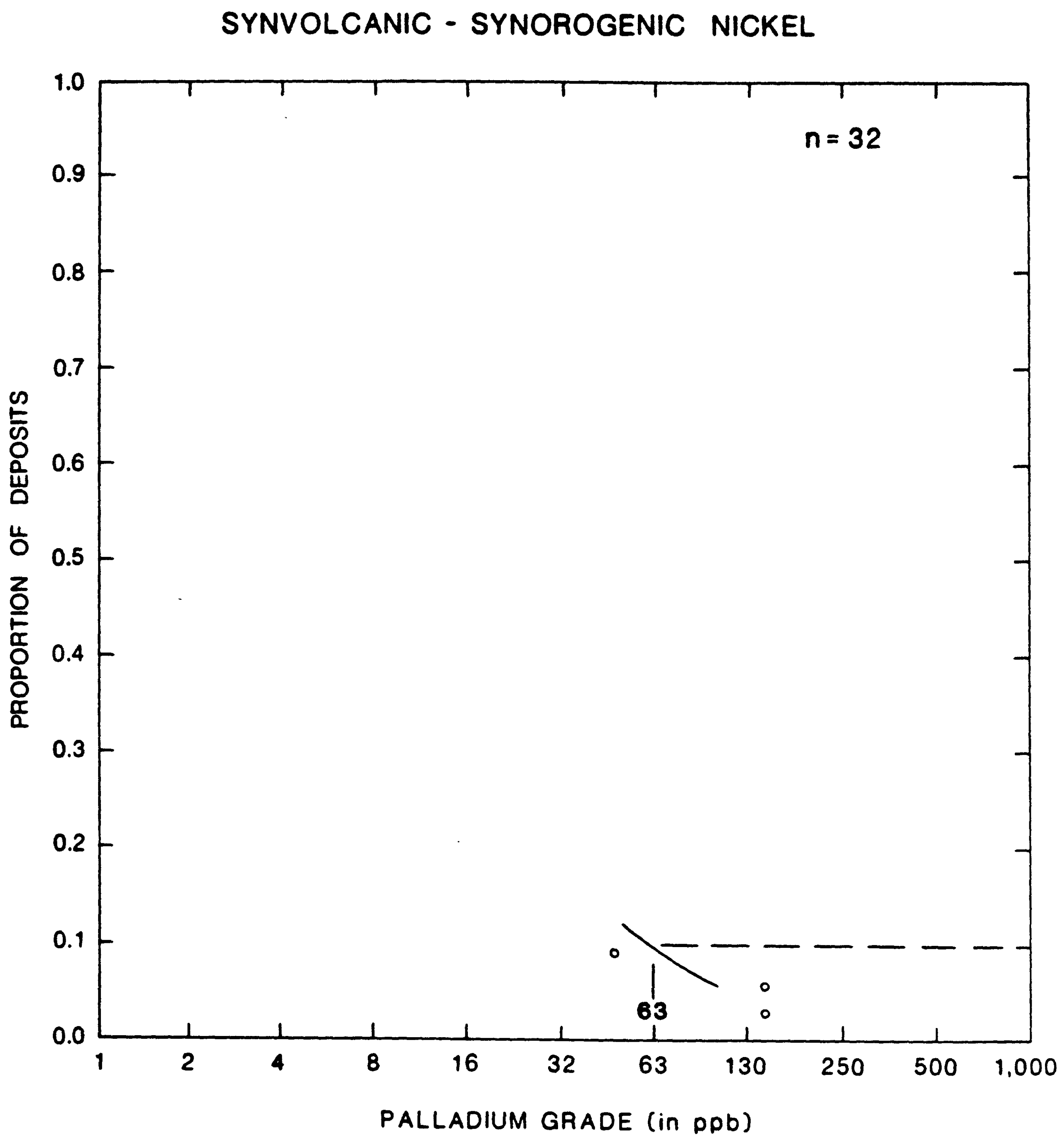
SYNVOLCANIC - SYNOROGENIC NICKEL

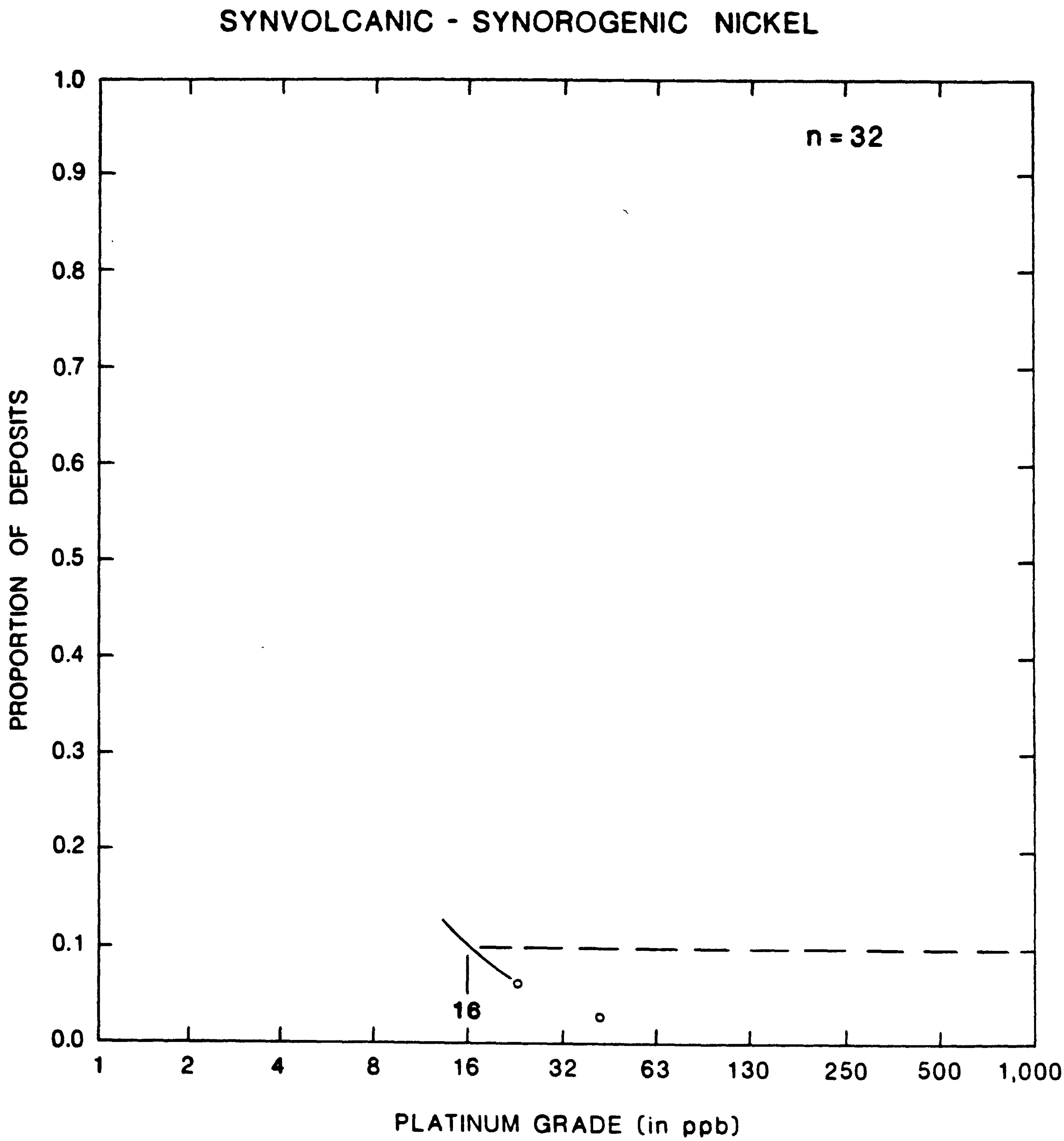



SYNVOLCANIC - SYNOROGENIC NICKEL
n = 32
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.13
0.47
1.3
0.032
0.056
0.1
0.18
0.32
0.56
1.0
1.8
3.2
5.6
10.0
COPPER GRADE (IN PERCENT)

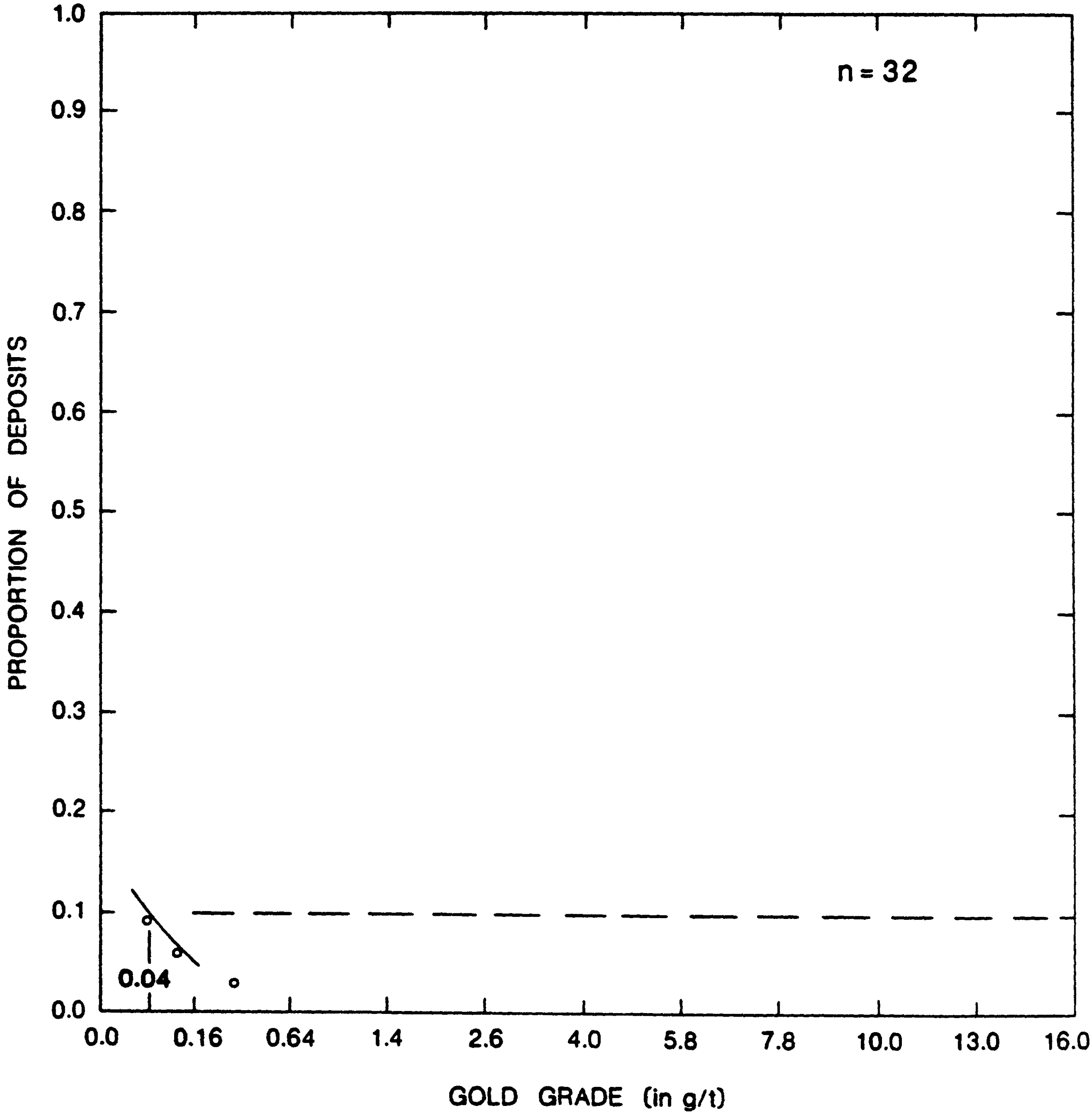

SYNVOLCANIC - SYNOROGENIC NICKEL
n = 32
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.35
0.77
1.6
0.032
0.056
0.1
0.18
0.32
0.56
1.0
1.8
3.2
5.6
10.0
NICKEL GRADE (IN PERCENT)


SYNVOLCANIC - SYNOROGENIC NICKEL
n= 32
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.017
0.0
0.01
0.04
0.09
0.16
0.25
0.36
0.49
0.64
0.81
1.0
COBALT GRADE (IN PERCENT)


SYNVOLCANIC - SYNOROGENIC NICKEL
n = 32
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
63
1
2
4
8
16
32
63
130
250
500
1,000
PALLADIUM GRADE (in ppb)


SYNVOLCANIC - SYNOROGENIC NICKEL
n = 32
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
16
1
2
4
8
16
32
63
130
250
500
1,000
PLATINUM GRADE (in ppb)

SYNVOLCANIC - SYNOROGENIC NICKEL



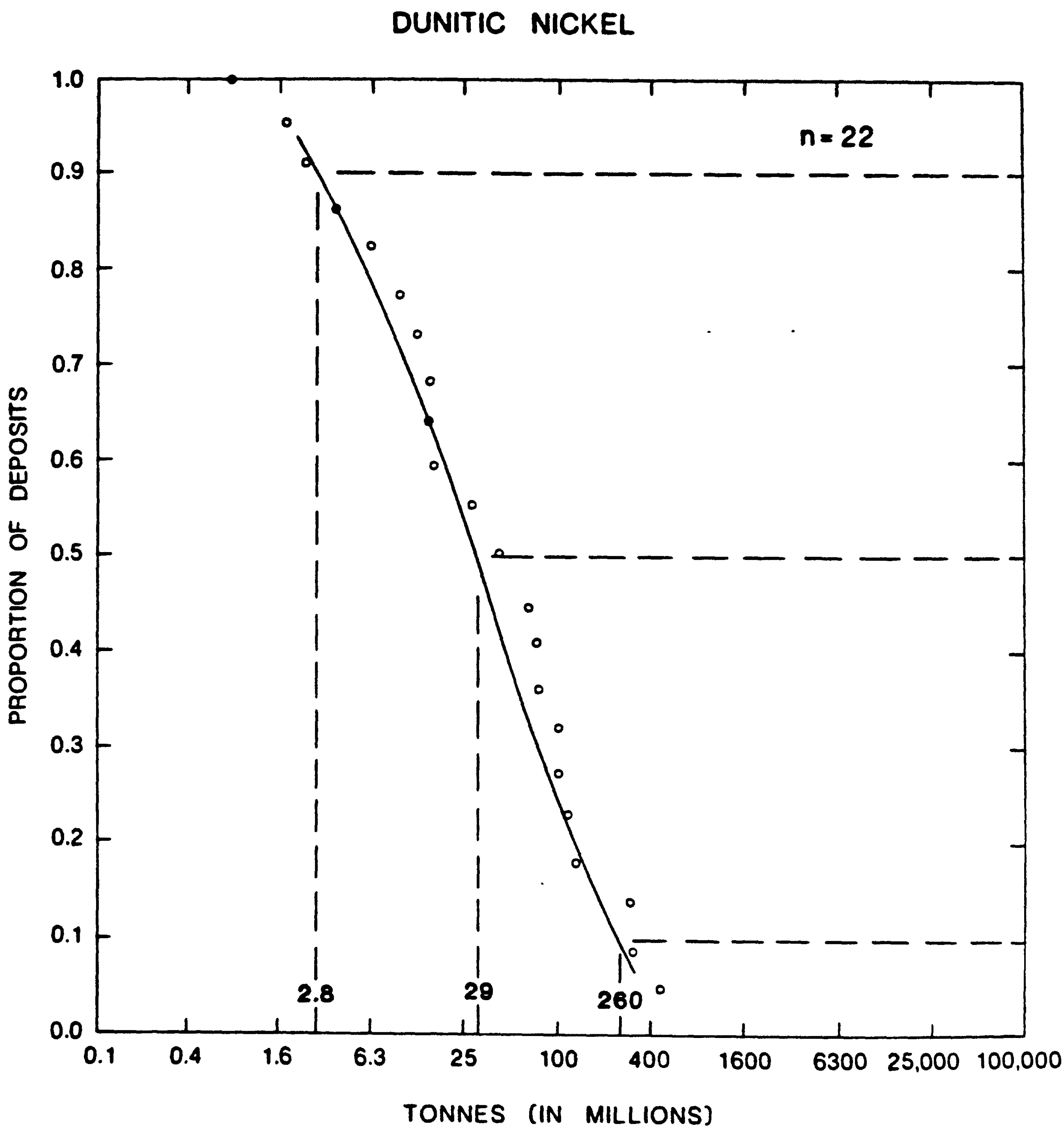
DEPOSIT TYPE Dunitic nickel MODEL NUMBER 1.8

AUTHOR D. A. Singer and N. J Page

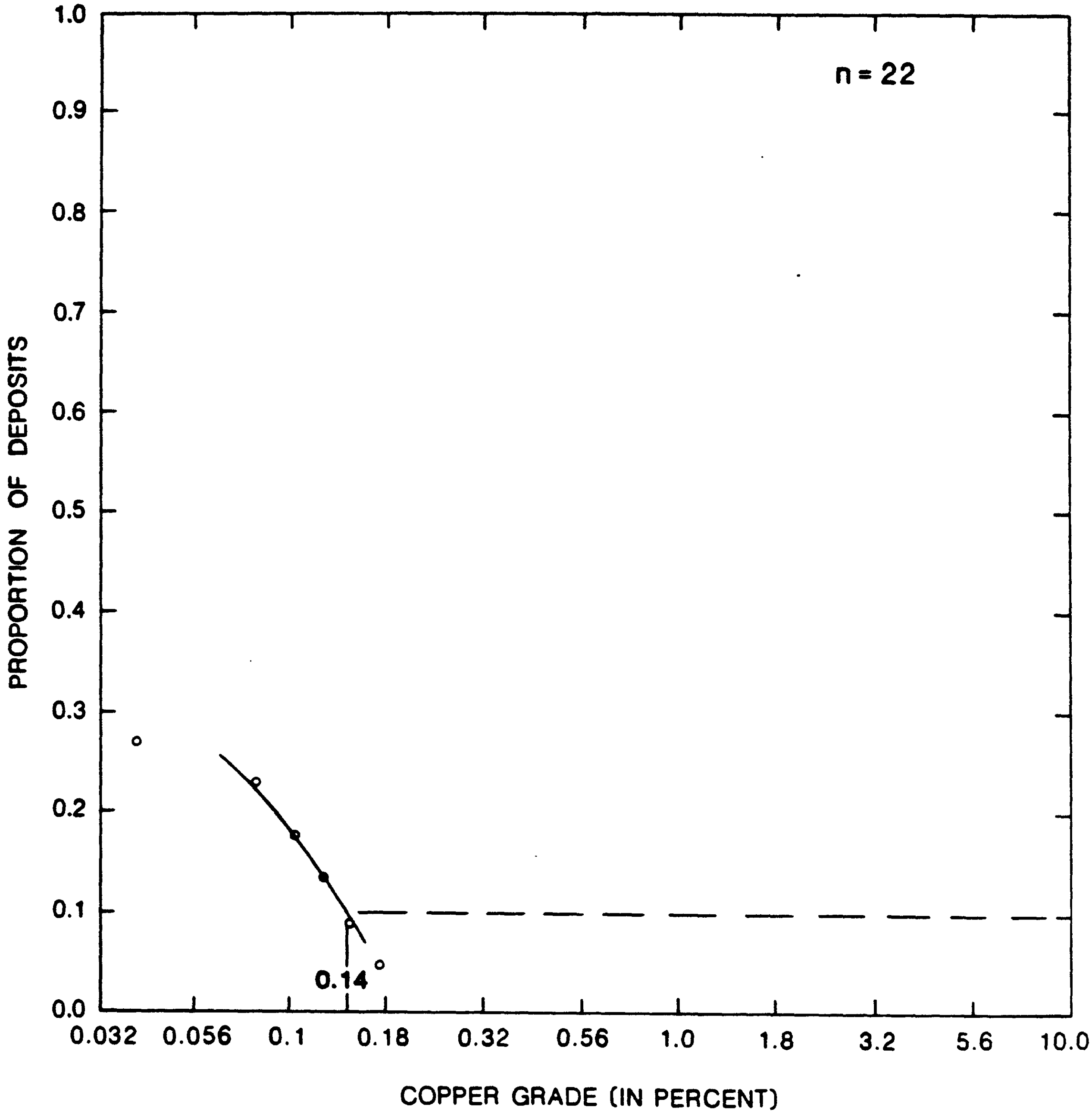
COMMENTS Tonnage is correlated with nickel grade (r=-0.54). Nickel grade is correlated with copper grade (r=0.84, n=12), with palladium grade (r=0.88, n=5), and with gold grade (r=0.94, n=5).

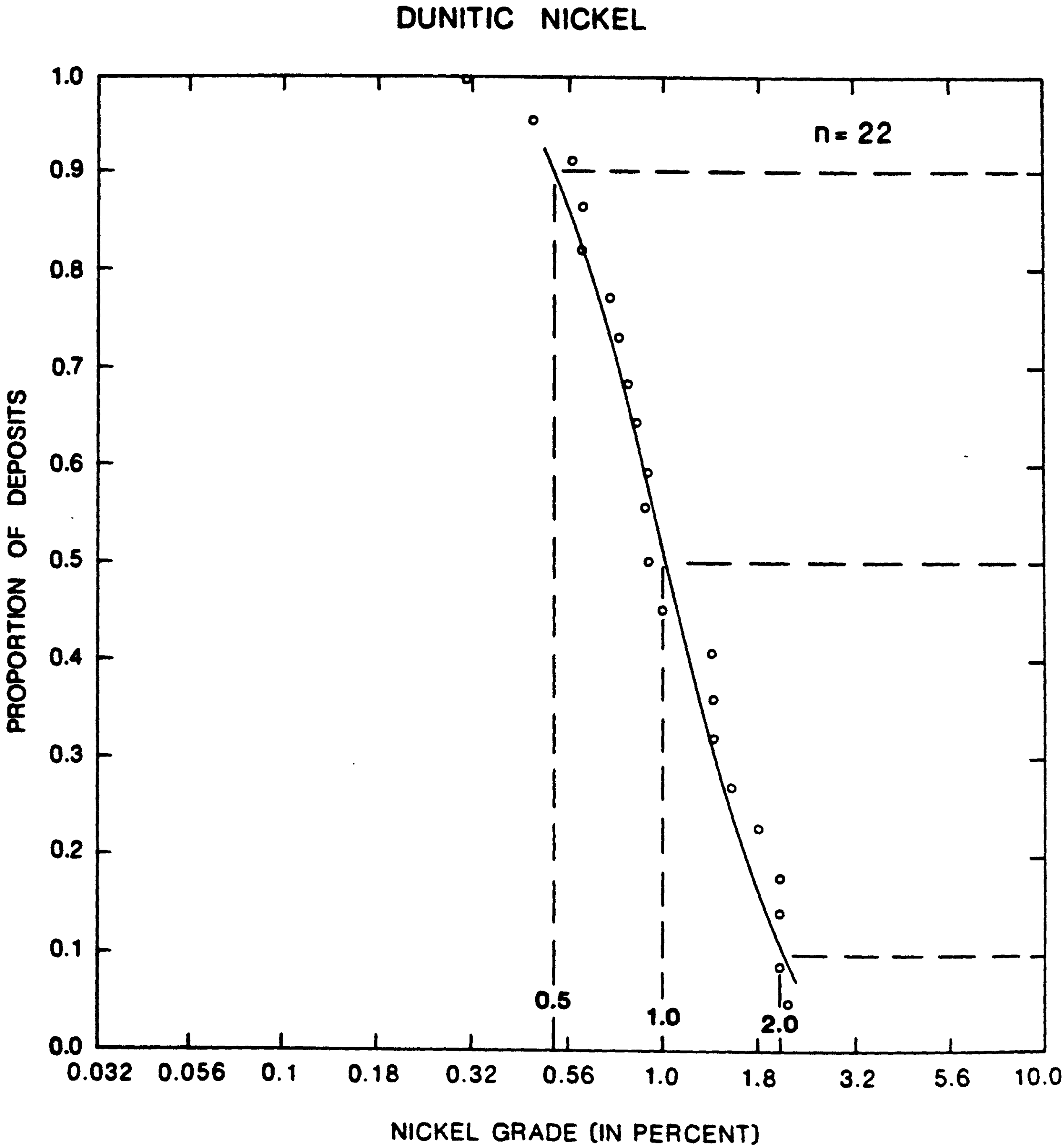
DEPOSITS

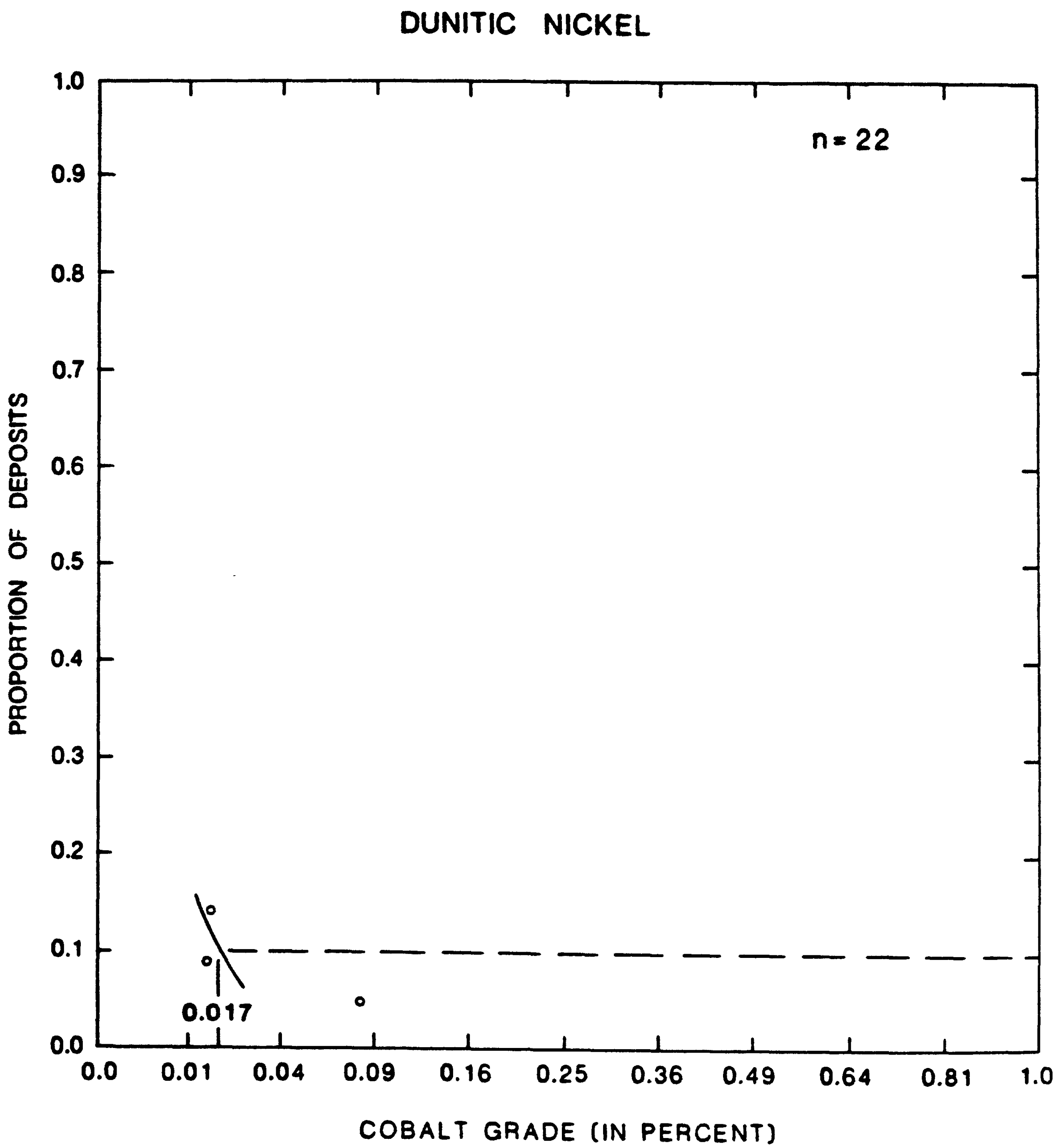
Name	Country
Agnew (Perseverance)	AUWA
Amax	CNMN
Birch Tree	CNMN
Black Swan	AUWA
Bowden Lake	CNMN
Bucko	CNMN
Discovery	CNMN
Dumont	CNQU
Forrestania Group	AUWA
Geol. Reser. No. 34	CNMN
Hambone	CNMN
Honeymoon Well	AUWA
Manibridge	CNMN
Moak	CNMN
Mt. Keith	AUWA
Mystery Lake	CNMN
Pipe	CNMN
Six Mile	AUWA
Soab N.	CNMN
Soab S.	CNMN
Thompson	CNMN
Weebo Bore	AUWA


DUNITIC NICKEL
n = 22
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2.8
29
260
0.1
0.4
1.6
6.3
25
100
400
1600
6300
25,000
100,000
TONNES (IN MILLIONS)

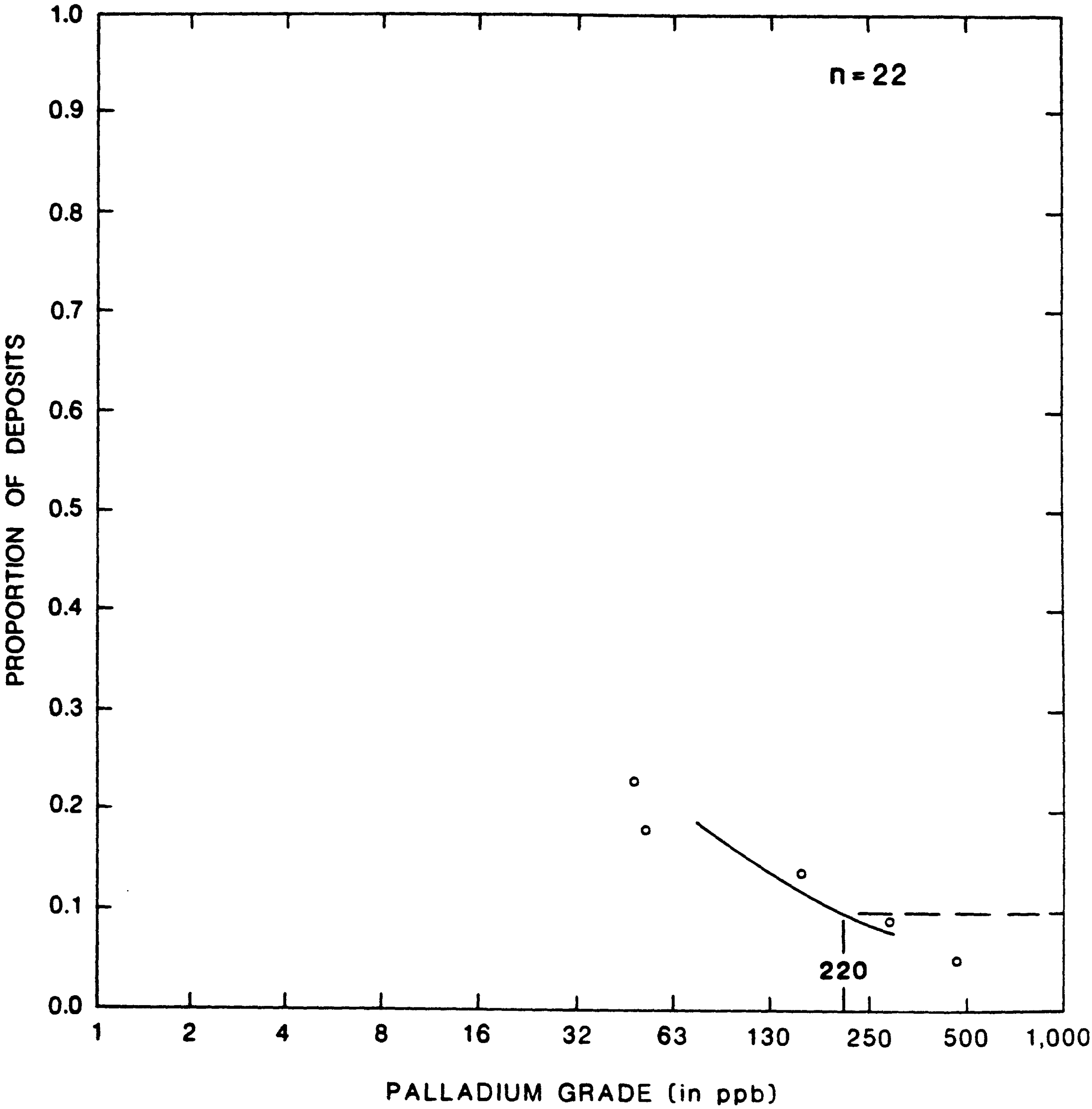
DUNITIC NICKEL

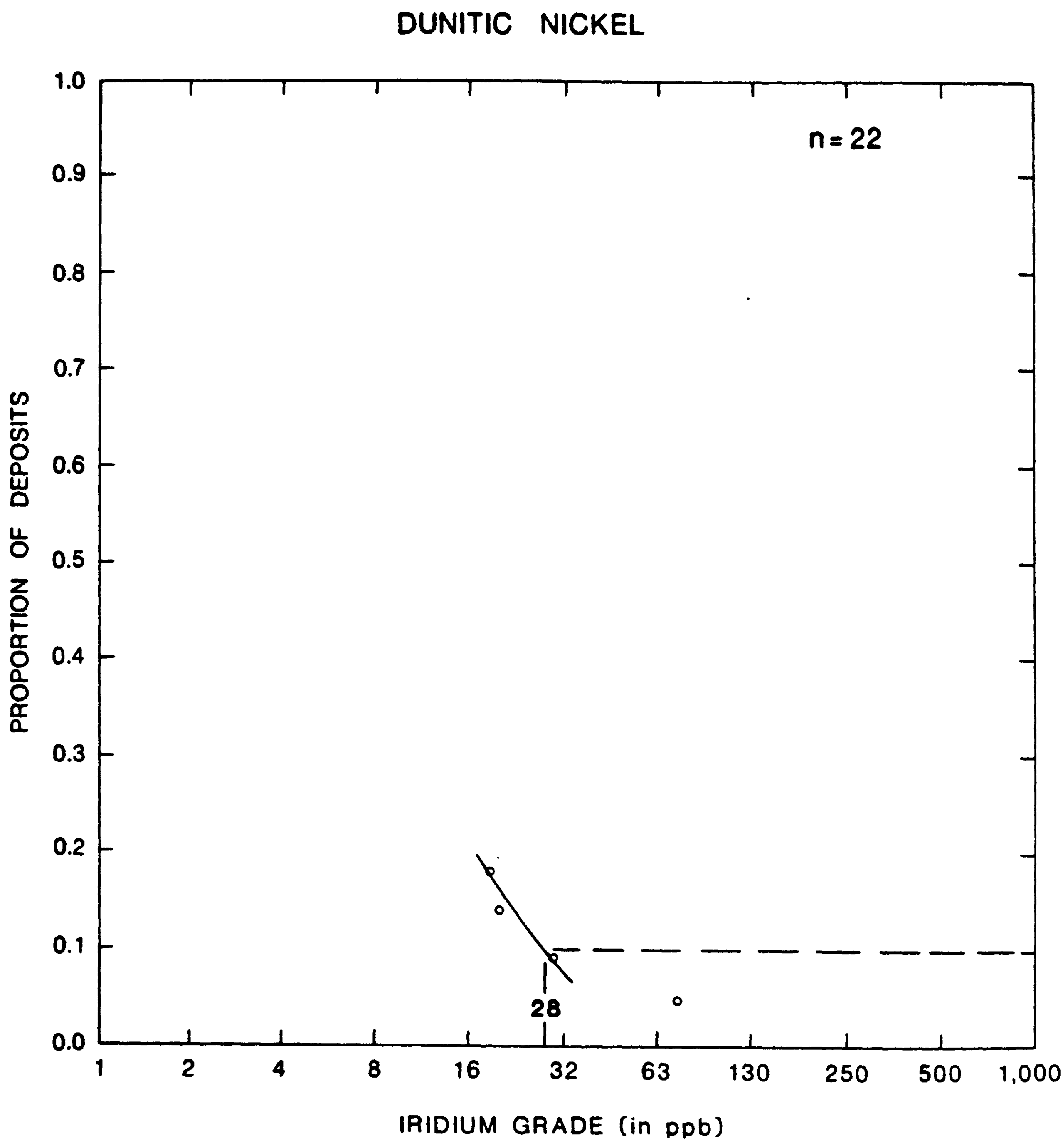


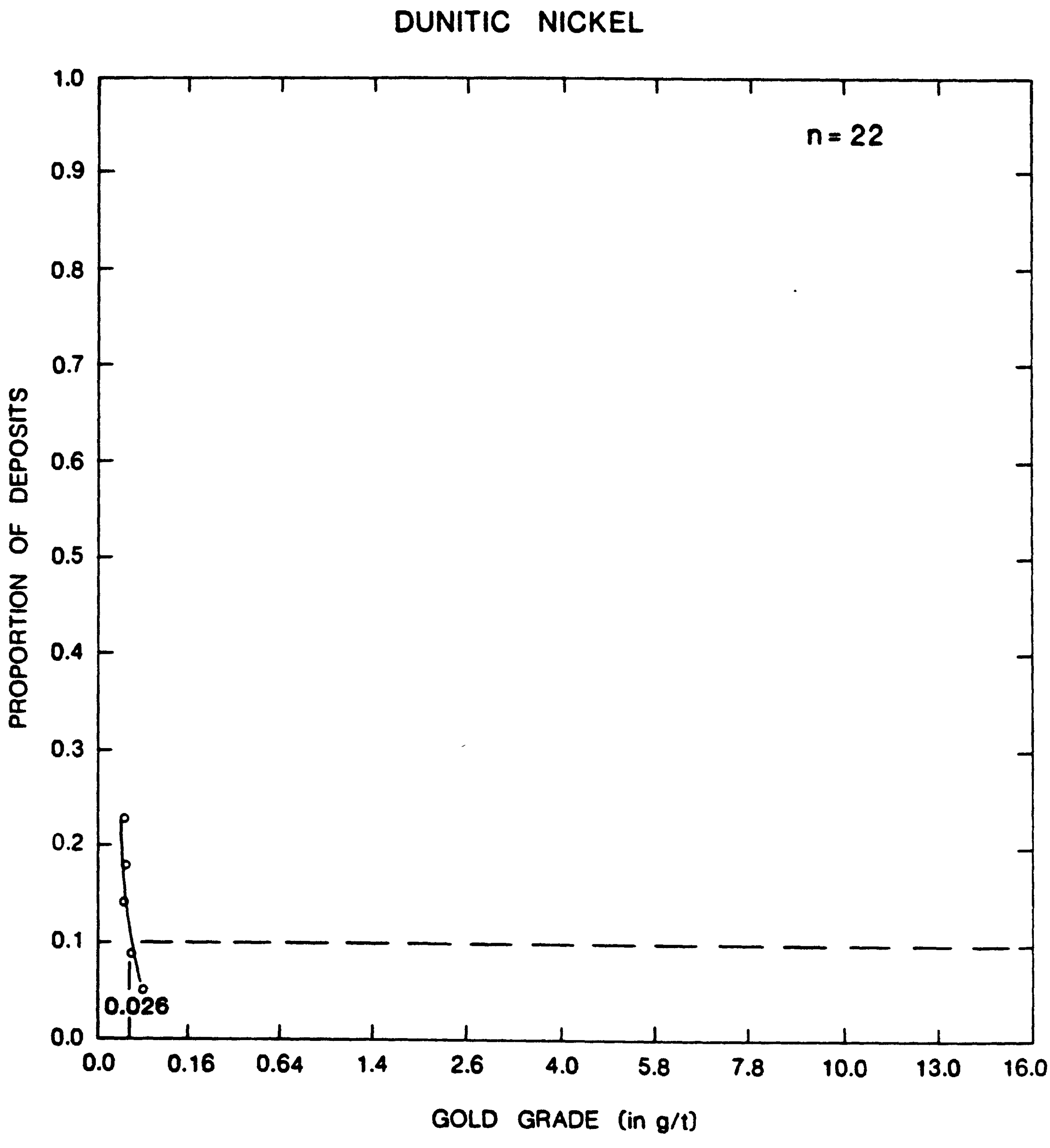

DUNITIC NICKEL
n = 22
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.5
1.0
2.0
0.032 0.056 0.1 0.18 0.32 0.56 1.0 1.8 3.2 5.6 10.0
NICKEL GRADE (IN PERCENT)


DUNITIC NICKEL
n= 22
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.017
0.0
0.01
0.04
0.09
0.16
0.25
0.36
0.49
0.64
0.81
1.0
COBALT GRADE (IN PERCENT)

DUNITIC NICKEL




DUNITIC NICKEL
n = 22
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
28
1
2
4
8
16
32
63
130
250
500
1,000
IRIDIUM GRADE (in ppb)


DUNITIC NICKEL
n = 22
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.026
0.0
0.16
0.64
1.4
2.6
4.0
5.8
7.8
10.0
13.0
16.0
GOLD GRADE (in g/t)

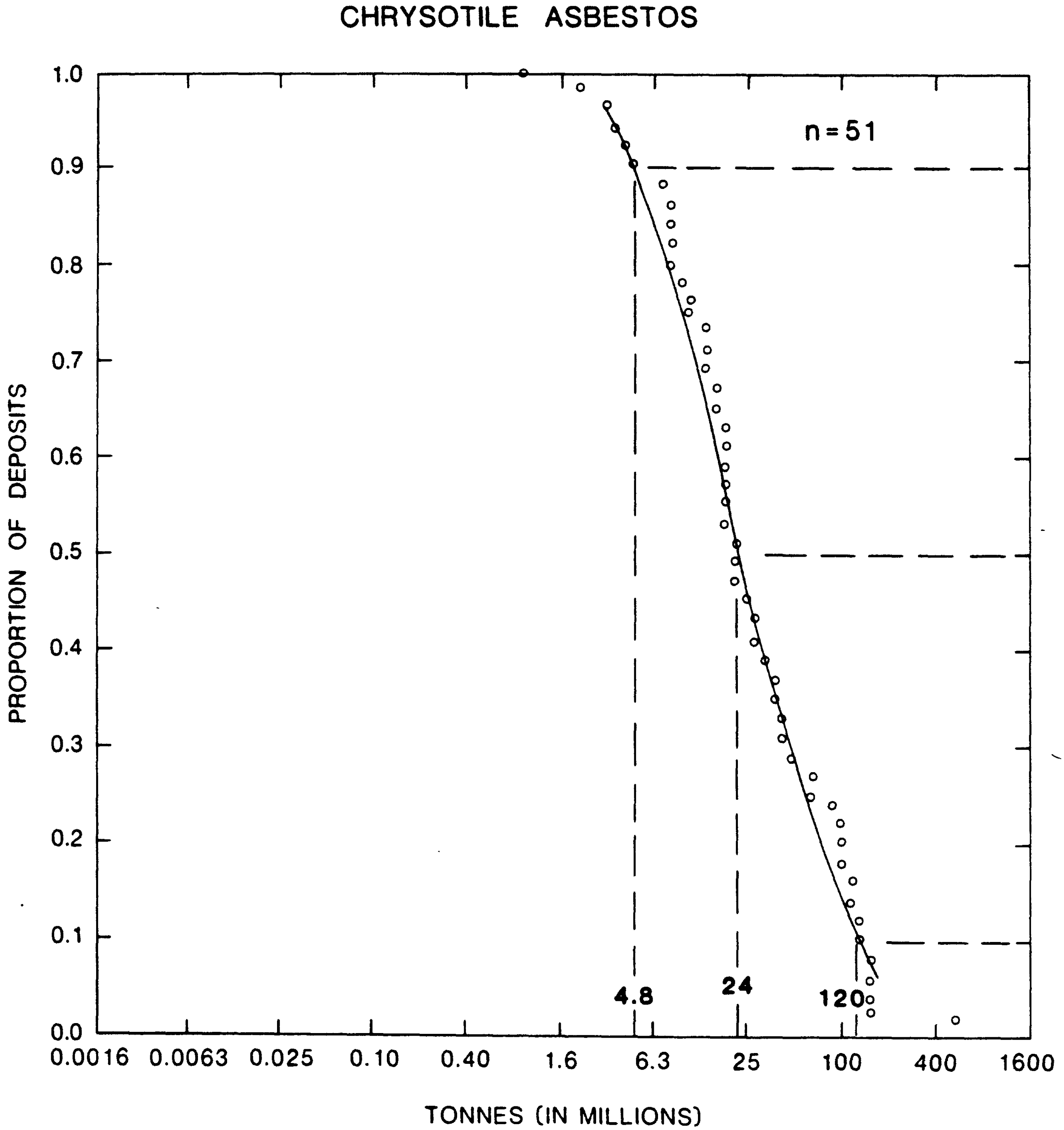
DEPOSIT TYPE Chrysotile asbestos MODEL NUMBER 1.9

AUTHOR G. Orris

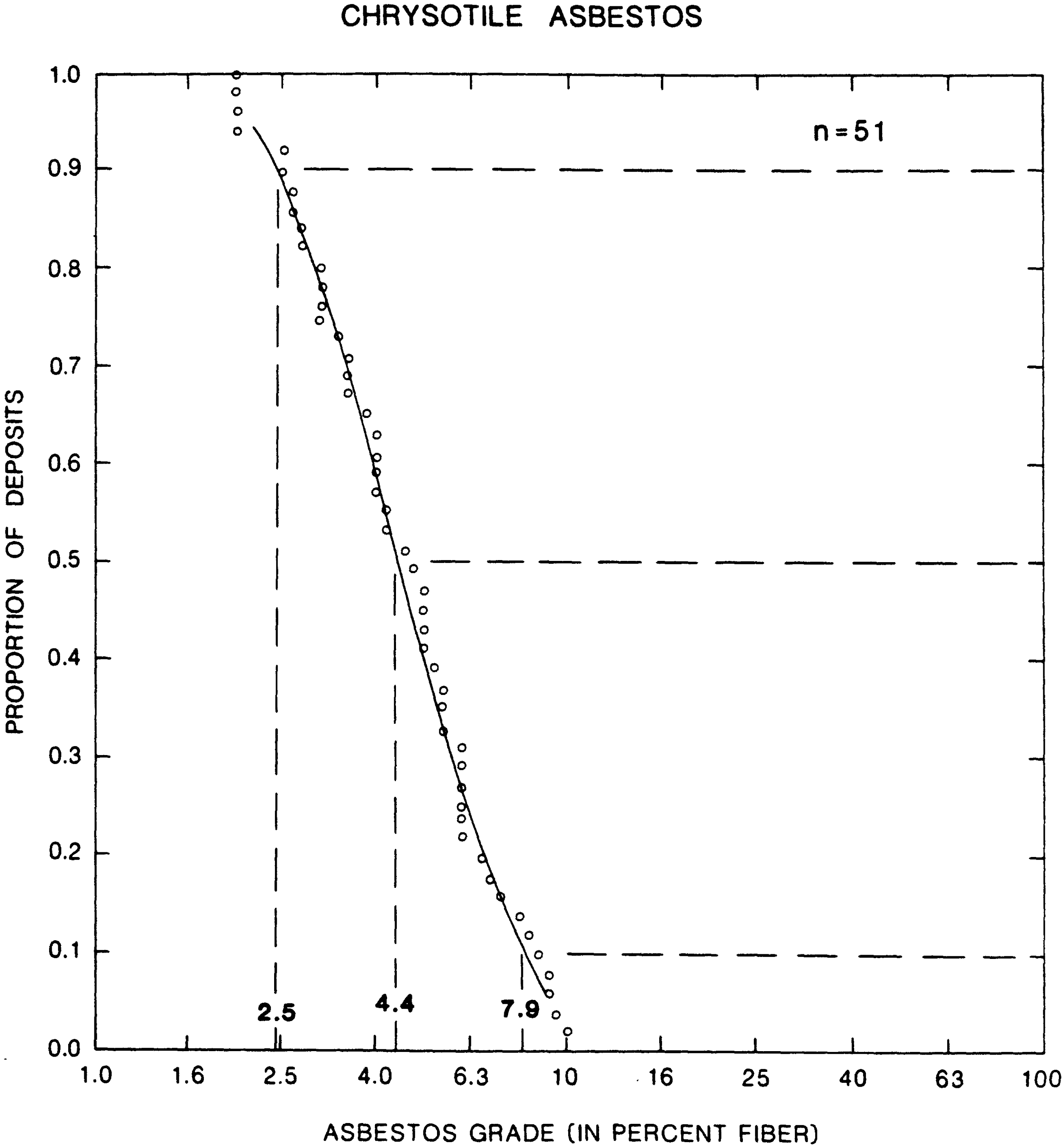
COMMENTS Long and short fibers are combined.

DEPOSITS

Name	Country	Name	Country
Abitibi	CNQU	McAdam	CNQU
Advocate	CNNF	McDame	CNBC
Asbestos Hill	CNQU	Midlothian	CNON
Asbestos Island	CNQU	Moladezhnoye	URRS
Bell Mine	CNQU	Msauli	SAFR
Belvidere	USVT	Munro	CNON
Black Lake	CNQU	National	CNQU
British Canadian	CNQU	Nicolet Asbestos	CNQU
Caley	CNYT	Normandie/Penhale	CNQU
Carey/East Broughton	CNQU	Pontbriand	CNQU
Cana Brava	BRZL	Qala-el-Nahl?	SUDN
Cassiar Mine	CNBC	Reeves	CNON
Clinton Creek	CNYT	Rex	CNYT
Continental	CNQU	Roberge Lake	CNQU
Copperopolis	USCA	St. Adrien Mtn.	CNQU
Courvan Mine	CNQU	St. Cyr	CNQU
Cranbourne	CNQU	Santiago Papalo	MXCO
Daffodil	CNON	Sayan	URRS
Eagle	USAK	Shihmien	CINA
Gilmont	CNQU	Steele Brook	CNQU
Golden Age	CNQU	Tuolumne	USCA
Jeffrey	CNQU	Windsor	CNQU
King-Beaver Mine	CNQU	Woodsreef Mine	AUNS
Kudu Asbestos Mine	ZIMB	Zindani	GREC
Lake Asbestos	CNQU		
Las Brisas	CLBA		
Lili	CNQU		



CHRYSOTILE ASBESTOS
n=51
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
4.8
24
120
0.0016
0.0063
0.025
0.10
0.40
1.6
6.3
25
100
400
1600
TONNES (IN MILLIONS)



CHRYSOTILE ASBESTOS
n=51
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2.5
4.4
7.9
1.0
1.6
2.5
4.0
6.3
10
16
25
40
63
100
ASBESTOS GRADE (IN PERCENT FIBER)

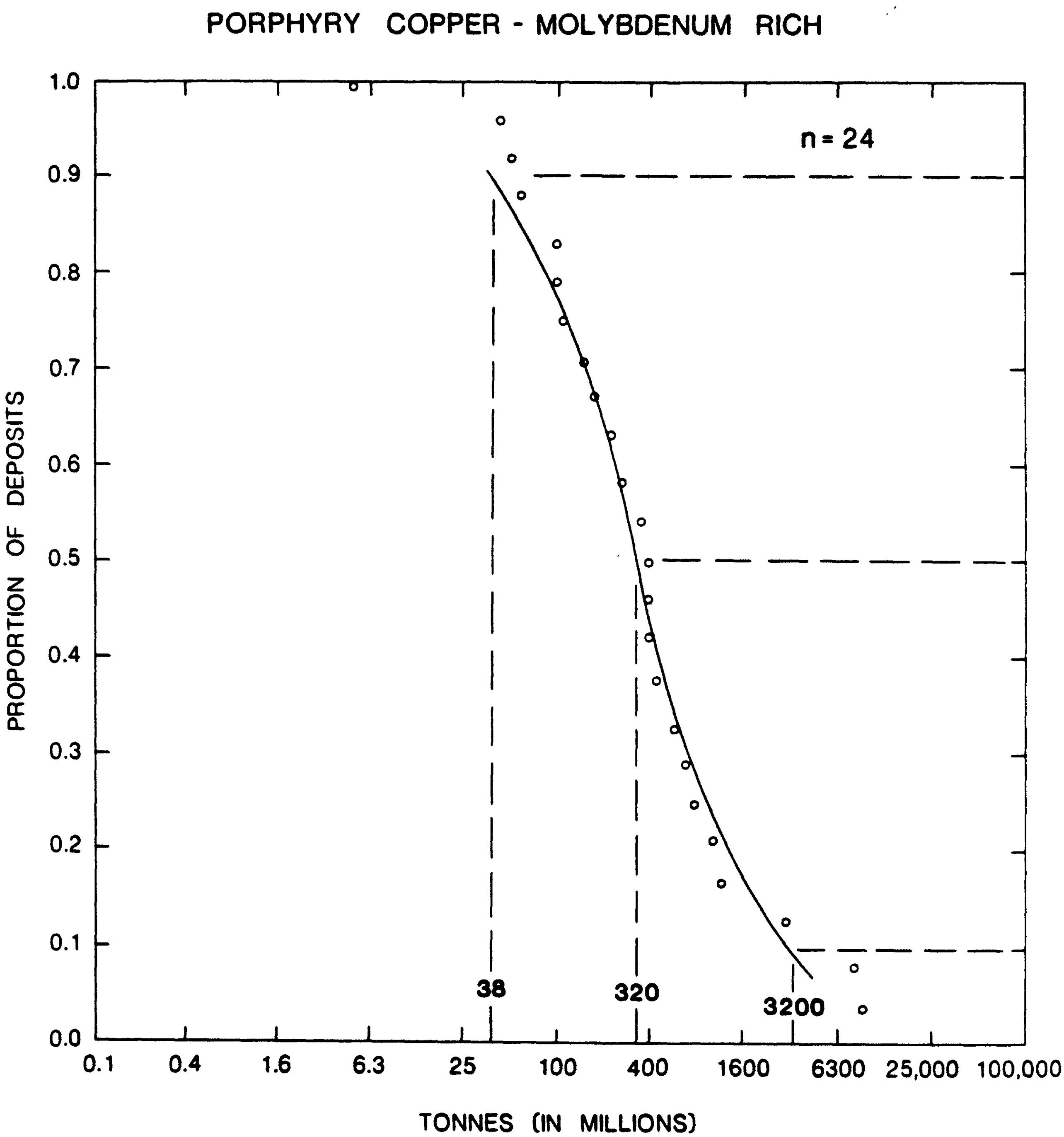
DEPOSIT TYPE Porphyry copper--molybdenum rich MODEL NUMBER 2.1

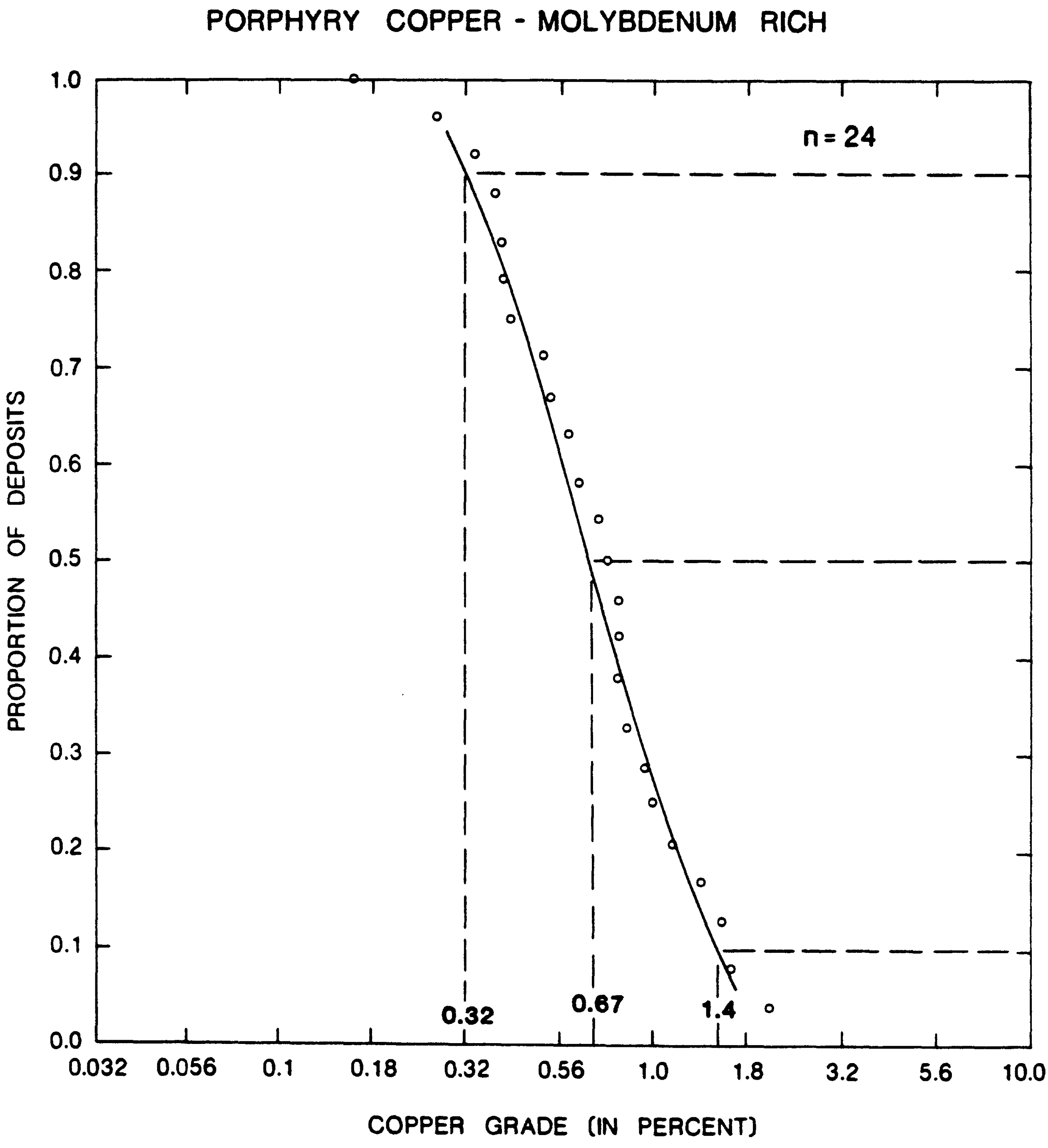
AUTHOR D. A. Singer and D. L. Mosier

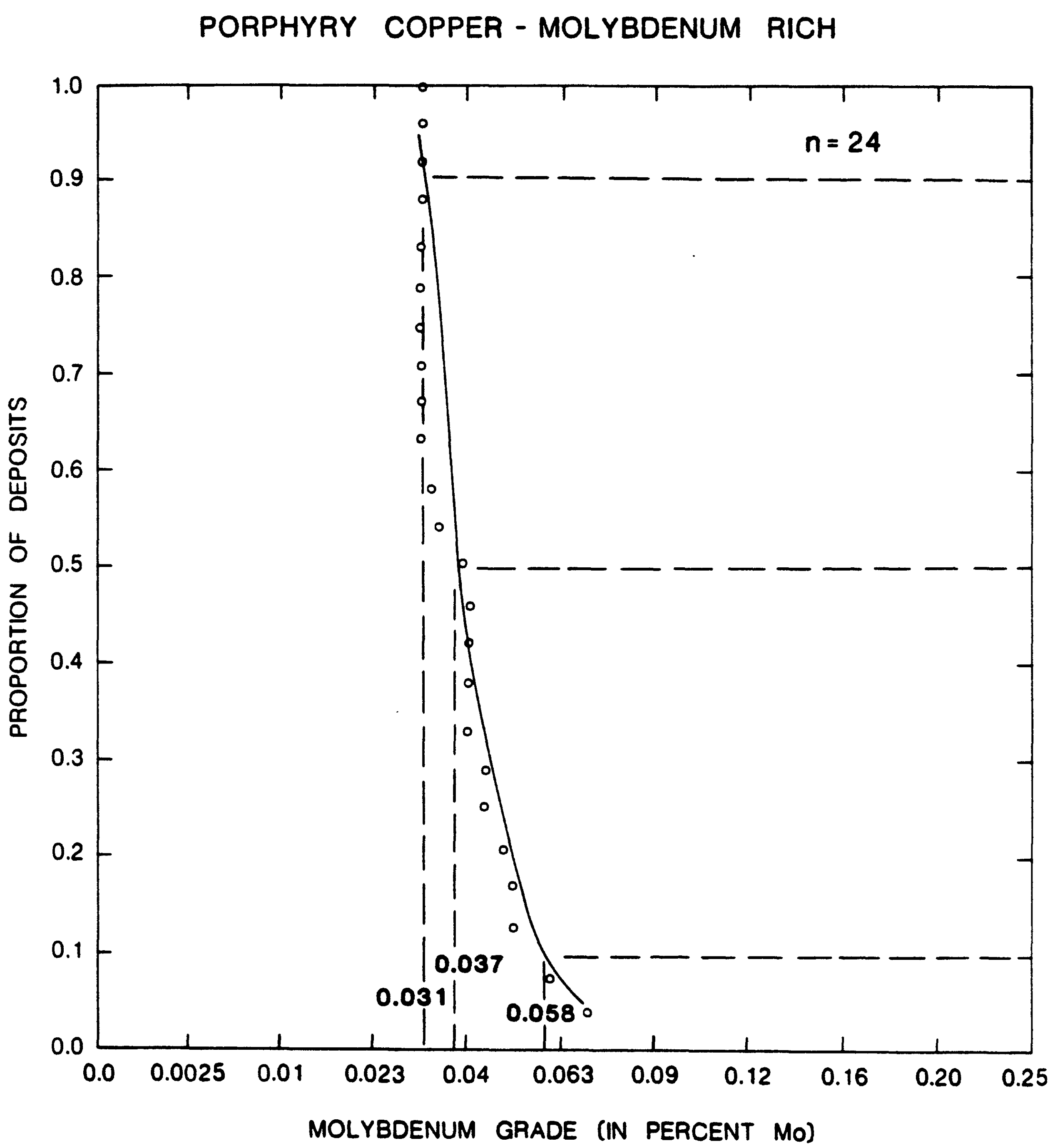
COMMENTS All porphyry copper deposits with reported molybdenum grades greater than 0.0299 percent were included in these plots. The grade for inclusion was arbitrarily selected. The criterion used to select deposits for these plots is not the same as that presented by Cox (1983a).

DEPOSITS

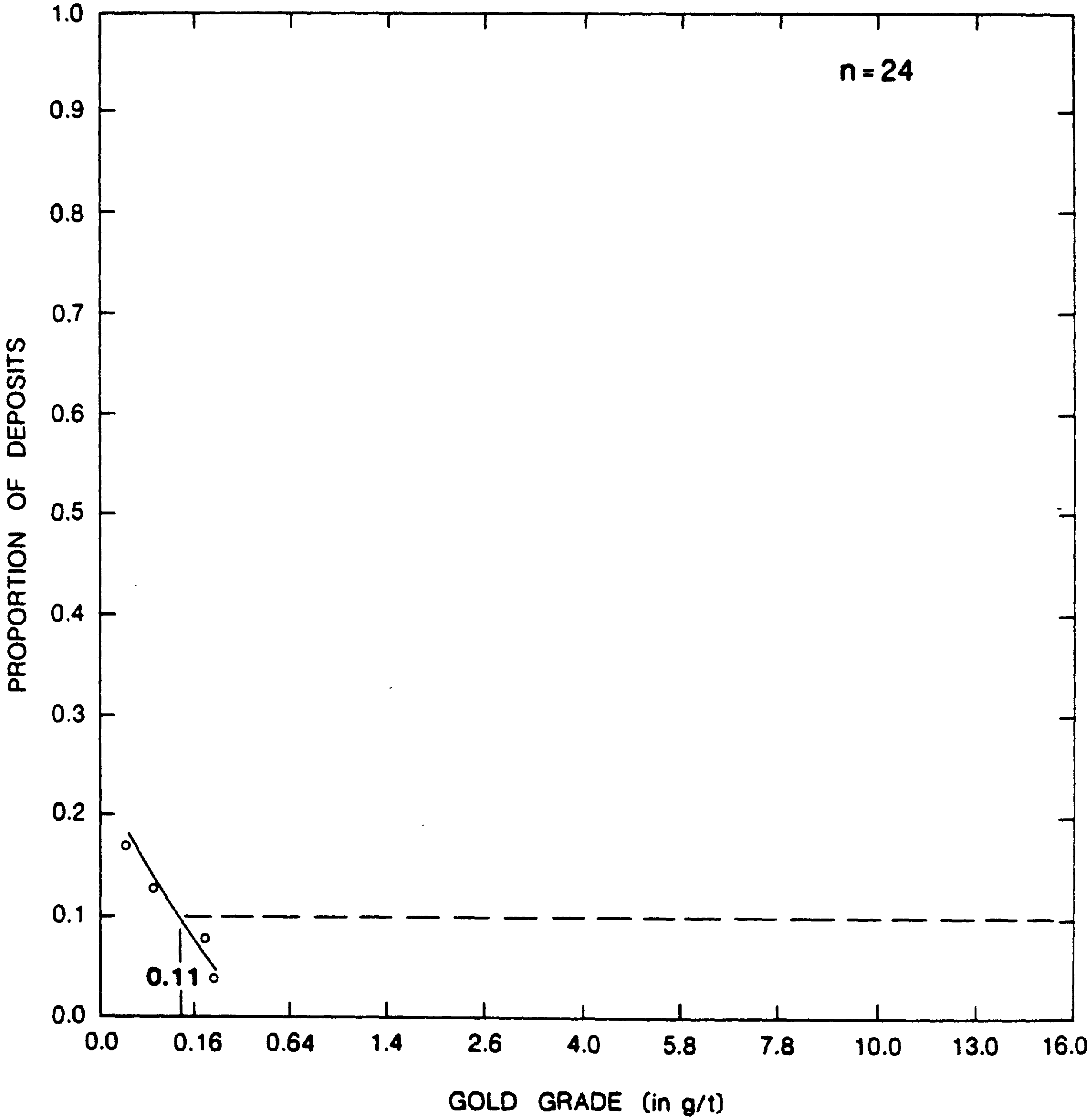
Name	Country
Ann	CNBC
Berg	CNBC
Bingham	USUT
Brenda	CNBC
Brenmac	USWA
Cerro Blanco	CILE
Chapi	PERU
Chaucha	ECDR
Chuquicamata	CILE
Cuajone	PERU
El Salvador	CILE
El Teniente	CILE
Esperanza	USAZ
Glacier Peak	USWA
Ithica Peak	USAZ
Kadzharan	URAM
Los Pelambres	CILE
Michiquillay	PERU
Mocoa	CLBA
Paramillos	AGTN
Pashpap	PERU
Quelleveco	PERU
Sar Cheshmeh	IRAN
Toquepala	PLPN

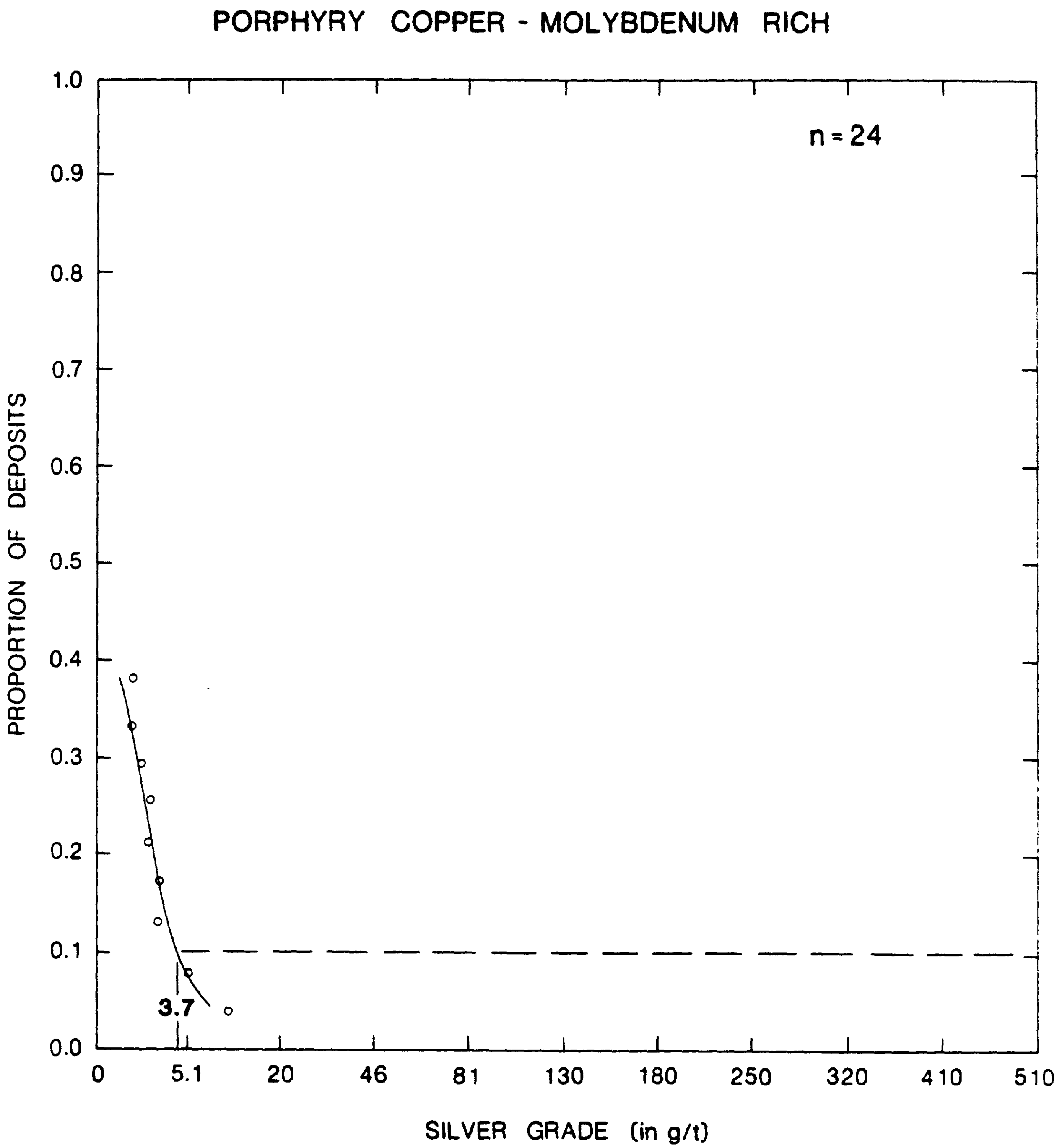

PORPHYRY COPPER - MOLYBDENUM RICH
n = 24
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
38
320
3200
0.1
0.4
1.6
6.3
25
100
400
1600
6300
25,000
100,000
TONNES (IN MILLIONS)


PORPHYRY COPPER - MOLYBDENUM RICH
n = 24
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.32
0.67
1.4
0.032
0.056
0.1
0.18
0.32
0.56
1.0
1.8
3.2
5.6
10.0
COPPER GRADE (IN PERCENT)


PORPHYRY COPPER - MOLYBDENUM RICH
n = 24
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.037
0.031
0.058
0.0
0.0025
0.01
0.023
0.04
0.063
0.09
0.12
0.16
0.20
0.25
MOLYBDENUM GRADE (IN PERCENT Mo)

PORPHYRY COPPER - MOLYBDENUM RICH





PORPHYRY COPPER - MOLYBDENUM RICH
n = 24
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
3.7
0
5.1
20
46
81
130
180
250
320
410
510
SILVER GRADE (in g/t)

DEPOSIT TYPE Porphyry copper--gold rich MODEL NUMBER 2.2

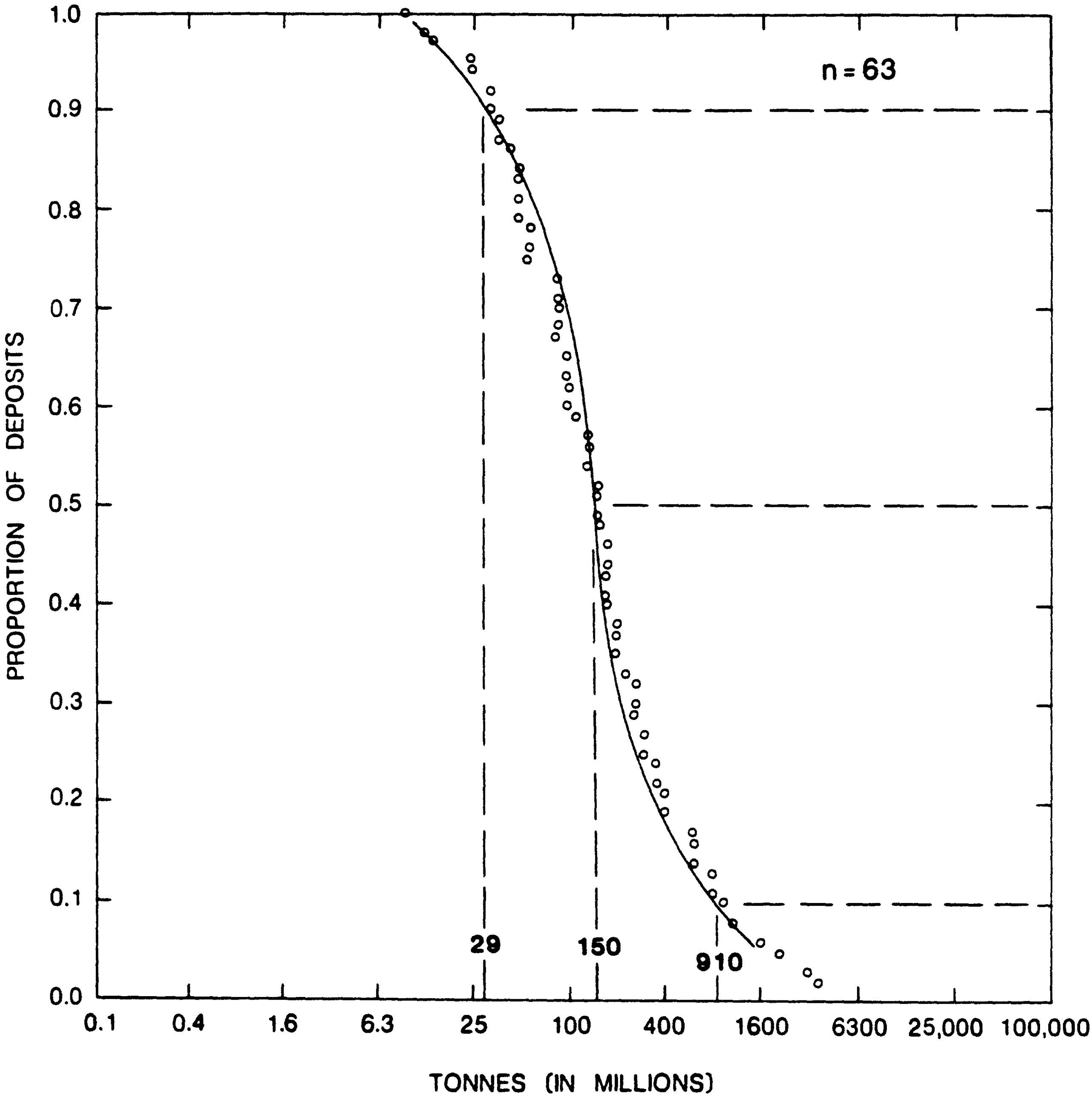
AUTHOR D. A. Singer and D. P. Cox

COMMENTS Porphyry copper deposits with reported gold grades greater than or equal to 0.034 g/t were included in these plots. The criterion for selection is based on the results of Sinclair and others (1982). Molybdenum grades are negatively correlated with gold grades (r = -0.49).

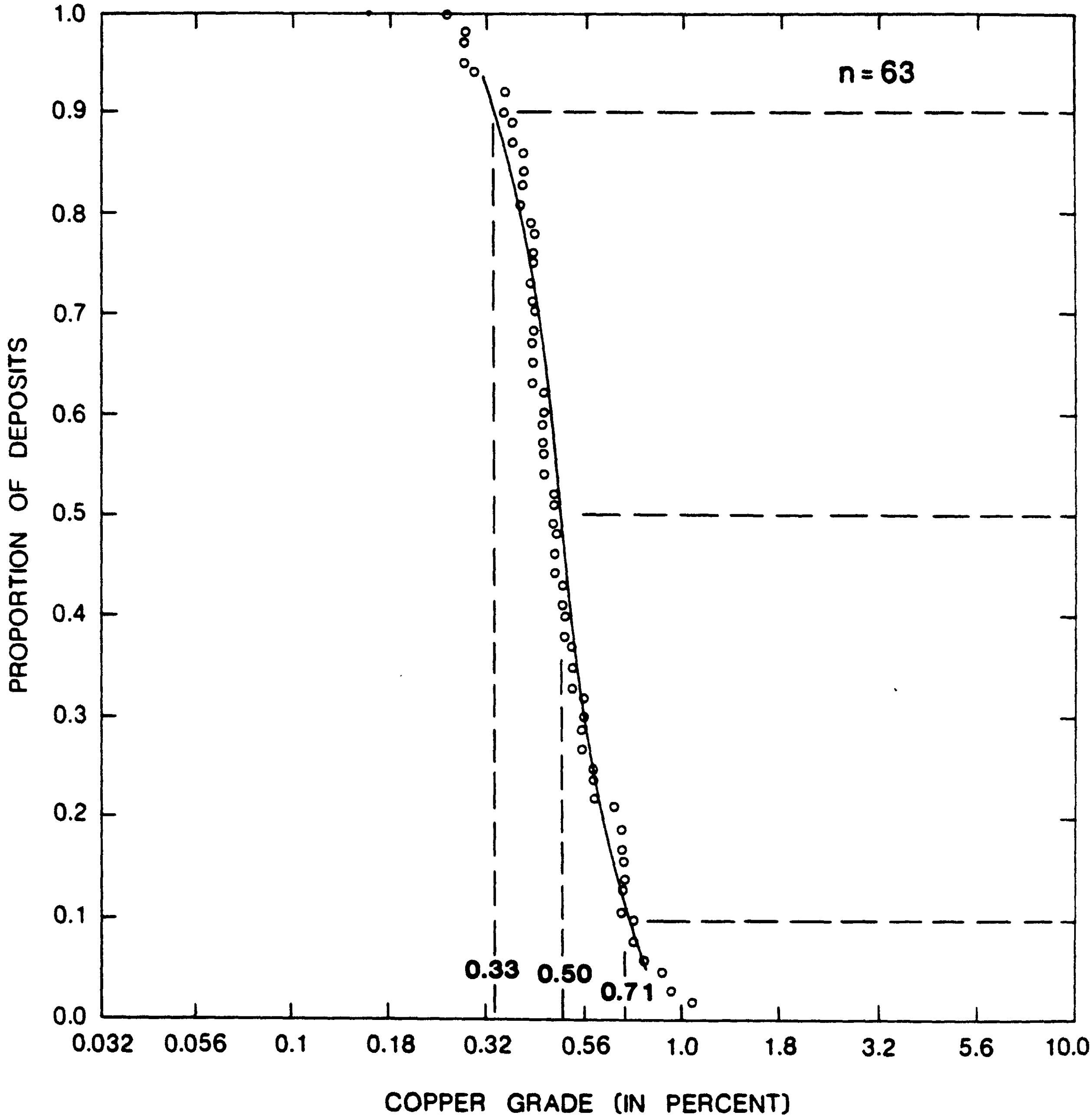
DEPOSITS

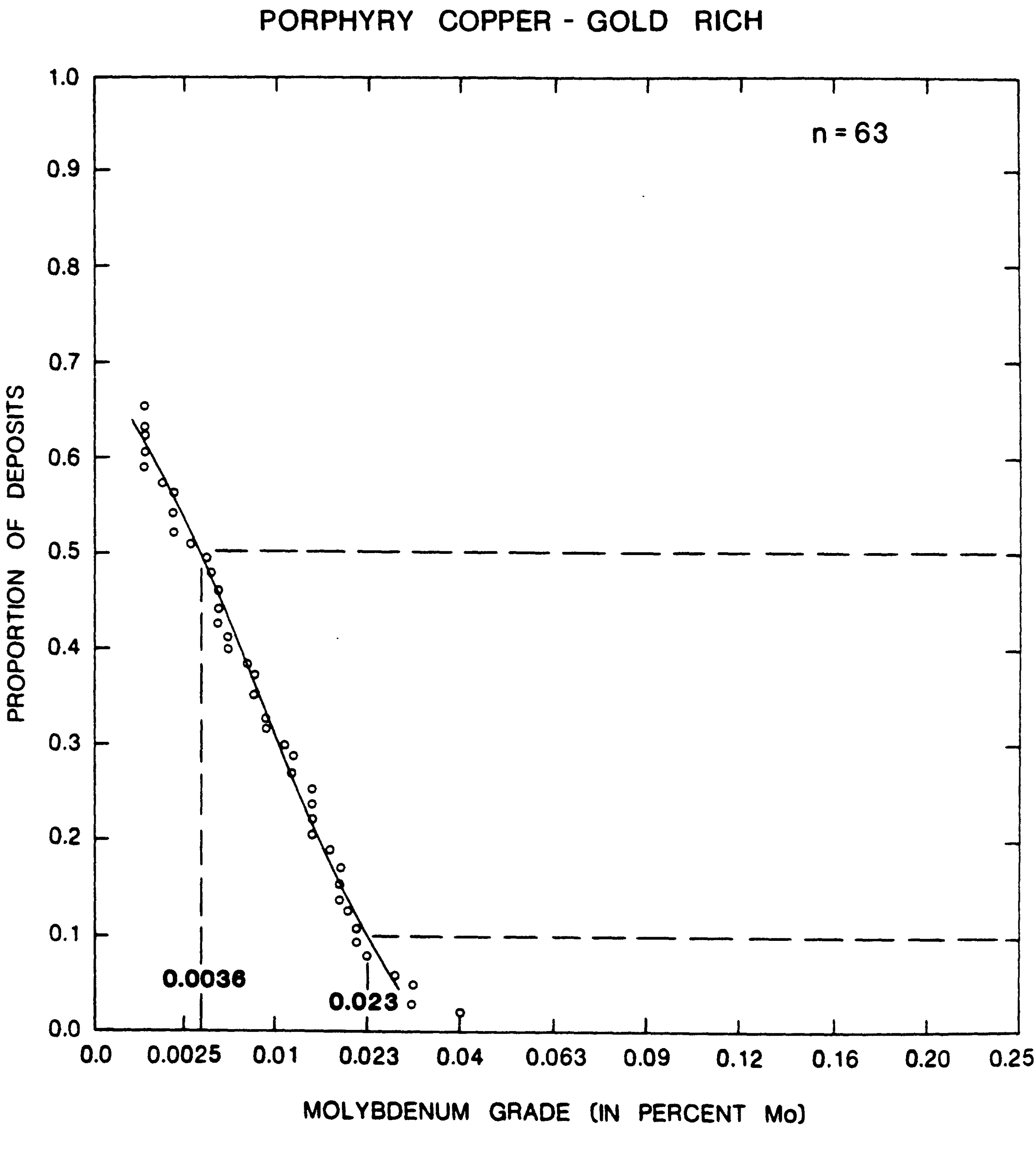
Name	Country	Name	Country
Afton	CNBC	La Alumbrera	AGTN
Ajo	USAZ	La Verde	MXCO
Amacan	PLPN	Lorraine	CNBC
Andacolla	CILE	Lumbay	PLPN
Atlas Lutopan	PLPN	Mamut	MDGS
Basay	PLPN	Mapula	PLPN
Bell Copper	CNBC	Marcopper	PLPN
Berg	CNBC	Marian	PLPN
Bingham	USUT	Morrison	CNBC
Boneng Lobo	PLPN	Mountain Mines	PLPN
Brenmac	USWA	Ok Tedi	PPNG
Cariboo Bell	CNBC	Orange Hill	USAK
Cash	CNYT	Panguna	PPNG
Casino	CNYT	Poison Mountain	CNBC
Cerro Colorado	PANA	Red Chris	CNBC
Copper Mountain	CNBC	Rio Vivi	PTRC
Cubuagan	PLPN	Safford (PD)	USAZ
Dexing	CINA	Saindak South	PKTN
Dizon	PLPN	San Antonio	PLPN
Ely	USNV	San Fabian	PLPN
Fish Lake	CNBC	Santo Nino	PLPN
Frieda River	PPNG	Santo Tomas	PLPN
Galore Creek	CNBC	Schaft Creek	CNBC
Gambier Island	CNBC	Sipalay	PLPN
Gaspe	CNQU	Star Mt.-Fubilan	PPNG
Granisle	CNBC	Star Mt.-Futik	PPNG
Hillsborough	USNM	Tanama	PTRC
Hinobaan	PLPN	Tawi-Tawi	PLPN
Ingerbelle	CNBC	Taysan	PLPN
Island Copper	CNBC	Toledo	PLPN
Kalamazoo	USAZ	Yandera	PPNG
Kennon	PLPN		

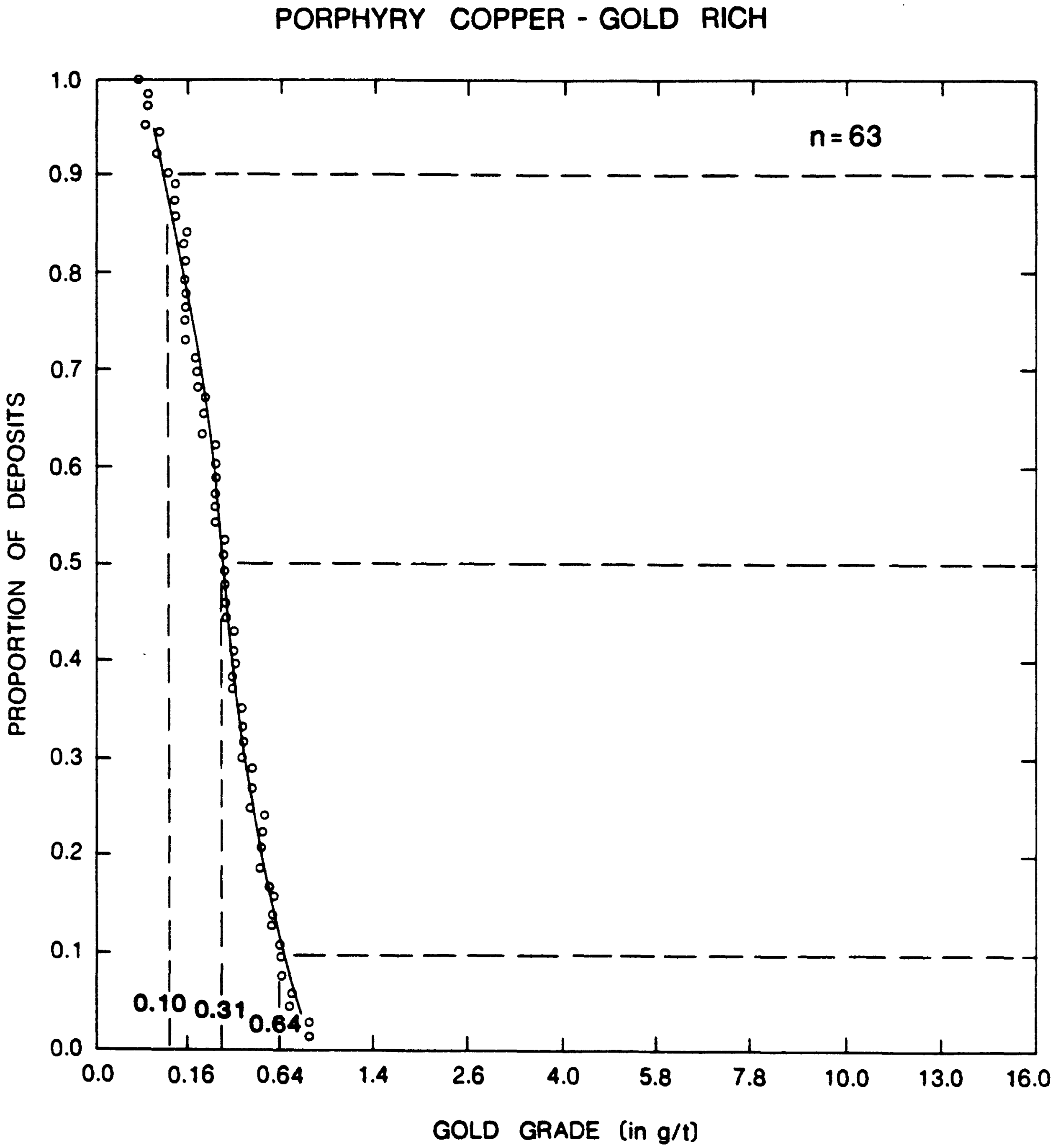
PORPHYRY COPPER - GOLD RICH



PORPHYRY COPPER - GOLD RICH

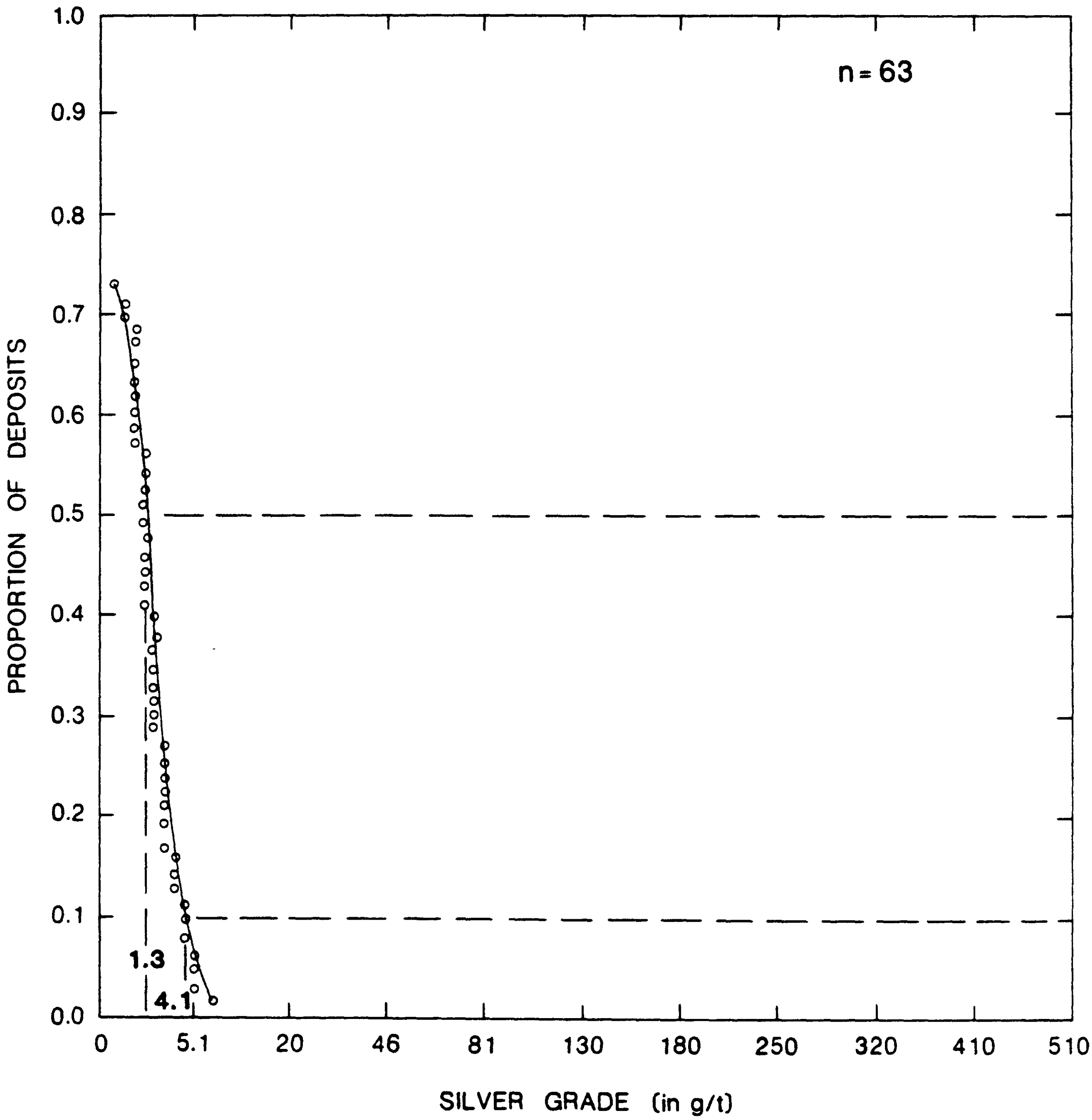



PORPHYRY COPPER - GOLD RICH
n = 63
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0036
0.023
0.0
0.0025
0.01
0.023
0.04
0.063
0.09
0.12
0.16
0.20
0.25
MOLYBDENUM GRADE (IN PERCENT Mo)



PORPHYRY COPPER - GOLD RICH
n = 63
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.10
0.31
0.64
0.0
0.16
0.64
1.4
2.6
4.0
5.8
7.8
10.0
13.0
16.0
GOLD GRADE (in g/t)

PORPHYRY COPPER - GOLD RICH



DEPOSIT TYPE Porphyry copper MODEL NUMBER none

AUTHOR D. A. Singer, D. L. Mosier, and D. P. Cox

COMMENTS All porphyry copper deposits with available grades and tonnages were included in these plots in order to provide a model for cases where it is not possible to use the gold-rich or molybdenum-rich models. Parts of the porphyry copper deposits which could be considered skarn were removed from these data and put into the copper skarn-porphyry copper model. Silver grades are positively correlated with molybdenum grades (r = 0.25) and with gold grades (r = 0.27). In both cases there are a large number of zero grades which could affect the correlations.

DEPOSITS

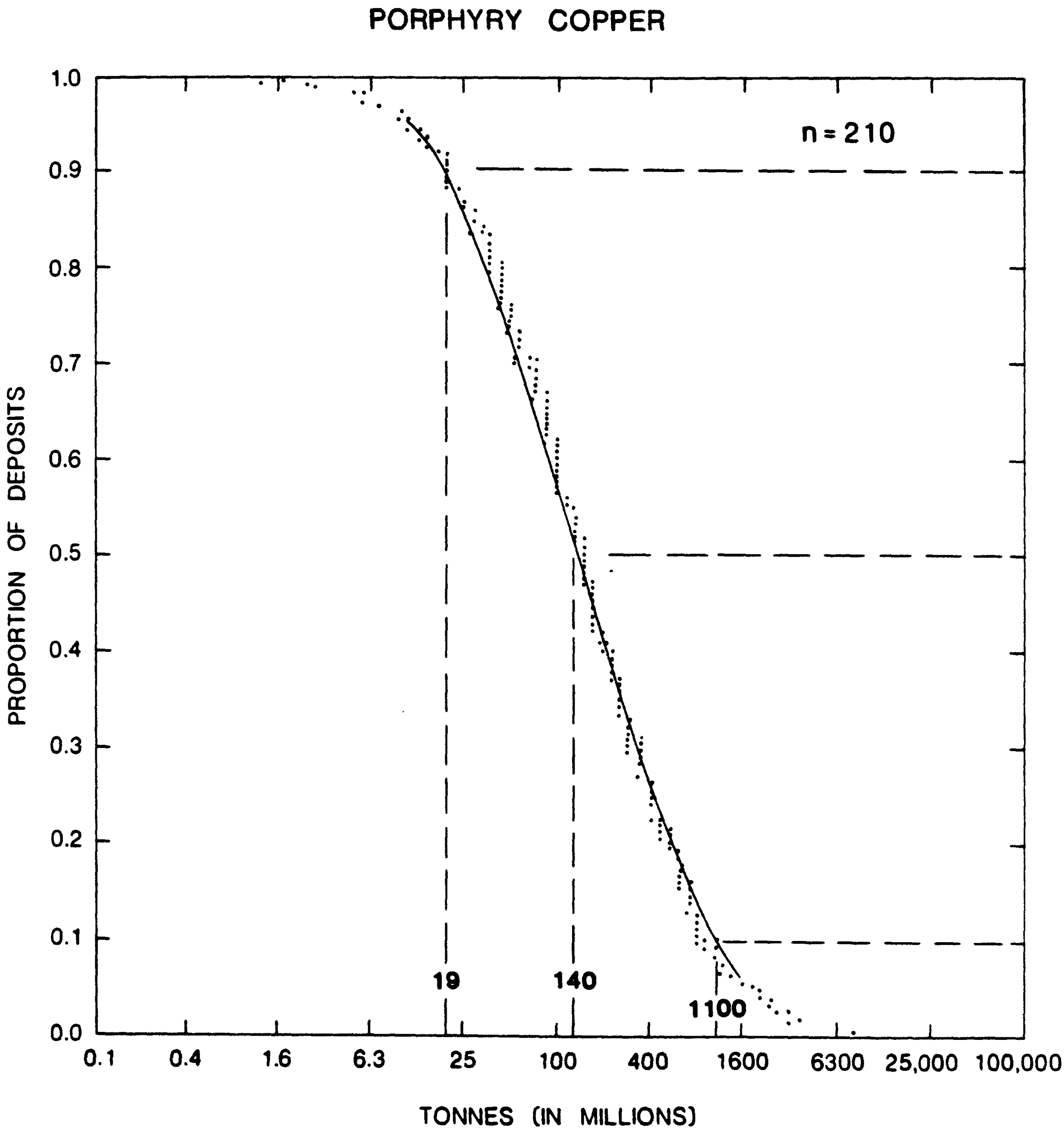
Name	Country	Name	Country	Name	Country
Adjuntas	PTRC	Brenda	CNBC	Cubuagan	PLPN
Afton	CNBC	Brenmac	USWA	Dexing	CINA
Ajax	CNBC	Butilad	PLPN	Dizon	PLPN
Ajo	USAZ	Butte	USMT	Dorothy	CNBC
Am	CNBC	Campanamah	AGTN	Eagle	CNBC
Amacan	PLPN	Cananea	MXCO	El Abra	CILE
Andacolla	CILE	Canariaco	PERU	El Arco	MXCO
Ann	CNBC	Cariboo Bell	CNBC	El Pachon	AGTN
Ann Mason	USNV	Carpenter	USAZ	El Salvador	CILE
Arie	PPNG	Cash	CNYT	El Soldado	CILE
Atlas Carmen	PLPN	Casino	CNYT	El Teniente	CILE
Atlas Frank	PLPN	Castle Dome	USAZ	Elatsite	BULG
Atlas Lutopan	PLPN	Catface	CNBC	Ely	USNV
Axe	CNBC	Catheart	USMN	Escondita	CILE
Aya Aya	PLPN	Cerro Blanco	CILE	Esperanza	CILE
Bagdad	USAZ	Cerro Colorado	CILE	Exotica	CILE
Basay	PLPN	Cerro Colorado	PANA	Fish Lake	CNBC
Bear	USNV	Cerro Verde	PERU	Florence	USAZ
Bell Copper	CNBC	Chapi	PERU	Frieda River	PPNG
Berg	CNBC	Chaucha	ECDR	Galaxy	CNBC
Bethlehem	CNBC	Chuquicamata	CILE	Galore Creek	CNBC
Big Onion	CNBC	Coalstoun	AUQL	Gambier Island	CNBC
Bingham	USUT	Copper Basin	USAZ	Gaspe	CNQU
Bisbee	USAZ	Copper Cities	USAZ	Gilbraltar	CNBC
Bluebird	USAZ	Copper Creek	USAZ	Glacier Peak	USWA
Bond Creek	USAK	Copper Mountain	CNBC	Granisle	CNBC
Boneng Lobo	PLPN	Cordon	PLPN	Hale-Mayabo	PLPN
Bozshchaku	URUR	Cuajone	PERU	Heddleston	USMT

(continued on next page)

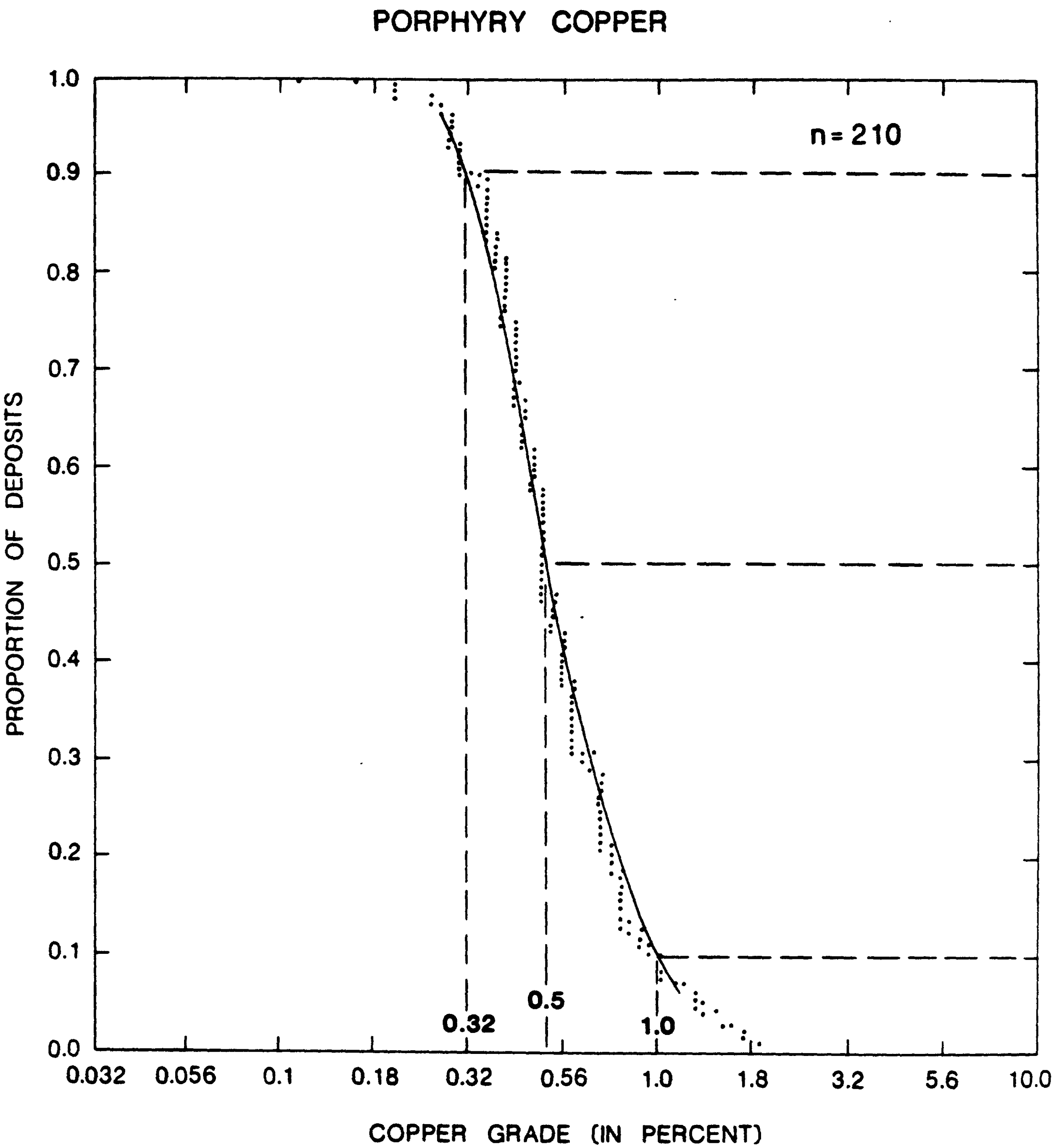
DEPOSIT TYPE Porphyry copper MODEL NUMBER none

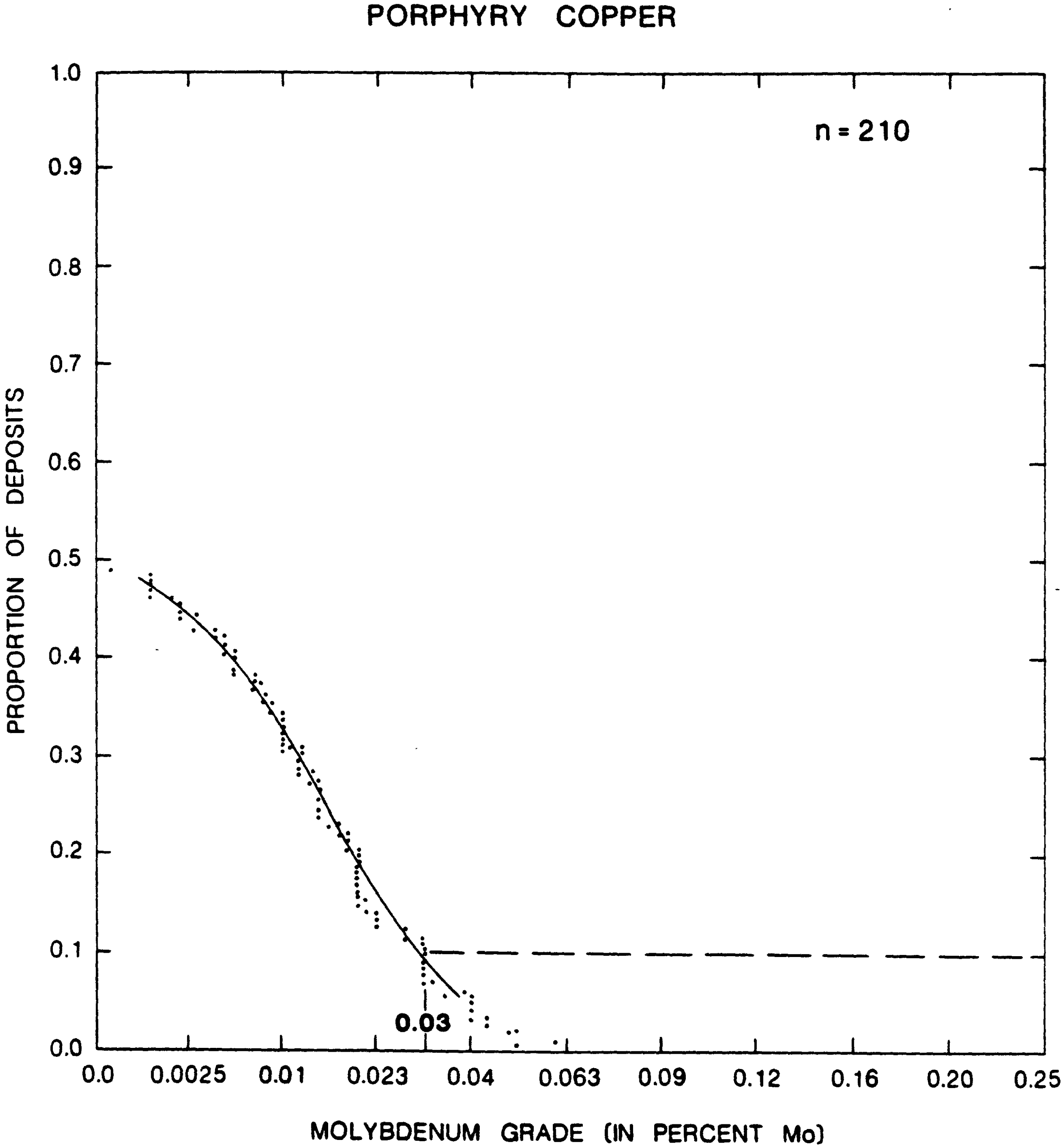
DEPOSITS (continued)

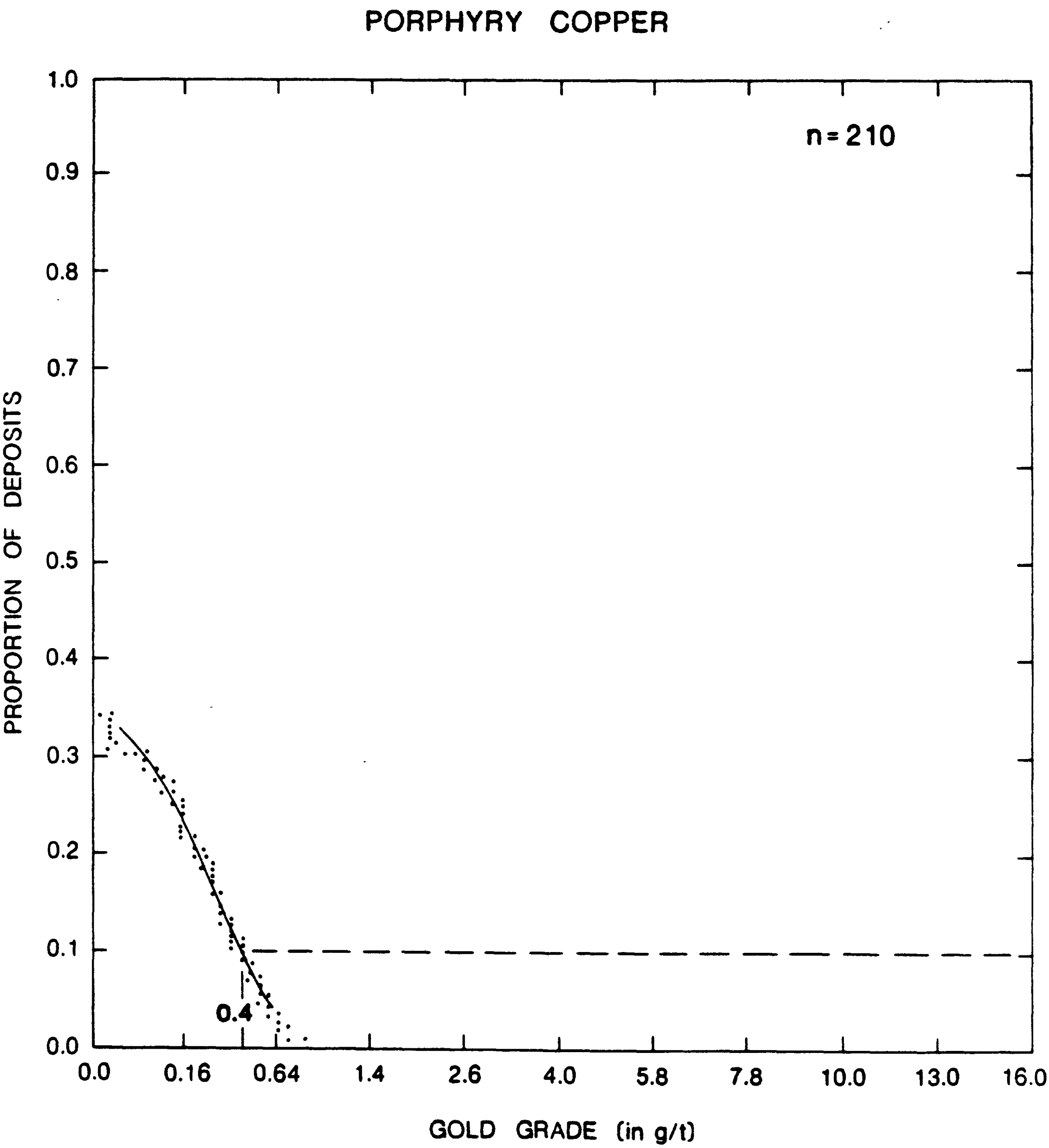
Name	Country	Name	Country	Name	Country
Helvetia	USAZ	Marcopper	PLPN	Rio Vivi	PTRC
Highmont	CNBC	Margaret	USWA	Sacaton (E-W)	USAZ
Hillsborough	USNM	Marian	PLPN	Safford (KCC)	USAZ
Hinobaan	PLPN	Mazama	USWA	Safford (PD)	USAZ
Huckleberry	CNBC	Metcalf	USAZ	Saindak East	PKTN
Ingerbelle	CNBC	Michiquillay	PERU	Saindak North	PKTN
Inguaran	MXCO	Middle Fork	USWA	Saindak South	PKTN
Ino-Capaya	PLPN	Mineral Butte	USAZ	Samar	PLPN
Inspiration	USAZ	Misty	CNBC	San Antonio	PLPN
Iron Mask	CNBC	Mocha	CILE	San Fabian	PLPN
Island Copper	CNBC	Mocoa	CLBA	San Juan	USAZ
Ithica Peak	USAZ	Moniwa	BRMA	San Xavier	USAZ
June	CNBC	Morenci	USAZ	Sanchez	USAZ
Kadzharan	URAM	Morochocha	PERU	Santa Rita	USNM
Kalamaton	PLPN	Morrison	CNBC	Santo Nino	PLPN
Kalamazoo	USAZ	Mountain Mines	PLPN	Santo Tomas	MXCO
Kalmakyr	URUZ	Mount Canninda	AUQL	Santo Tomas	PLPN
Kennon	PLPN	Namosi East	FIJI	Sar Cheshmeh	IRAN
King-King	PLPN	Namosi West	FIJI	Schaft Creek	CNBC
Kirwin	USWY	North Fork	USWA	Sierra Gorda	CILE
Kounrad	URKZ	Ok	CNBC	Silver Bell	USAZ
Krain	CNBC	Ok Tedi	PPNG	Sipalay	PLPN
Kwanika	CNBC	Orange Hill	USAK	Star Mt.-Fubilan	PPNG
La Alumbrera	AGTN	Pampa Norte	CILE	Star Mt.-Futik	PPNG
La Caridad	MXCO	Panguna	PPNG	Star Mt.-Nong River	PPNG
La Florida	MXCO	Paramillos	AGTN	Star Mt.-Olgal	PPNG
La Verde	MXCO	Parks	AUNS	Sugarloaf Hill	CNBC
Lakeshore	USAZ	Pashpap	PERU	Tagpura	PLPN
Lights Creek	USCA	Petaquilla	PANA	Tanama	PTRC
Lornex	CNBC	Philippine	PLPN	Tawi-Tawi	PLPN
Lorraine	CNBC	Pima-Mission	USAZ	Taysan	PLPN
Los Bronces	CILE	Plurhinler	THLD	Toledo	PLPN
Los Pelambres	CILE	Poison Mountain	CNBC	Toquepala	PERU
Los Pilares	MXCO	Potrerillos	CILE	Trojan	CNBC
Lumbay	PLPN	Primer	CNBC	Twin Buttes	USAZ
Luna-Bash	PLPN	Quebrada Blanca	CILE	Tyrone	USNM
MacArthur	USNV	Quelleveco	PERU	Valley Copper	CNBC
Maggie	CNBC	Ray	USAZ	Vekol Copper	USAZ
Majdanpek	YUGO	Recsk	HUNG	Washington	MXCO
Mamut	MDGS	Red Chris	CNBC	Yandera	PPNG
Mantos Blanco	CILE	Red Mountain	USAZ	Yeoval	AUNS
Mapula	PLPN	Rio Blanco	CILE	Yerrington	USNV

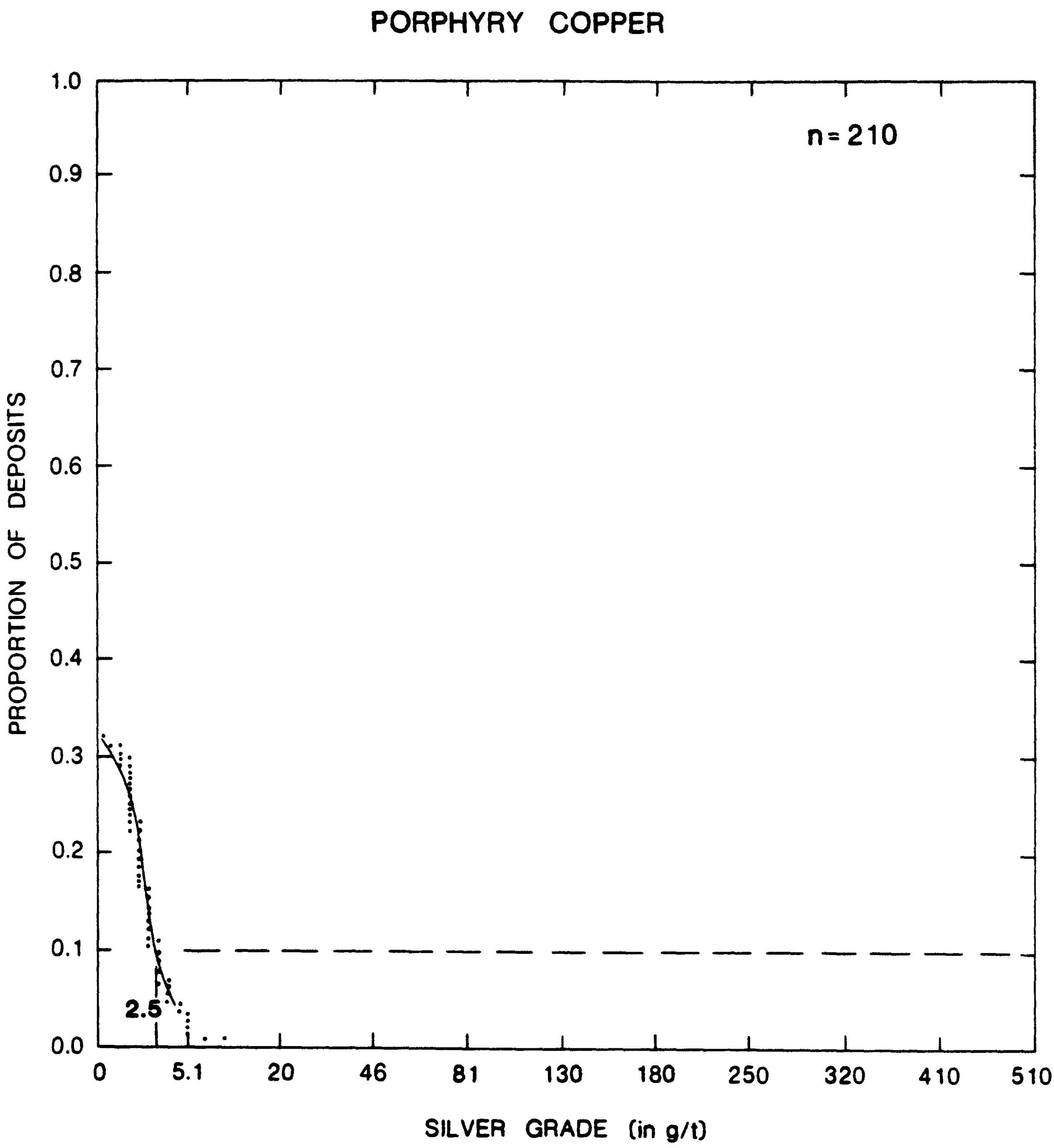


PORPHYRY COPPER
n = 210
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
19
140
1100
0.1
0.4
1.6
6.3
25
100
400
1600
6300
25,000
100,000
TONNES (IN MILLIONS)


PORPHYRY COPPER
n = 210
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PROPORTION OF DEPOSITS
0.32
0.5
1.0
0.032
0.056
0.1
0.18
0.32
0.56
1.0
1.8
3.2
5.6
10.0
COPPER GRADE (IN PERCENT)


PORPHYRY COPPER
n = 210
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.03
0.0
0.0025
0.01
0.023
0.04
0.063
0.09
0.12
0.16
0.20
0.25
MOLYBDENUM GRADE (IN PERCENT Mo)


PORPHYRY COPPER
n=210
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.4
0.0
0.16
0.64
1.4
2.6
4.0
5.8
7.8
10.0
13.0
16.0
GOLD GRADE (in g/t)


PORPHYRY COPPER
n=210
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2.5
0
5.1
20
46
81
130
180
250
320
410
510
SILVER GRADE (in g/t)

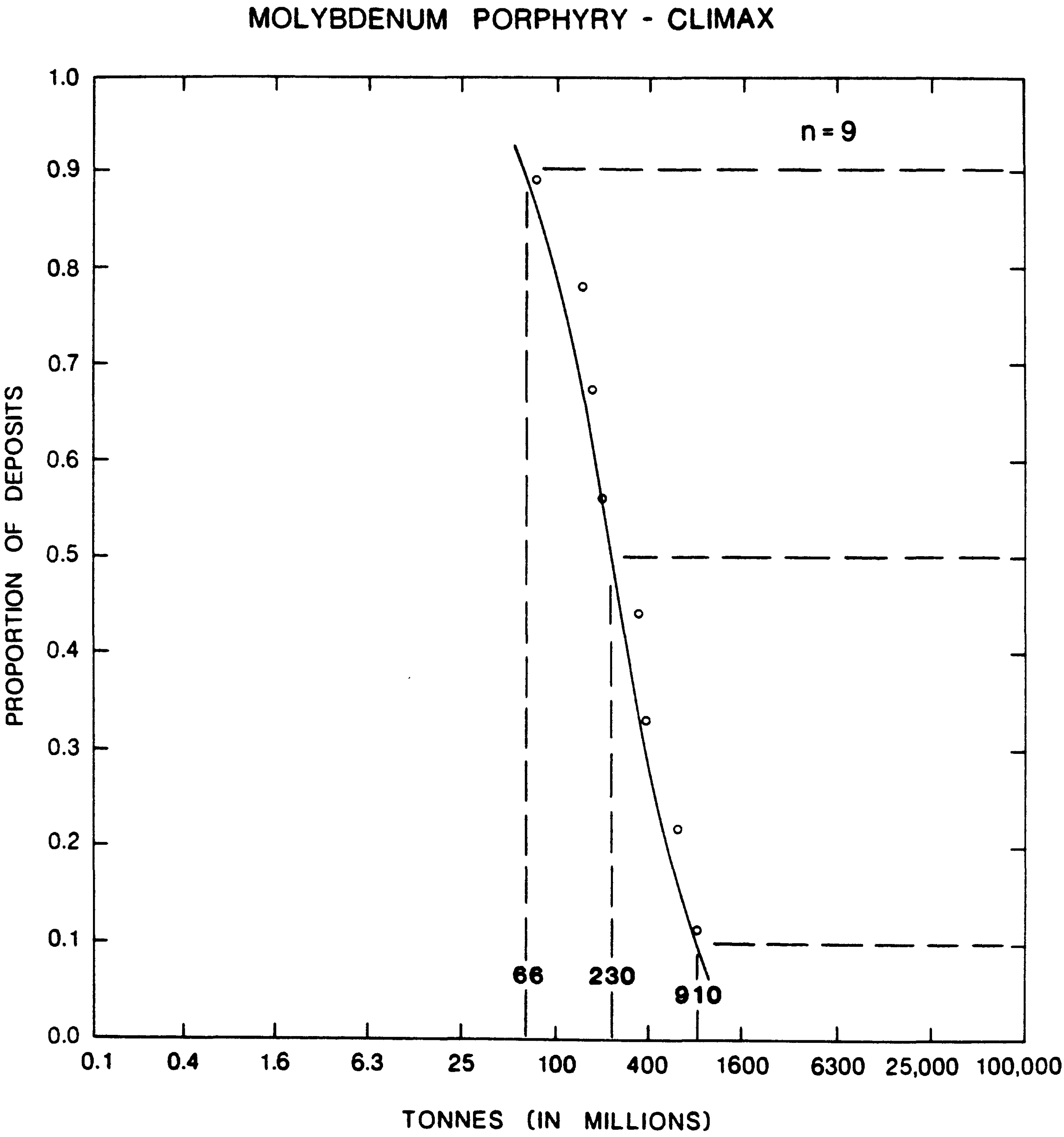
DEPOSIT TYPE Molybdenum porphyry--Climax MODEL NUMBER 2.3

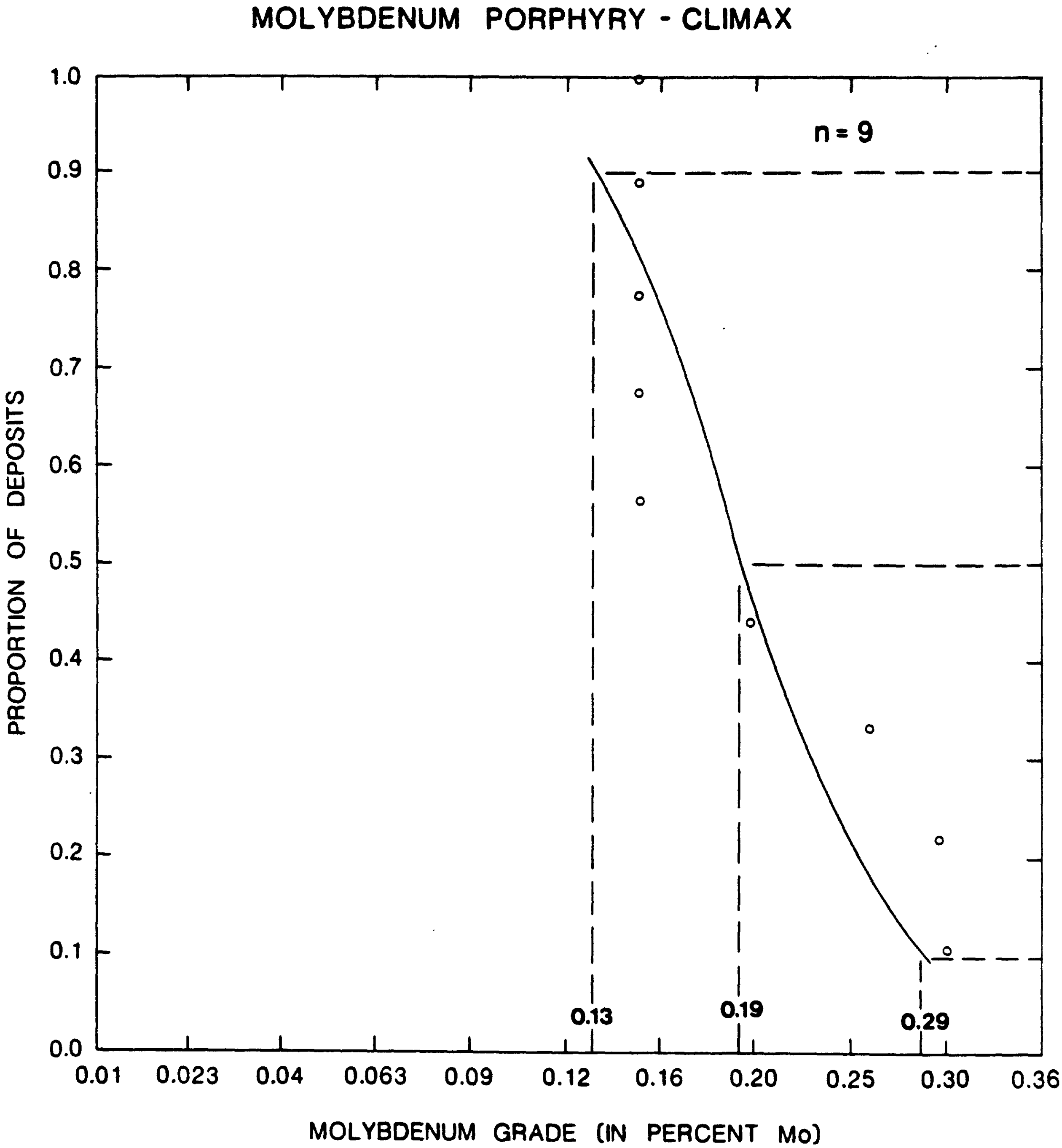
AUTHOR D. A. Singer, T. G. Theodore, and D. L. Mosier

COMMENTS none

DEPOSITS

Name	Country
Big Ben	USMT
Climax	USCO
Henderson	USCO
Malmbjerg	GRLD
Mount Emmons	USCO
Mount Hope	USNV
Pine Grove	USUT
Questa-Goat Hill	USNM
Redwell	USCO


MOLYBDENUM PORPHYRY - CLIMAX
n = 9
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
66
230
910
0.1
0.4
1.6
6.3
25
100
400
1600
6300
25,000
100,000
TONNES (IN MILLIONS)



MOLYBDENUM PORPHYRY - CLIMAX
n = 9
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.13
0.19
0.29
0.01
0.023
0.04
0.063
0.09
0.12
0.16
0.20
0.25
0.30
0.36
MOLYBDENUM GRADE (IN PERCENT Mo)

DEPOSIT TYPE Molybdenum porphyry (low F type) MODEL NUMBER 2.4

AUTHOR W. D. Menzie and T. G. Theodore

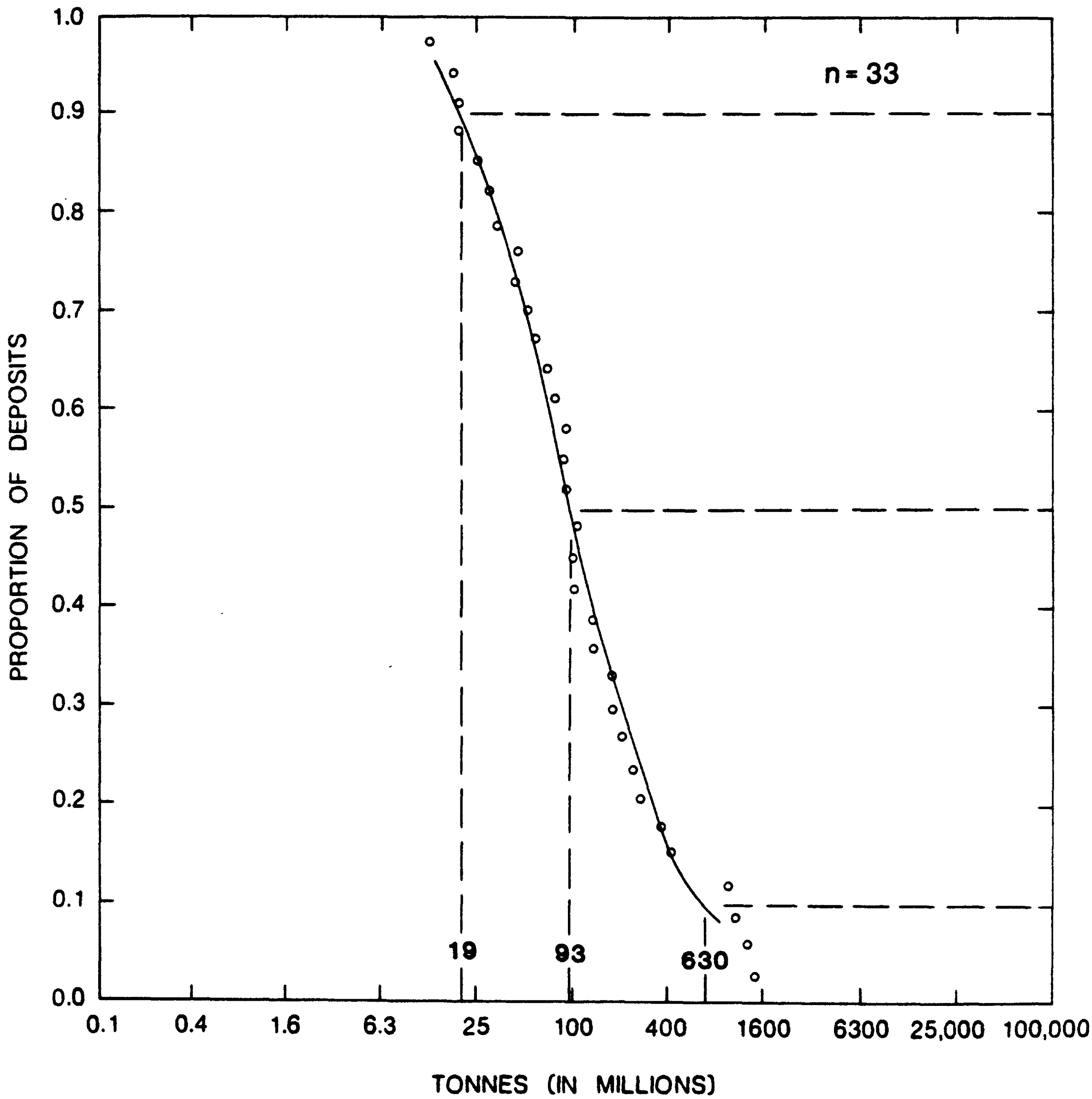
DATA REFERENCES Theodore and Menzie, 1983.

COMMENTS none

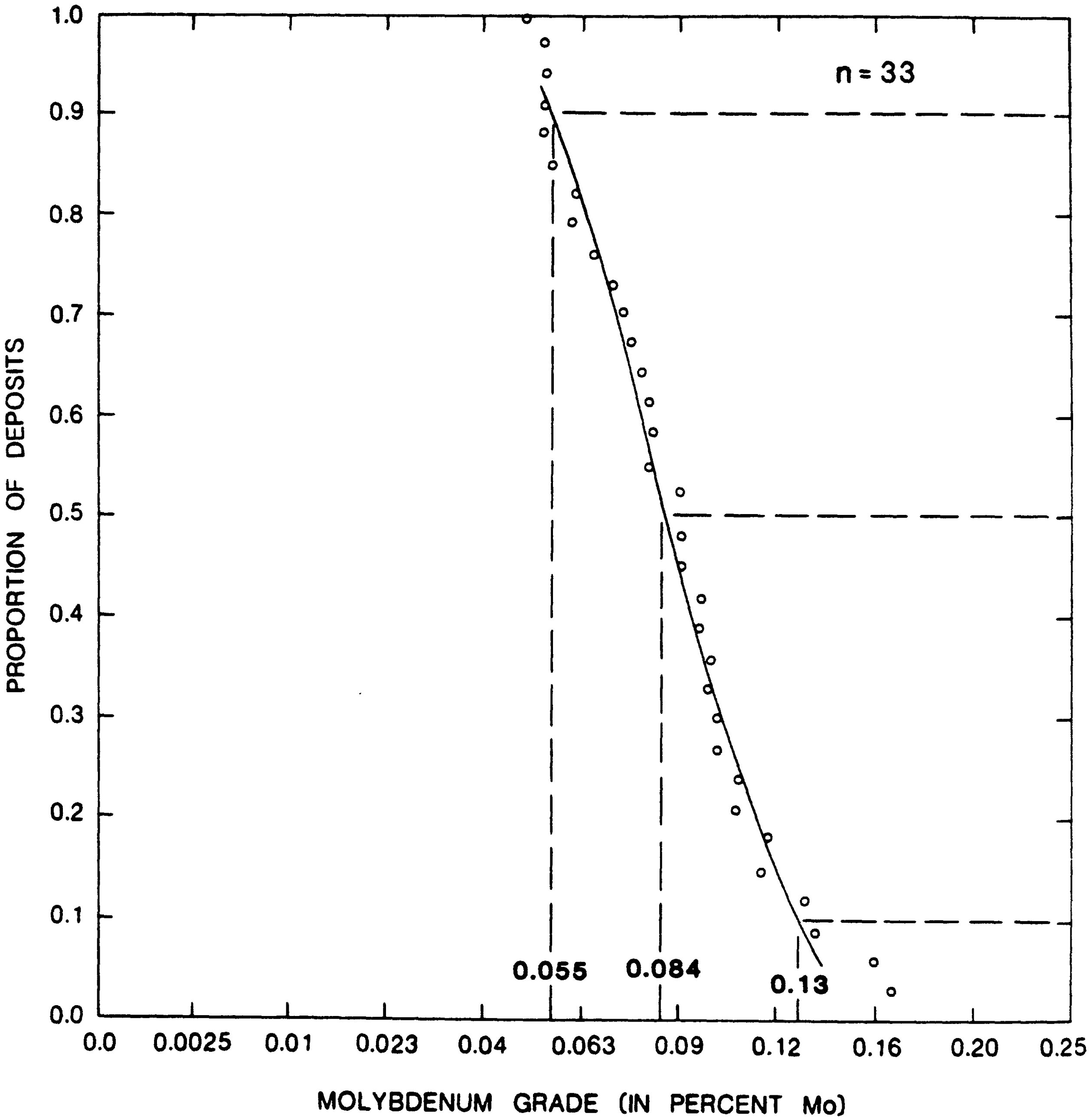
DEPOSITS

Name	Country
Anduramba	AUQL
Adanac (Ruby Creek)	CNBC
Ajax (Dak River)	CNBC
B. C. Moly	CNBC
Bell Molybdenum	CNBC
Boss Mountain	CNBC
Boswell River	CNYT
Buckingham	USNV
Cannivan Gulch	USMT
Carmi	CNBC
Creston	MXCO
Endako	CNBC
Gem	CNBC
Glacier Gulch	CNBC
Hall	USNV
Haskin Mountain	CNBC
Karen	CNBC
Lucky Ship	CNBC
Machkatica	YUGO
Mount Thomlinson	CNBC
Mount Tolman	USWA
Pine Nut	USNV
Pitman (JB)	CNBC
Quartz Hill	USAK
Red Bird	CNBC
Red Mountain	CNYT
Serb Creek	CNBC
Setting Net Lake	CNON
Storie	CNBC
Sunshine Creek	CNBC
Thompson Creek	USID
Trout Lake	CNBC
UV Industries	USNV

MOLYBDENUM PORPHYRY - LOW FLUORINE



MOLYBDENUM PORPHYRY - LOW FLUORINE



DEPOSIT TYPE Iron skarn

MODEL NUMBER 2.5

AUTHOR D. L. Mosier and W. D. Menzie

COMMENTS Some of the data represent districts.

DEPOSITS

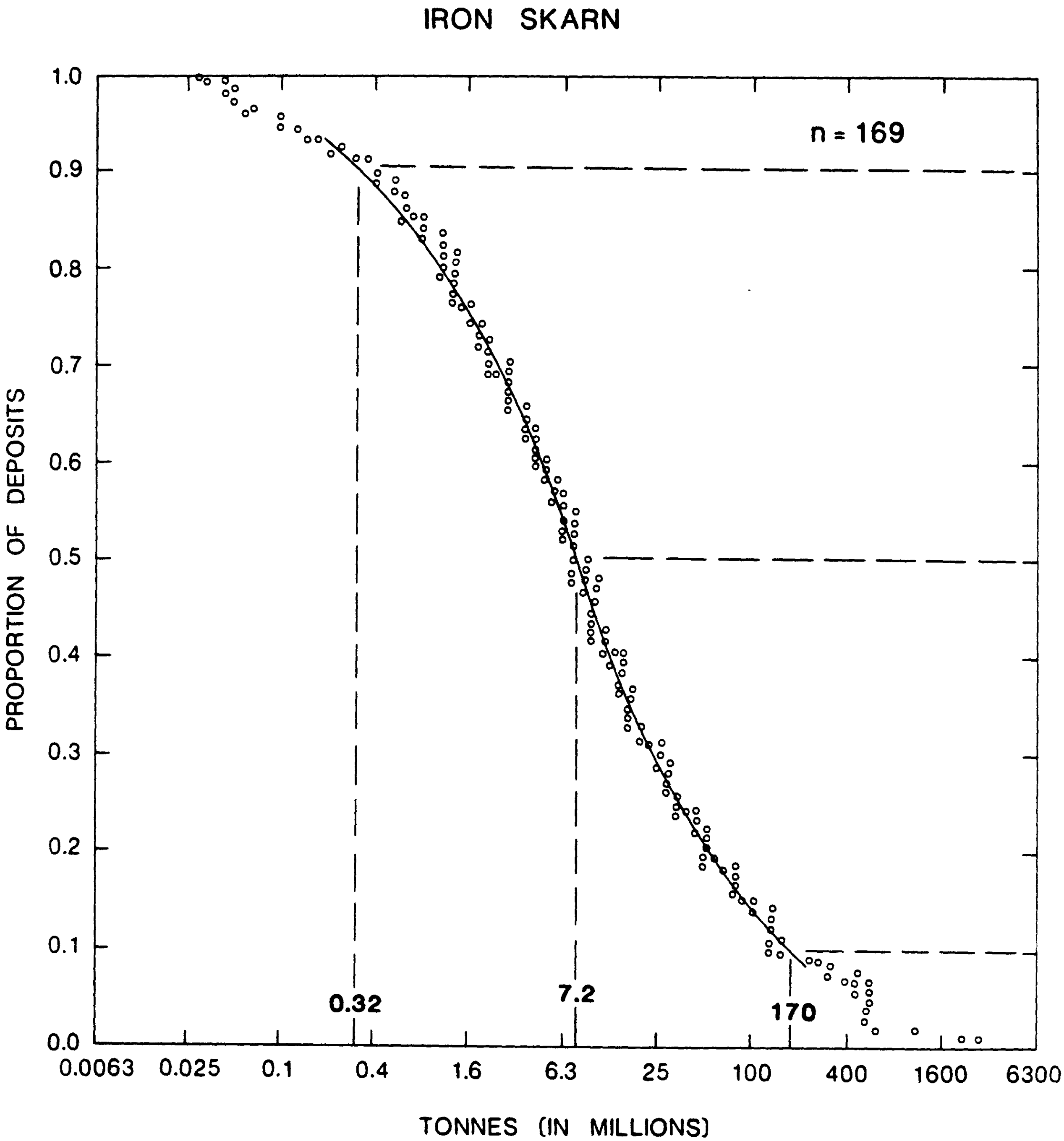
Name	Country	Name	Country
Adaevka central	URUR	Daiquiri	CUBA
Adaevka north	URUR	Dammer Nissar	PKTN
Adaevka south	URUR	Dannemora	SWDN
Agalteca	HNDR	Dayton	USNV
Ain Mokra	ALGR	Divrigi	TRKY
Ain Oudrer	ALGR	Dungun	MDGS
Akatani	JAPN	Dzama	URUR
Alagada	PORT	Eagle Mountain	USCA
Aleshinka	URUR	El Pedroso	SPAN
Argonaut	CNBC	El Sol y La Luna	MXCO
Asvan	TRKY	El Volcan-Piedra Iman	MXCO
Auerbach	URUR	Eltay	URUR
Ayazmant	TRKY	Estyunin	URUR
Baghain	IRAN	Fierro-Hannover	USNM
Baisoara	RMNA	Gallinas	USNM
Beck	USCA	Giresun	TRKY
Beni Douala	ALGR	Gora Magnitnaya	URUR
Benkala	URUR	Gora Vysokaya	URUR
Bessermer	CNON	Hatillo	DMRP
Bizmisen-Akusagi	TRKY	Hercules	MXCO
Blairton	CNON	Hierro Indio	AGTN
Bolsherechensk	URUR	Huacravilca	PERU
Bulacan	PLPN	Hualpai	CNBC
Brynor	CNBC	Huancabamba	PERU
Calabogie	CNON	Hull	CNQU
Camiglia	ITLY	Imanccasa	PERU
Capacmarca	PERU	Ino	JAPN
Capitan	USNM	Iron Duke	CNBC
Carmen	CILE	Iron Hat	USCA
Cave Canyon	USCA	Iron Mike	CNBC
Cehegin	SPAN	Iron Mountain (Colfax Co.)	USNM
Chichibu	JAPN	Iron Mountain (Sierra Co.)	USNM
Childs Mine	CNON	Iron Springs	USUT
Colquemarca	PERU	Jedway	CNBC
Copper Flat	USNM	Jerez de los Caballeros	SPAN
Cuchillo-Negro	USNM	Jib	CNBC

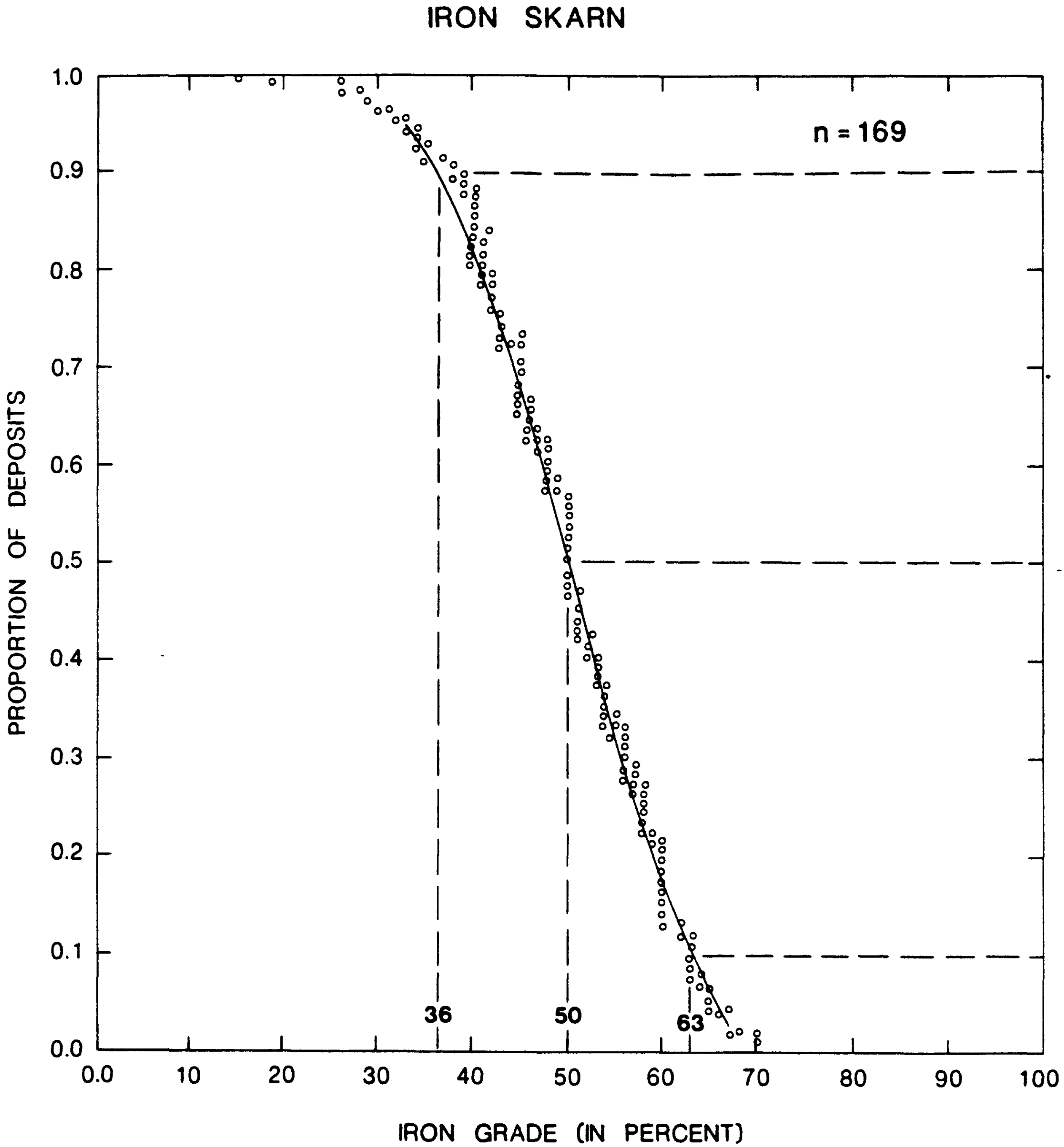
(continued on next page)

DEPOSIT TYPE Iron skarn MODEL NUMBER 2.5

DEPOSITS (continued)

Name	Country	Name	Country	Name	Country
Jicarilla	USNM	Mogpog	PLPN	Santa Lucia	PERU
Jones Camp	USNM	Monte Carmelo	NCRG	Santa Rita	USNM
Juncos	CNBC	Munesada	JAPN	Sarbay	URUR
Kachar	URUR	Nimpkish	CNBC	Senor de Huarquisa	PERU
Kalkan	TRKY	Novo Maslovo	URUR	Severnoe I	URUR
Kambaikhin central	URUR	Novo Peschansk	URUR	Severnoe II	URUR
Kambaikhin east	URUR	Ocna de Fier	RMNA	Severnoe III	URUR
Kambaikhin north	URUR	Old Dad Mountains	USCA	Shagyrkul	URUR
Karamadazi	TRKY	Orogrande	USNM	Shasta-California	USCA
Kaunisvaara-Masugnsbyn	SWDN	Osokino-Aleksandrovsk	URUR	Shinyama	JAPN
Kesikkopru	TRKY	Pambuhan Sur	PLPN	Silver Lakes	USCA
Kozyrevka	URUR	Pampachiri	PERU	Sorka	URUR
Kroumovo	URUR	Paracale	PLPN	Sosva	URUR
Kruglogorsk	URUR	Pena Colorada	MXCO	South Sarbay	URUR
Kurzhunkul	URUR	Perda Niedda	ITLY	Takanokura	JAPN
La Carmen	MXCO	Persberg	SWDN	Tapairihua	PERU
La Laguna	DMRP	Peschansk	URUR	Techa	URUR
La Paloma	MXCO	Picila	MXCO	Tecolote	USNM
La Piedra Iman	MXCO	Piddig	PLPN	Tepustete	MXCO
Las Animas Cerro Prieto	MXCO	Plagia	GREC	Texada	CNBC
Las Truchas	MXCO	Pokrovsk	URUR	Tovarnica	YUGO
Larap-Calambayungan	PLPN	Rankin	CNON	Tsaitsukou	CINA
Lava Bed	USCA	Recibimiento	MXCO	Val Di Peio	ITLY
Lebyazhka	URUR	Rondoni	PERU	Valuev	URUR
Livitaca-Velille	PERU	Rose	CNBC	Vorontsovka	URUR
Lomonosov	URUR	Rudna Glava	YUGO	Vulcan	USCA
Maanshan	HONG	Sabana Grande	DMRP	Vyhne	CZCL
Mac	CNBC	Samli	TRKY	Wagasennin	JAPN
Marbella	SPAN	San Carlos	MXCO	Yellow Jacket	USNM
Marmoraton	CNON	San Juan de Chacna	PERU	Zanitza	MXCO
Martinovo	BULG	San Leone	ITLY	Zarikan	IRAN
Maslovo	URUR	Sankyo	JAPN	Zeballos	CNBC
Mati	PLPN				


IRON SKARN
n = 169
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PROPORTION OF DEPOSITS
0.32
7.2
170
0.0063
0.025
0.1
0.4
1.6
6.3
25
100
400
1600
6300
TONNES (IN MILLIONS)


IRON SKARN
n = 169
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
36
50
63
0.0
10
20
30
40
50
60
70
80
90
100
IRON GRADE (IN PERCENT)

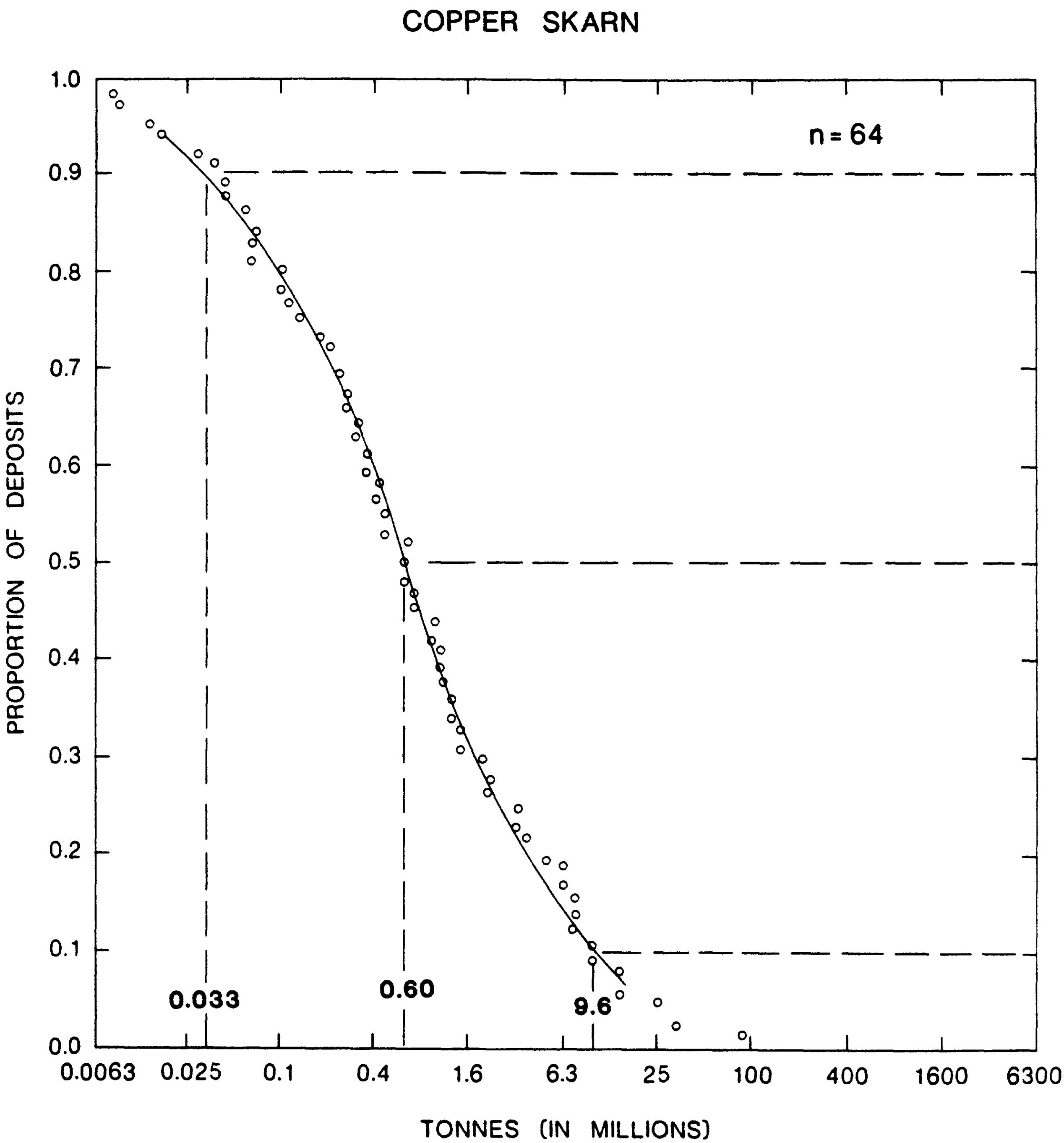
DEPOSIT TYPE Copper skarn MODEL NUMBER 2.6

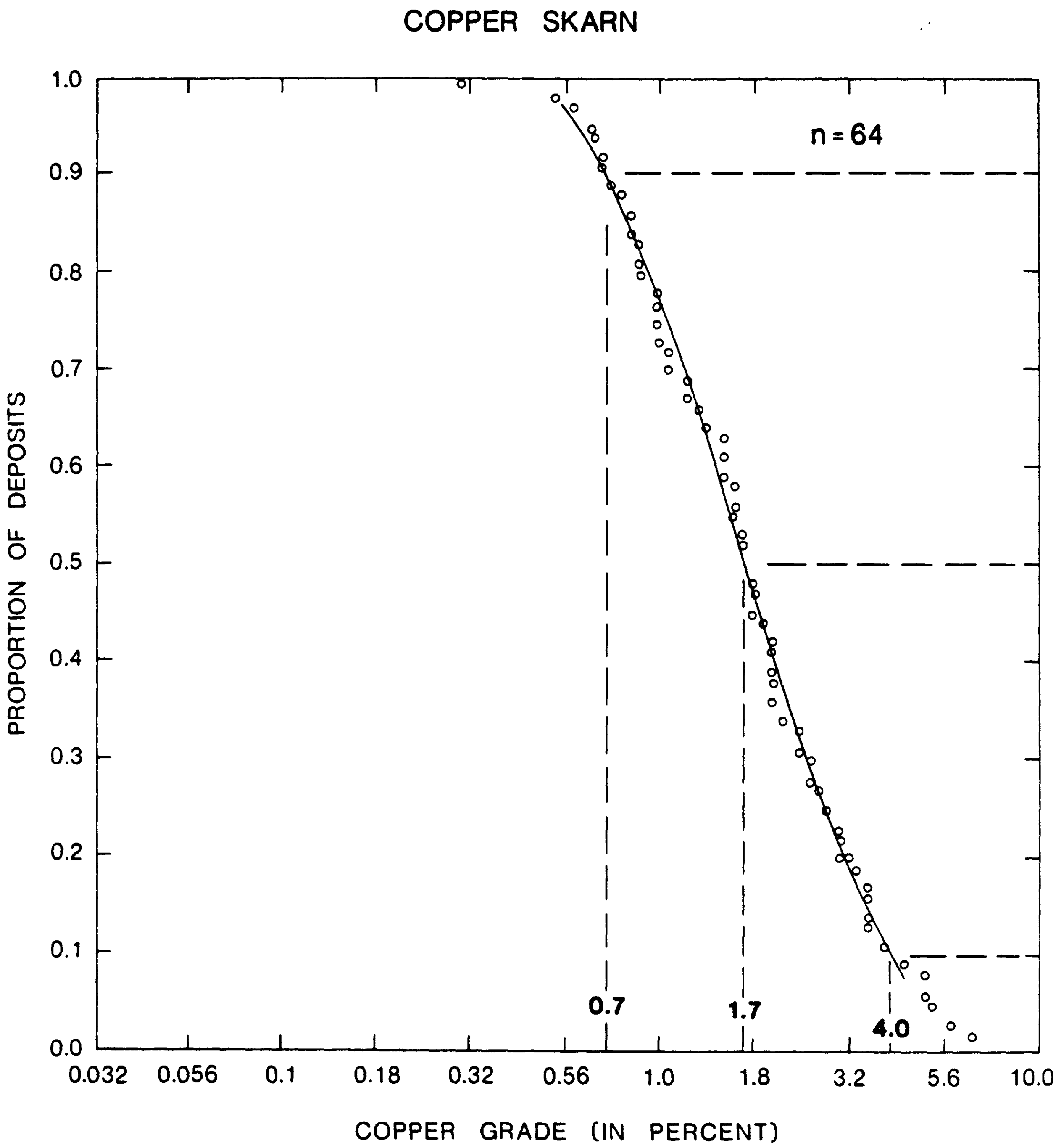
AUTHOR G. M. Jones and W. D. Menzie

COMMENTS Data used in this model were restricted to copper skarns associated with barren stocks as recommended by Einaudi and others (1981). Some of the data are from districts. At the five percent level there is a negative correlation between tonnage and copper grade (r = -0.30).

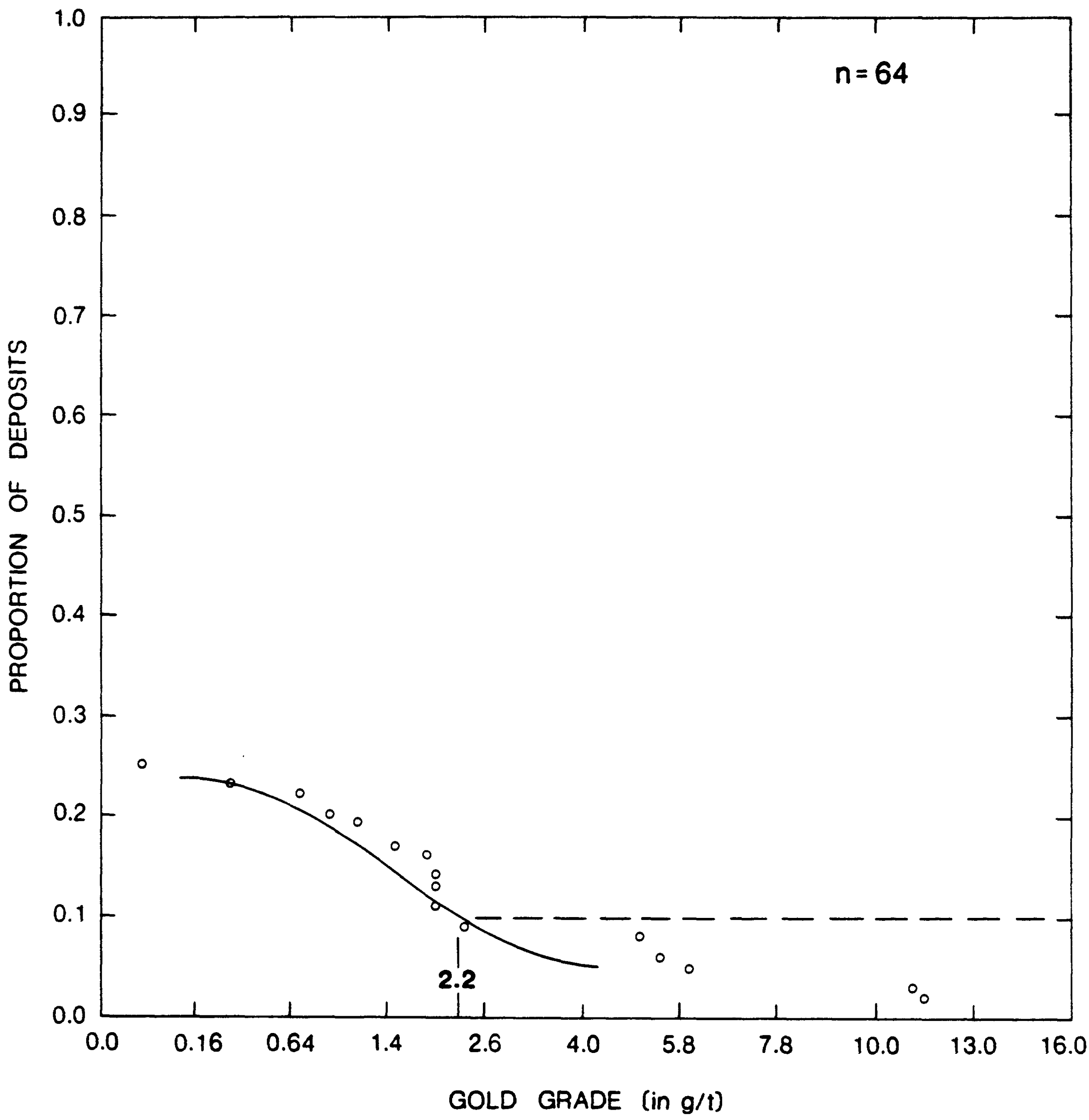
DEPOSITS

Name	Country	Name	Country
Agordo-Brosso	ITLY	Loei-Chiengkarn	THLD
Arctic Chief	CNYT	Ludwig	USNV
B. C.	CNBC	Mackey	USID
Benson Lake	CNBC	Malko Trnova	BULG
Best Chance	CNYT	Marble Bay	CNBC
Black Cub	CNYT	Mason Valley-Malachite	USNV
Blue Grouse	CNBC	McConnell	USNV
Bluestone	USNV	Meme Zone	HATI
Caledonia	CNBC	Mina El Sapo	CLBA
Cassius	HATI	Mina Vieja	CLBA
Casting	USNV	Mother Lode-Sunset	CNBC
Cerro de Cobre	CLBA	Obira	JAPN
Chalcobamba	PERU	Oregon	CNBC
Coast Copper	CNBC	Oro Denoro (Ema)	CNBC
Cobriza	PERU	Phoenix	CNBC
Concepcion Del Oro	MXCO	Queen Victoria (Swift)	CNBC
Copper Queen	CNBC	Rosita	NCRG
Cornell	CNBC	San Pedro	USNM
Cowley Creek	CNYT	Sasca Montana	RMNA
Douglas Hill	USNV	Sasagatani	JAPN
Gem	CNYT	Snowshoe	USNM
Hiragane	JAPN	Strandzha	BULG
Hope	CNBC	Tasu-Wesfrob	CNBC
Iide	JAPN	Tintaya	PERU
Indian Chief	CNBC	Traversella	ITLY
Kamaishi	JAPN	Tsumo	JAPN
Kedbeg Copper	URUR	Vananda	CNBC
Keewenaw	CNYT	War Eagle	CNYT
Kodiak Cub	CNYT	Western Nevada	USNV
Lily (Ikeno)	CNBC	Wexford	CNBC
Little Chief	CNYT	Yreka	CNBC
Lucky Four	CNBC	Zip	CNBC

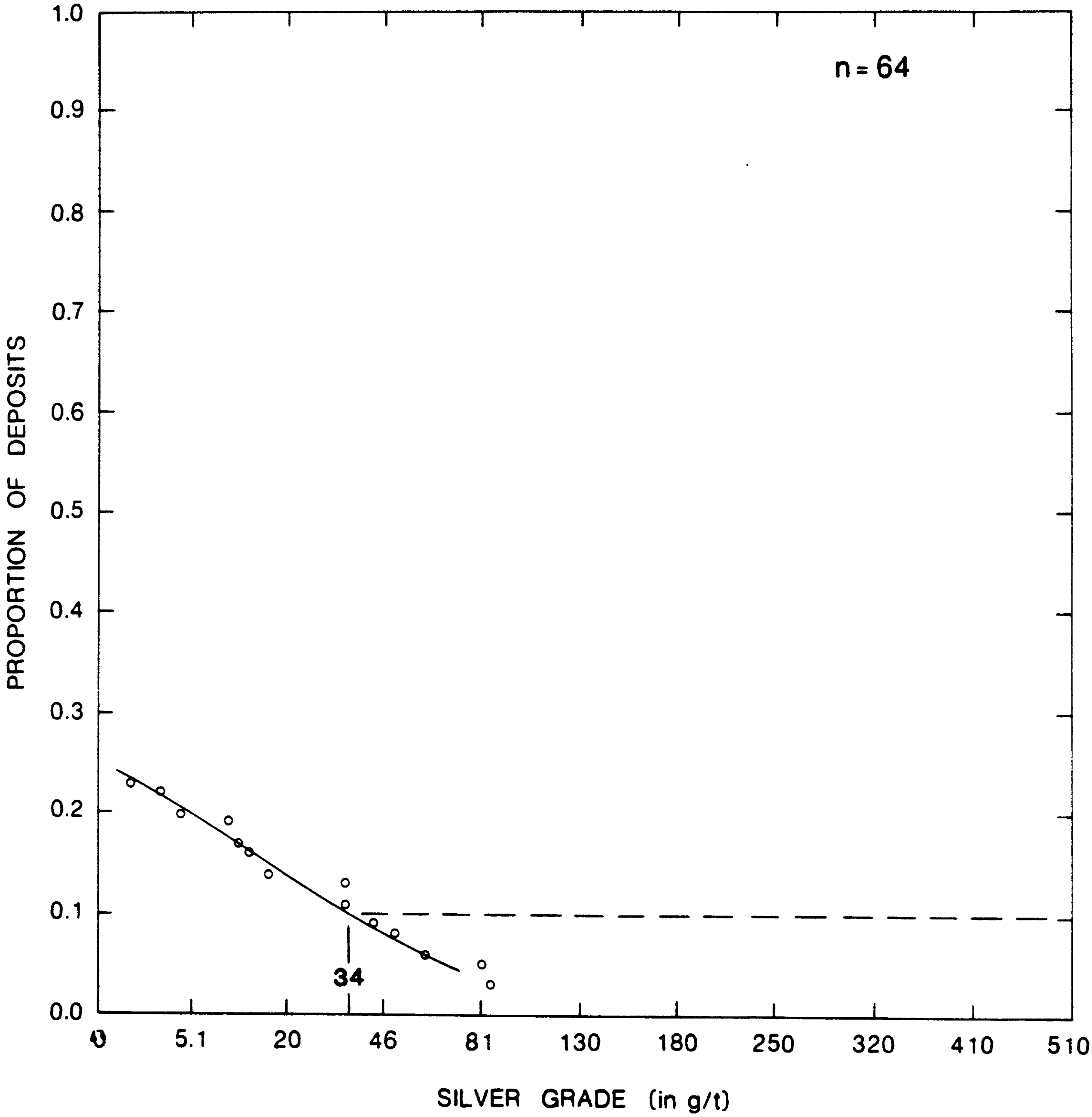

COPPER SKARN
n = 64
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.033
0.60
9.6
0.0063
0.025
0.1
0.4
1.6
6.3
25
100
400
1600
6300
TONNES (IN MILLIONS)


COPPER SKARN
n = 64
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.7
1.7
4.0
0.032
0.056
0.1
0.18
0.32
0.56
1.0
1.8
3.2
5.6
10.0
COPPER GRADE (IN PERCENT)

COPPER SKARN



COPPER SKARN



DEPOSIT TYPE Copper skarn--porphyry copper MODEL NUMBER none

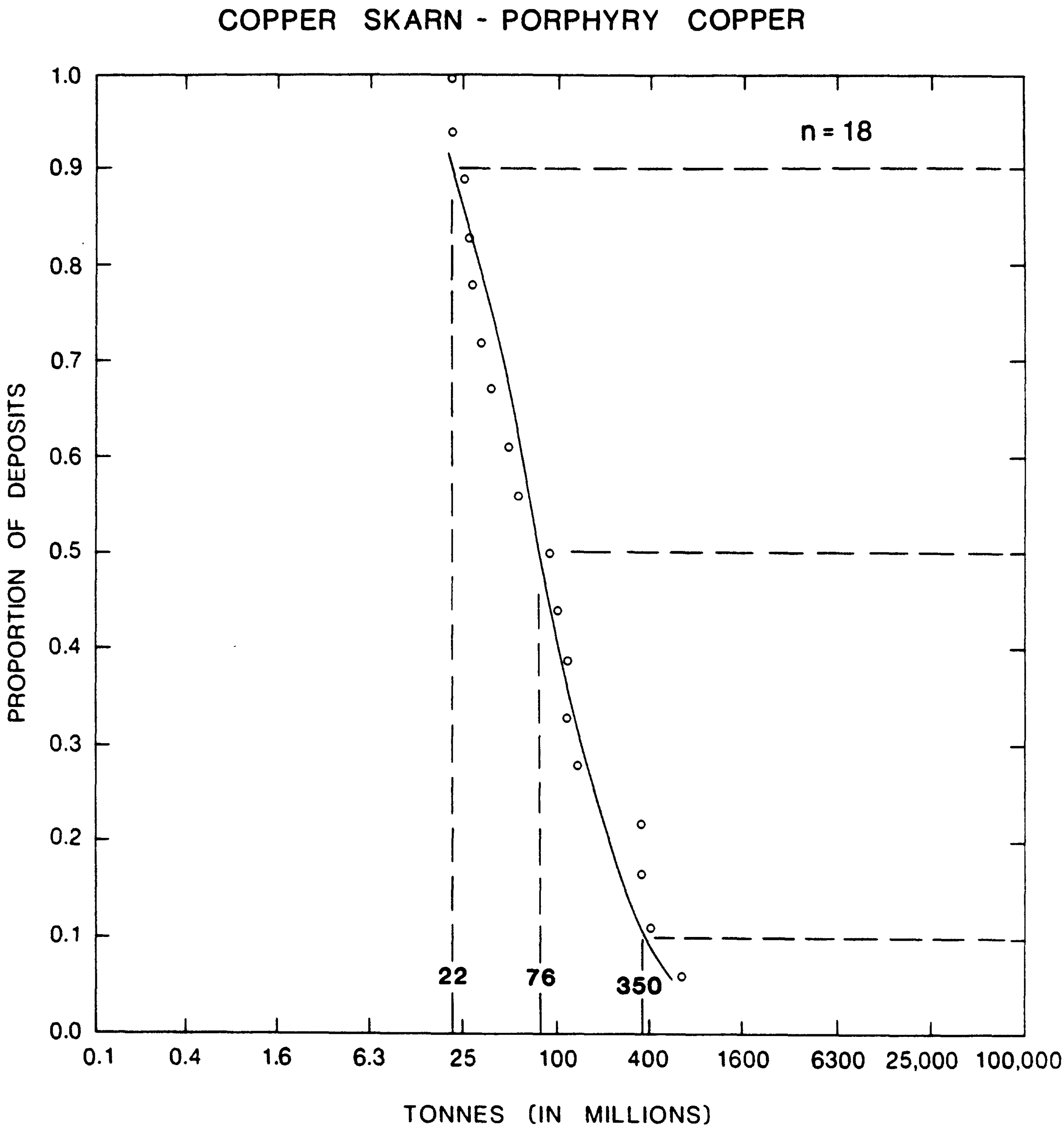
AUTHOR D. A. Singer

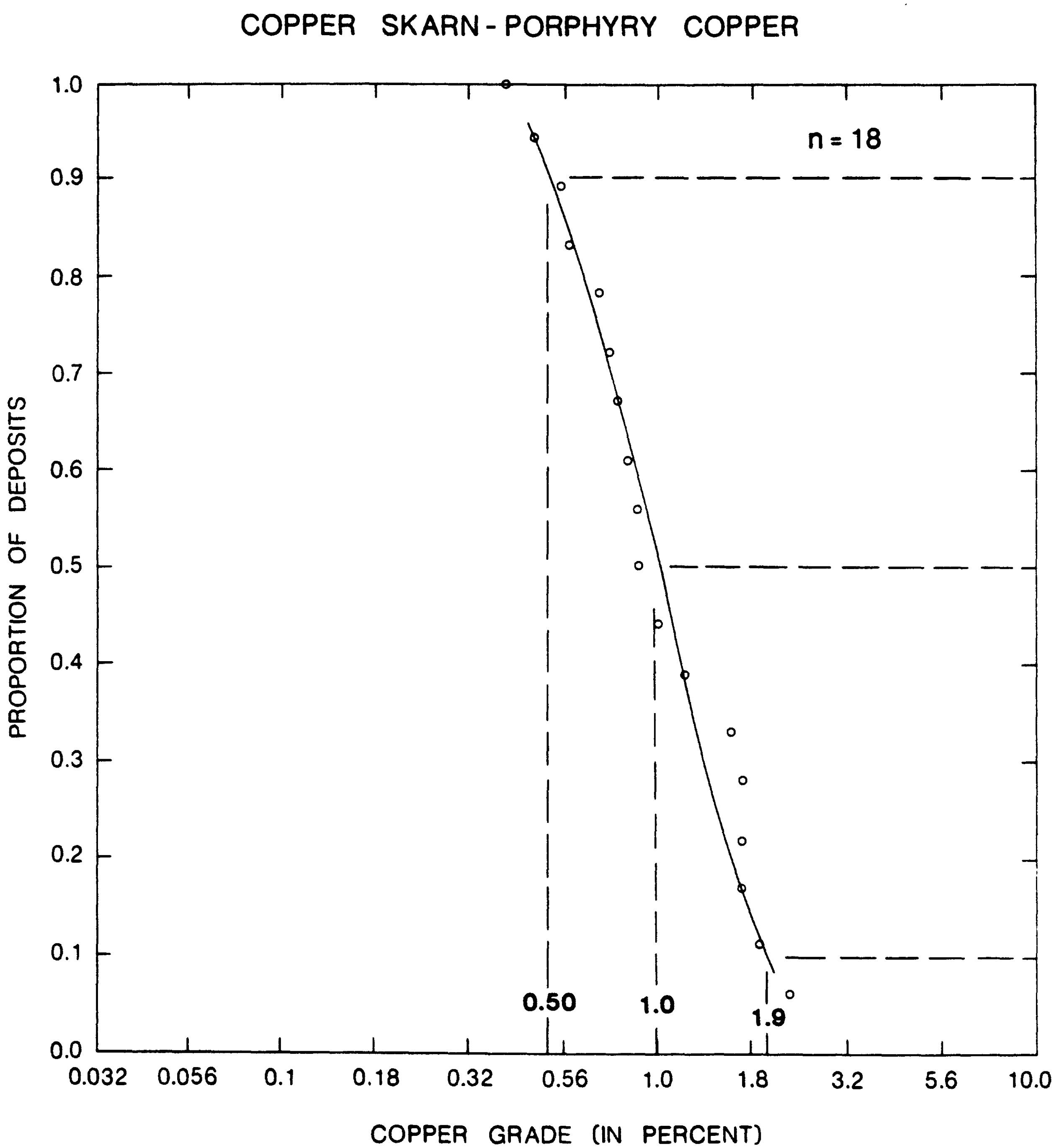
DATA REFERENCES Einaudi and others, 1981; Einaudi, 1981.

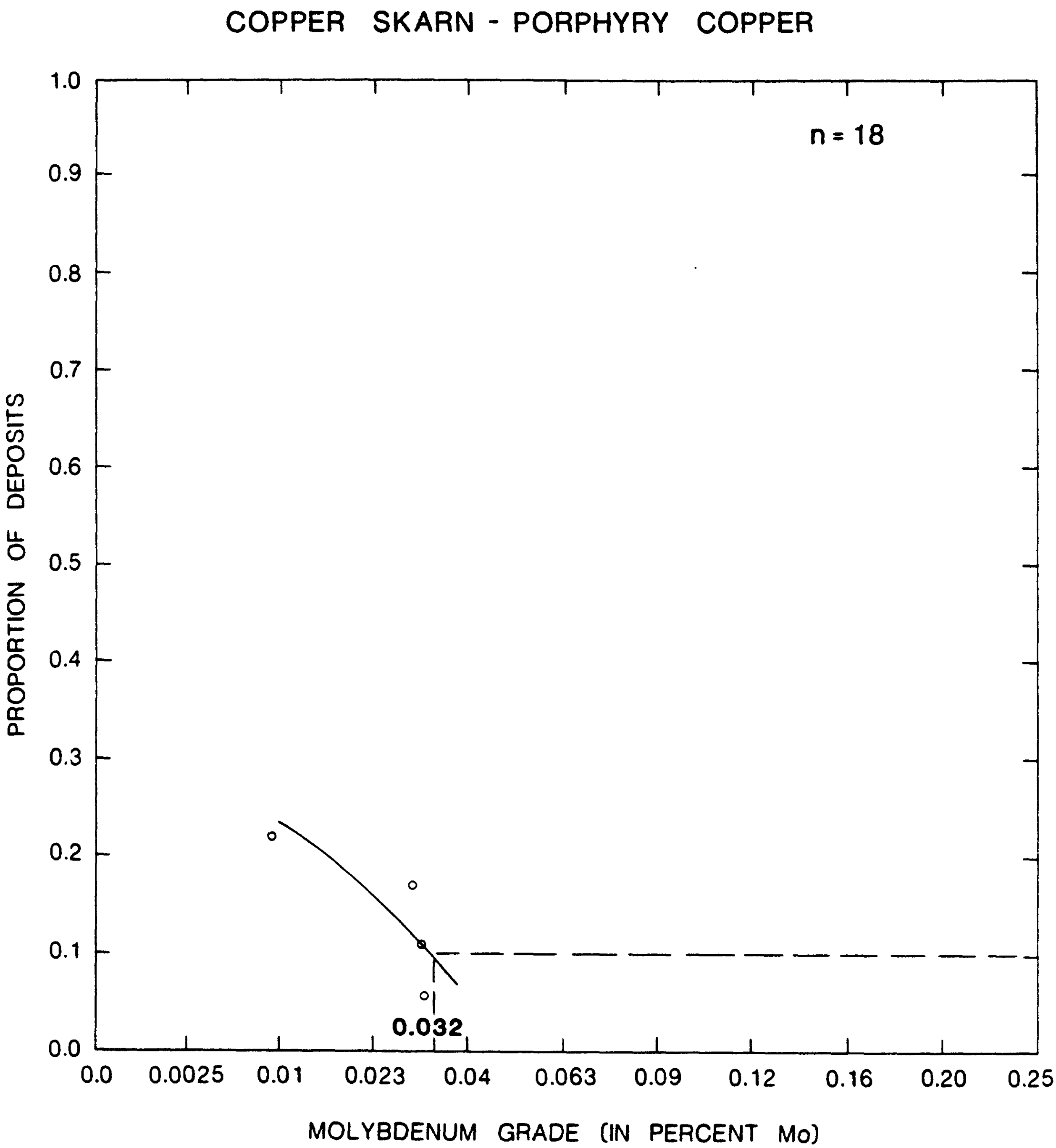
COMMENTS Skarn copper deposits associated with porphyry copper deposits are included in this model. Tonnages and grades attributable to skarn were estimated for some deposits from estimated proportions of skarn provided by Einaudi and others (1981) and Einaudi (1981).

DEPOSITS

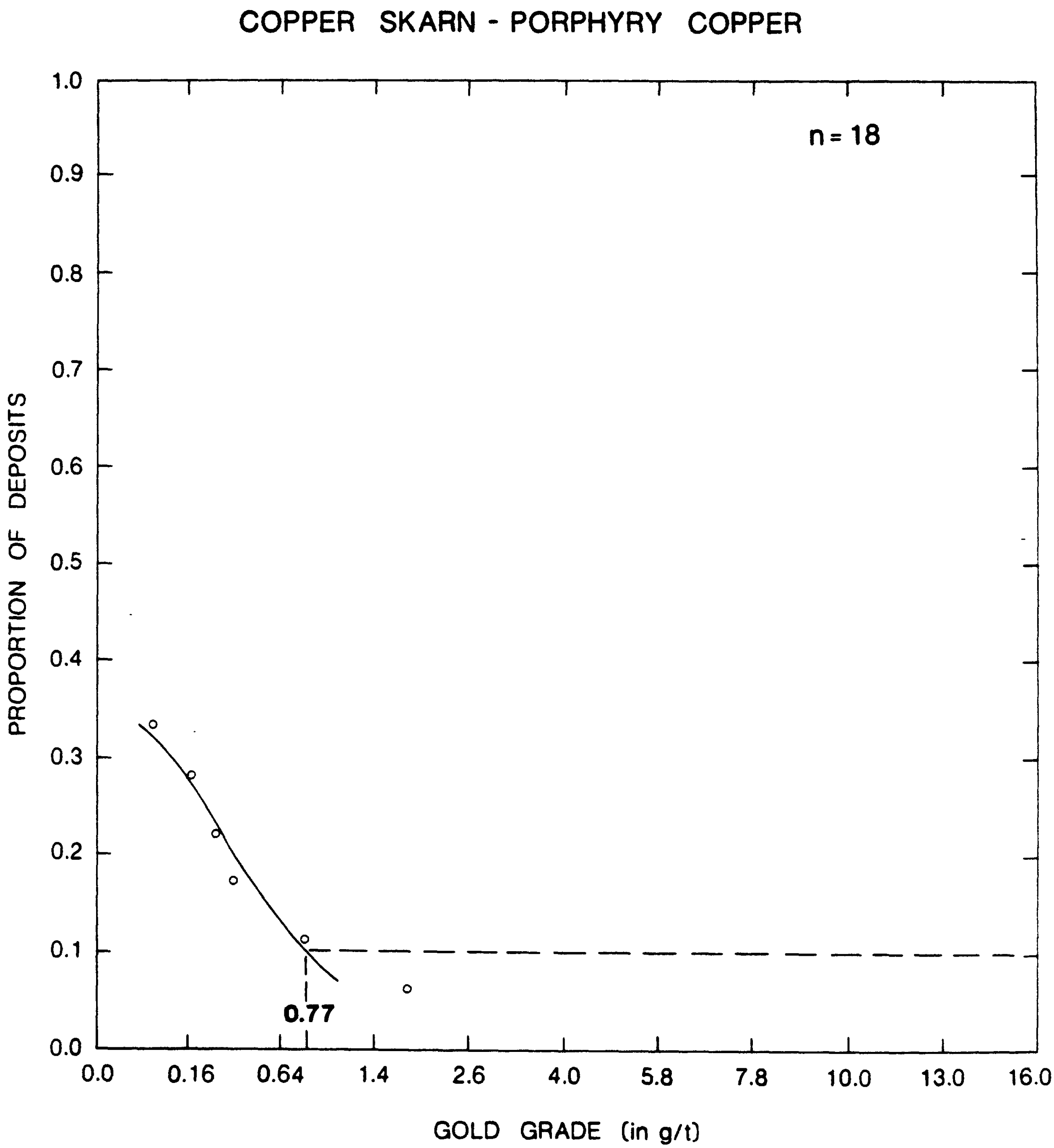
Name	Country
Cananea (Cepote)	MXCO
Carr Fork	USUT
Christmas	USNM
Continental	USNM
Copper Basin	USNV
Copper Canyon	USNV
Craigmont	CNBC
Ely	USNV
Gaspe (Needle Mountain)	CNQU
Gold Coast	PPNG
Lakeshore	USAZ
Lyon	USNV
Pima-Mission	USAZ
Potrerillos	CILE
Recsk	HUNG
Santa Rita	USNM
Silver Bell	USAZ
Twin Buttes	USAZ

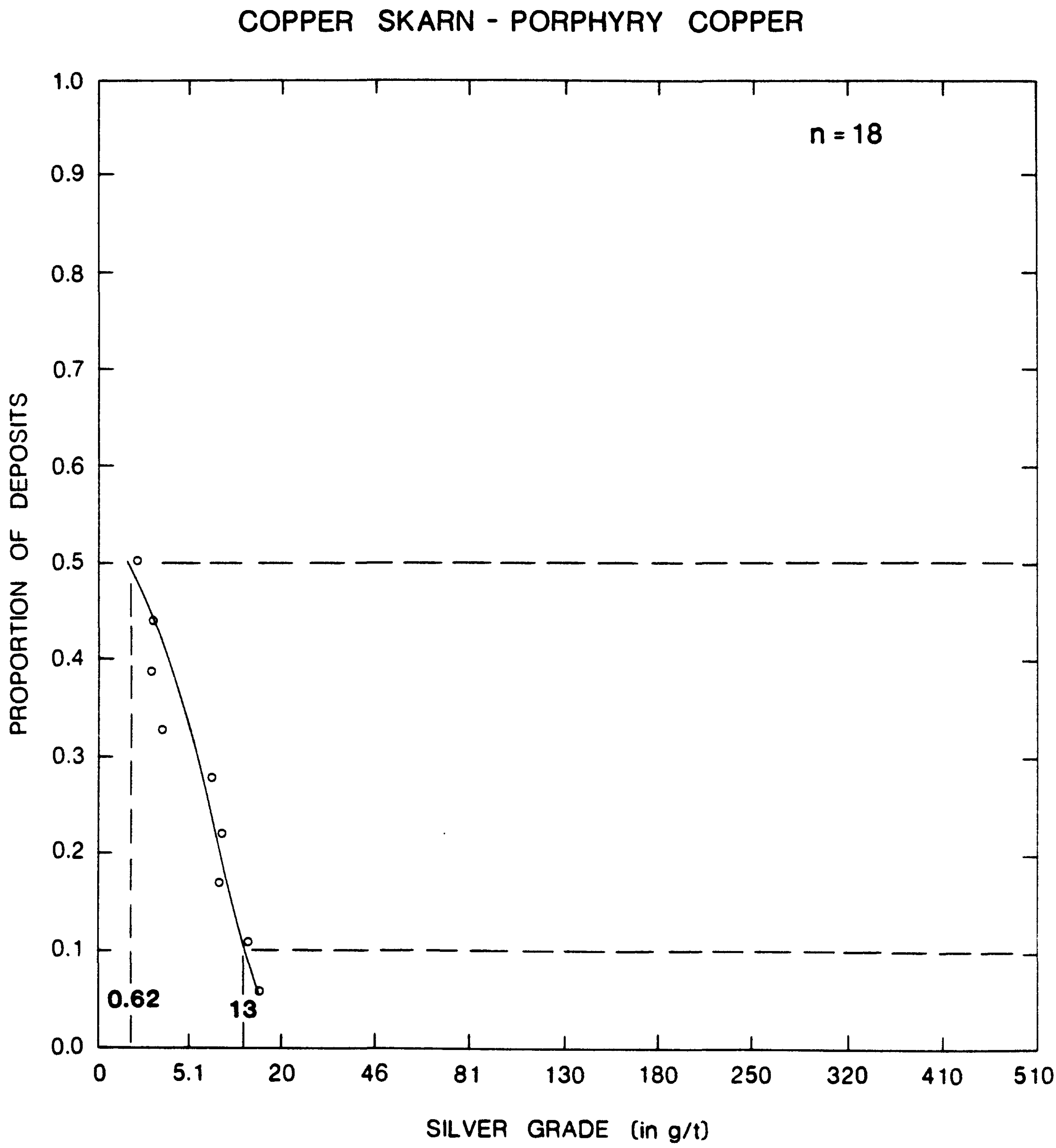

COPPER SKARN - PORPHYRY COPPER
n = 18
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
22
76
350
0.1
0.4
1.6
6.3
25
100
400
1600
6300
25,000
100,000
TONNES (IN MILLIONS)


COPPER SKARN - PORPHYRY COPPER
n = 18
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.50
1.0
1.9
0.032
0.056
0.1
0.18
0.32
0.56
1.0
1.8
3.2
5.6
10.0
COPPER GRADE (IN PERCENT)



COPPER SKARN - PORPHYRY COPPER
n = 18
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PROPORTION OF DEPOSITS
0.032
0.0
0.0025
0.01
0.023
0.04
0.063
0.09
0.12
0.16
0.20
0.25
MOLYBDENUM GRADE (IN PERCENT Mo)


COPPER SKARN - PORPHYRY COPPER
n = 18
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.77
0.0
0.16
0.64
1.4
2.6
4.0
5.8
7.8
10.0
13.0
16.0
GOLD GRADE (in g/t)



COPPER SKARN - PORPHYRY COPPER
n = 18
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.62
13
0
5.1
20
46
81
130
180
250
320
410
510
SILVER GRADE (in g/t)

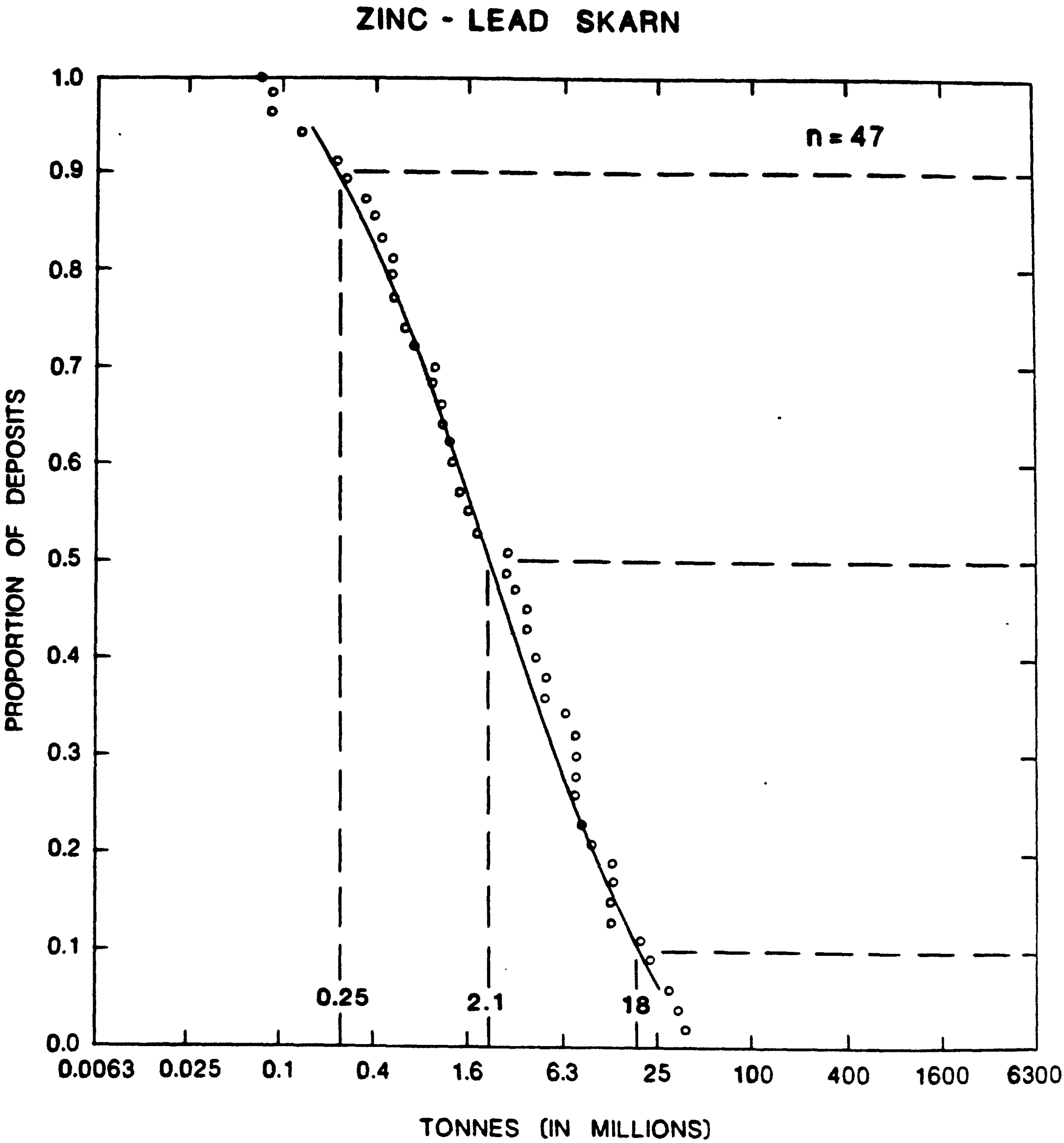
DEPOSIT TYPE Zinc-lead skarn MODEL NUMBER 2.7

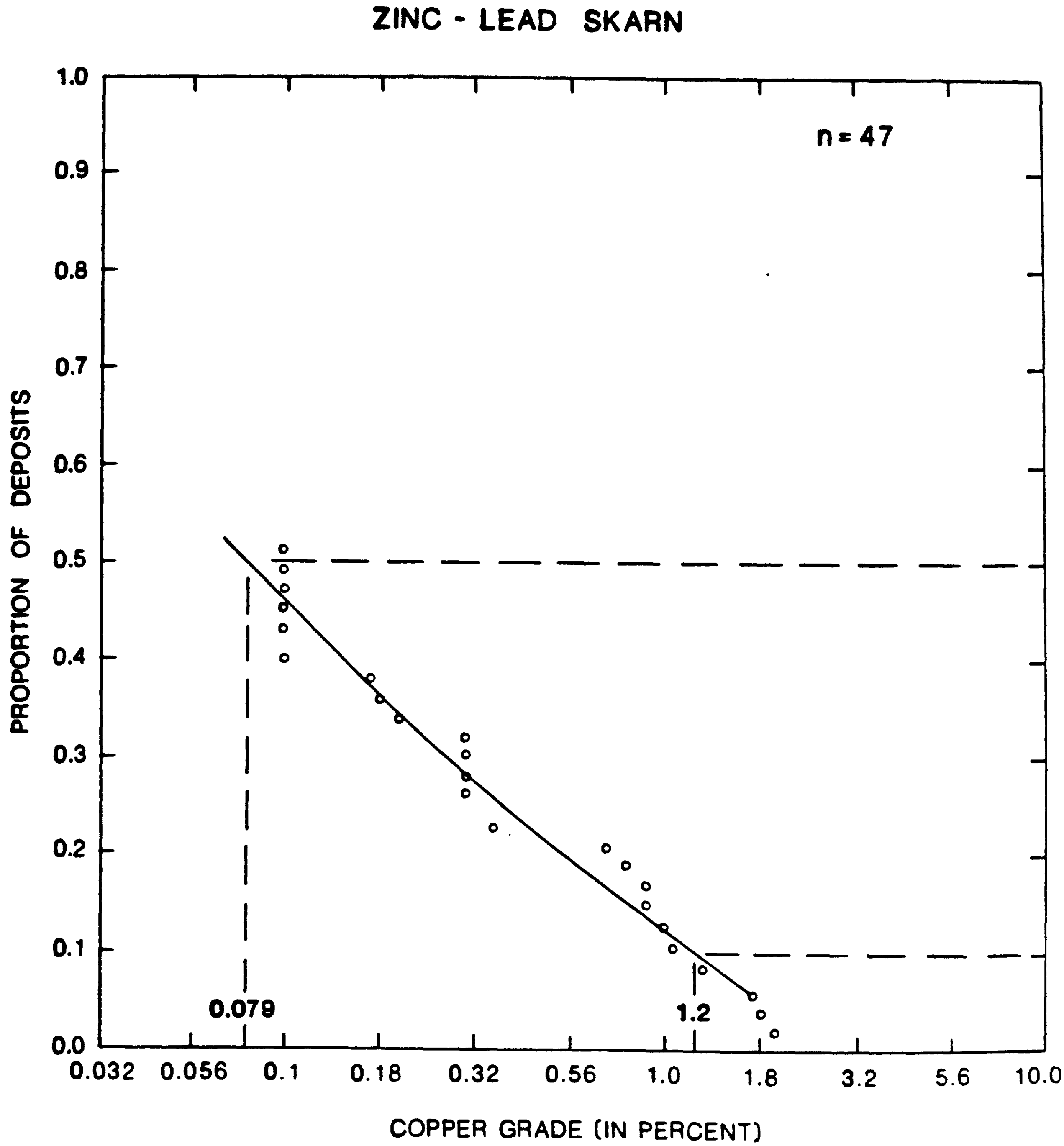
AUTHOR D. L. Mosier

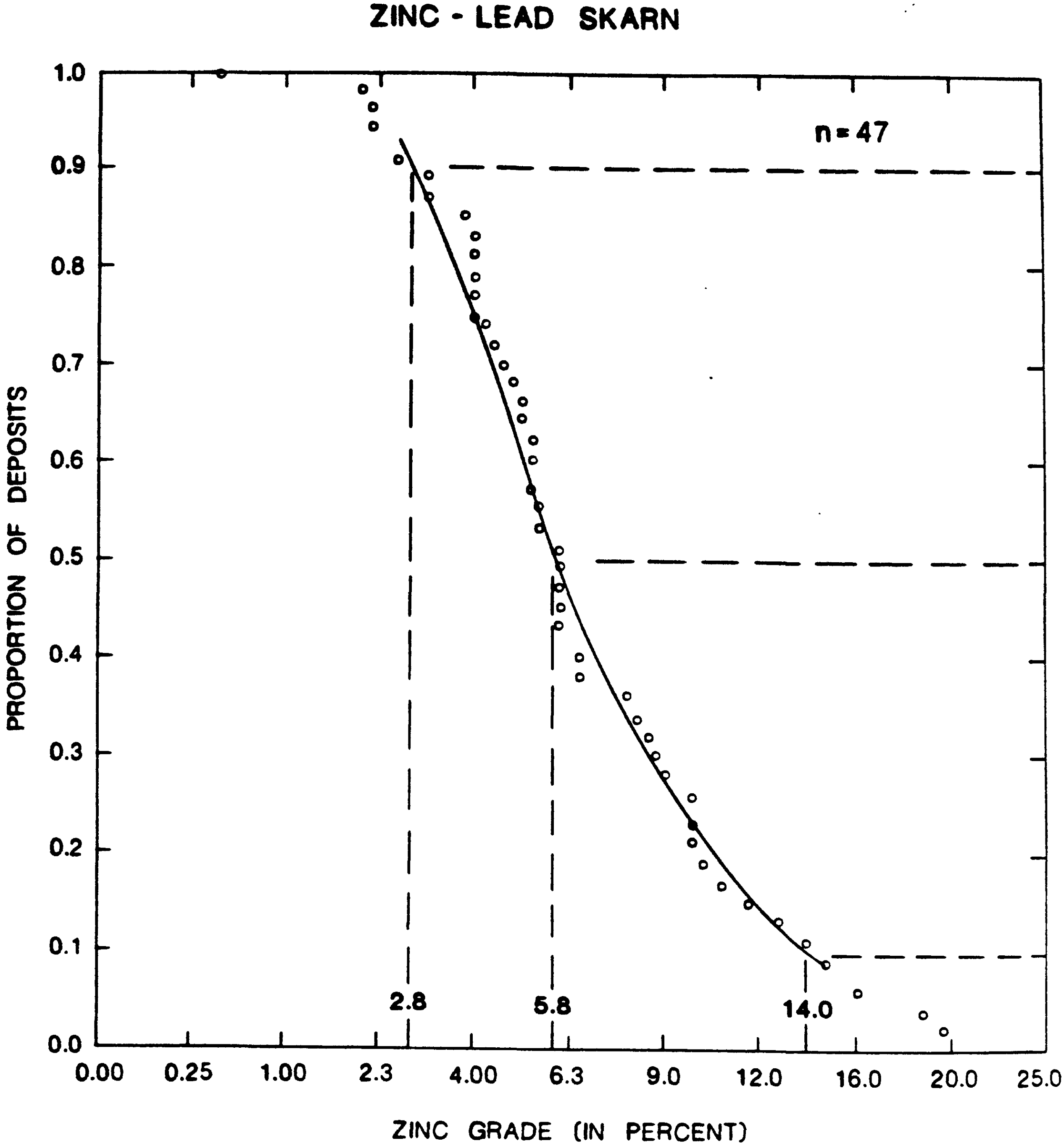
COMMENTS Lead grade is correlated with zinc grade (r=0.53, n=45).

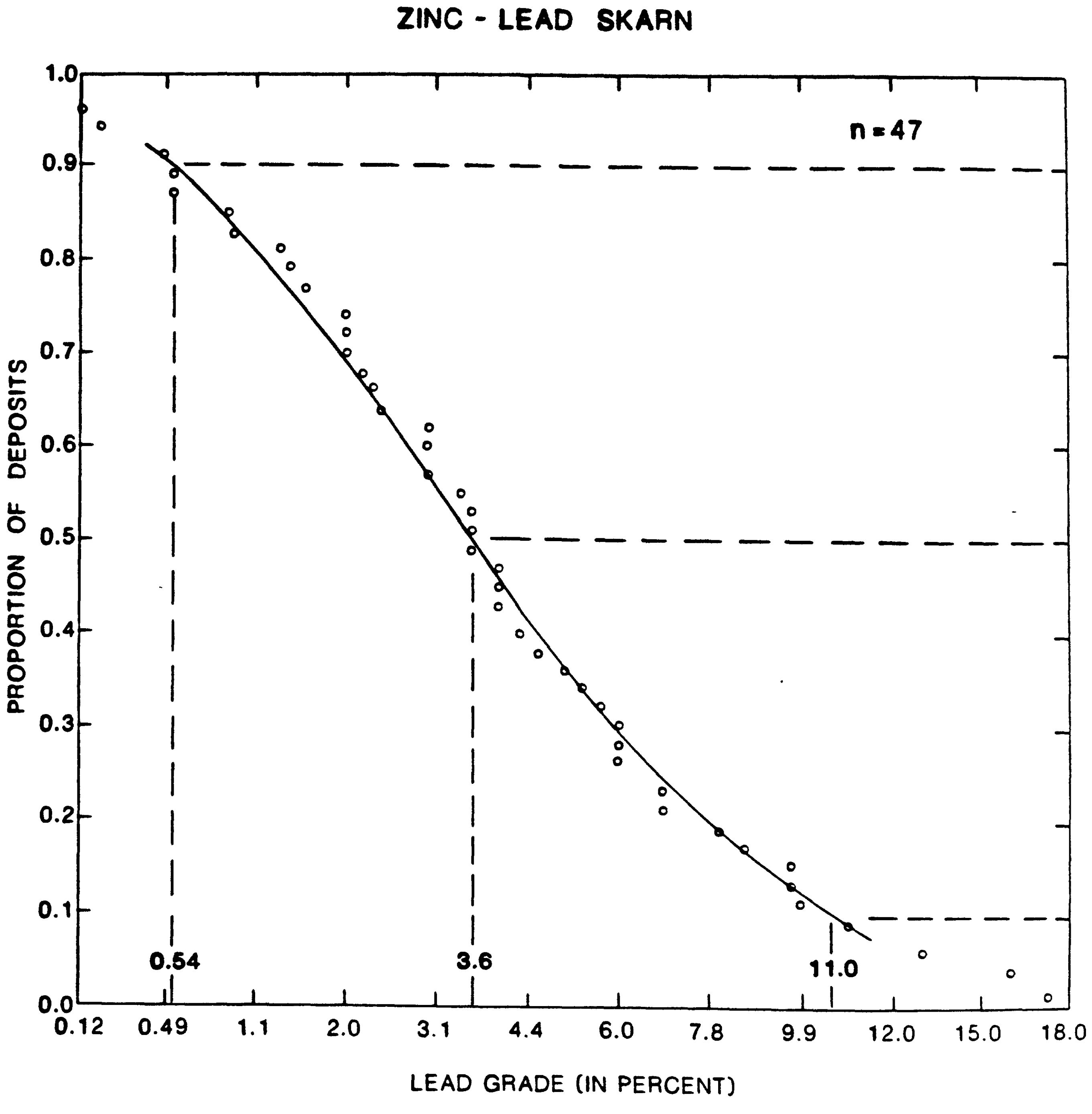
DEPOSITS

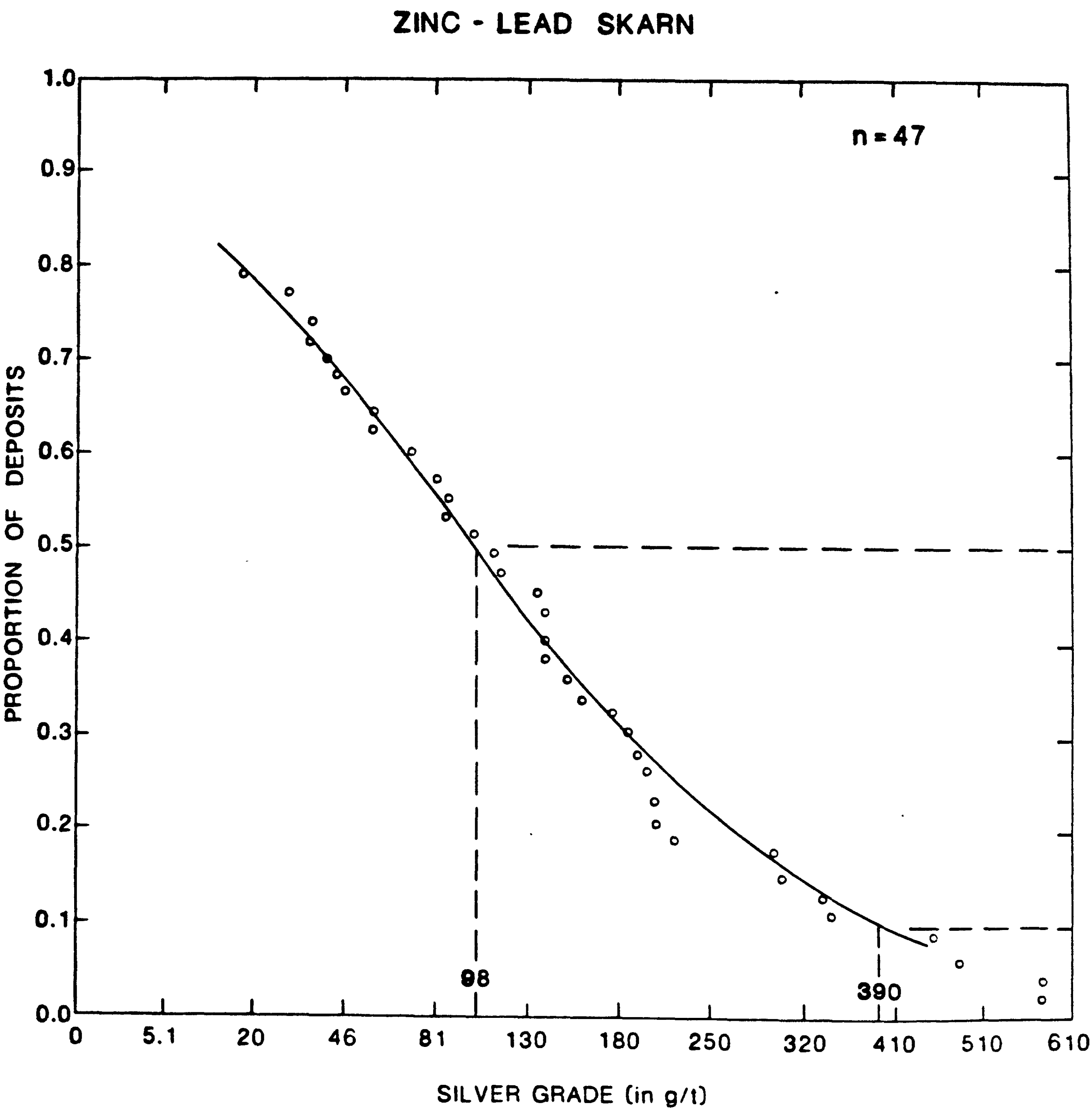
Name	Country	Name	Country
Aguilar	AGTN	Nyseter	NRWY
Ajvalija	YUGO	Parroquio-Magistral	MXCO
Ammeberg	SWDN	Ryllshyttan	SWDN
Aravaipa	USAZ	Sala	SWDN
Black Hawk	USNM	San Martin	MXCO
Bluebell	CNBC	Santa Eulalia	MXCO
Chalchihuites	MXCO	Saxberget	SWDN
Dolores	MXCO	Shuikoushan	CINA
El Mochito	HNDR	Staritrg	YUGO
Empire	USNM	Stollberg	SWDN
Falun	SWDN	Svardsio	SWDN
Garpenberg	SWDN	Tetyukhe	URRS
Garpenberg Odal	SWDN	Tienpaoshan	CINA
Groundhog	USNM	Trepca	YUGO
Kalvbacken	SWDN	Uchucchacua	PERU
Kamioka	JAPN	Ulchin	SKOR
Lampazos	MXCO	Velardena	MXCO
Magno	CNBC	Washington Camp	USAZ
Mazapil	MXCO	Yanchiachangtze	CINA
McDame Belle	CNBC	Yeonhwa I	SKOR
Meat Cove	CNNS	Yeonhwa II	SKOR
Mount Hundere	CNYT	Zimapan	MXCO
Naica	MXCO	Zip	CNBC
Nakatatsu	JAPN		


ZINC - LEAD SKARN
n = 47
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.25
2.1
18
0.0063
0.025
0.1
0.4
1.6
6.3
25
100
400
1600
6300
TONNES (IN MILLIONS)


ZINC - LEAD SKARN
n = 47
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.079
1.2
0.032
0.056
0.1
0.18
0.32
0.56
1.0
1.8
3.2
5.6
10.0
COPPER GRADE (IN PERCENT)


ZINC - LEAD SKARN
n=47
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2.8
5.8
14.0
0.00
0.25
1.00
2.3
4.00
6.3
9.0
12.0
16.0
20.0
25.0
ZINC GRADE (IN PERCENT)


ZINC - LEAD SKARN
n=47
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.54
3.6
11.0
0.12
0.49
1.1
2.0
3.1
4.4
6.0
7.8
9.9
12.0
15.0
18.0
LEAD GRADE (IN PERCENT)


ZINC - LEAD SKARN
n = 47
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
98
390
0
5.1
20
46
81
130
180
250
320
410
510
610
SILVER GRADE (in g/t)

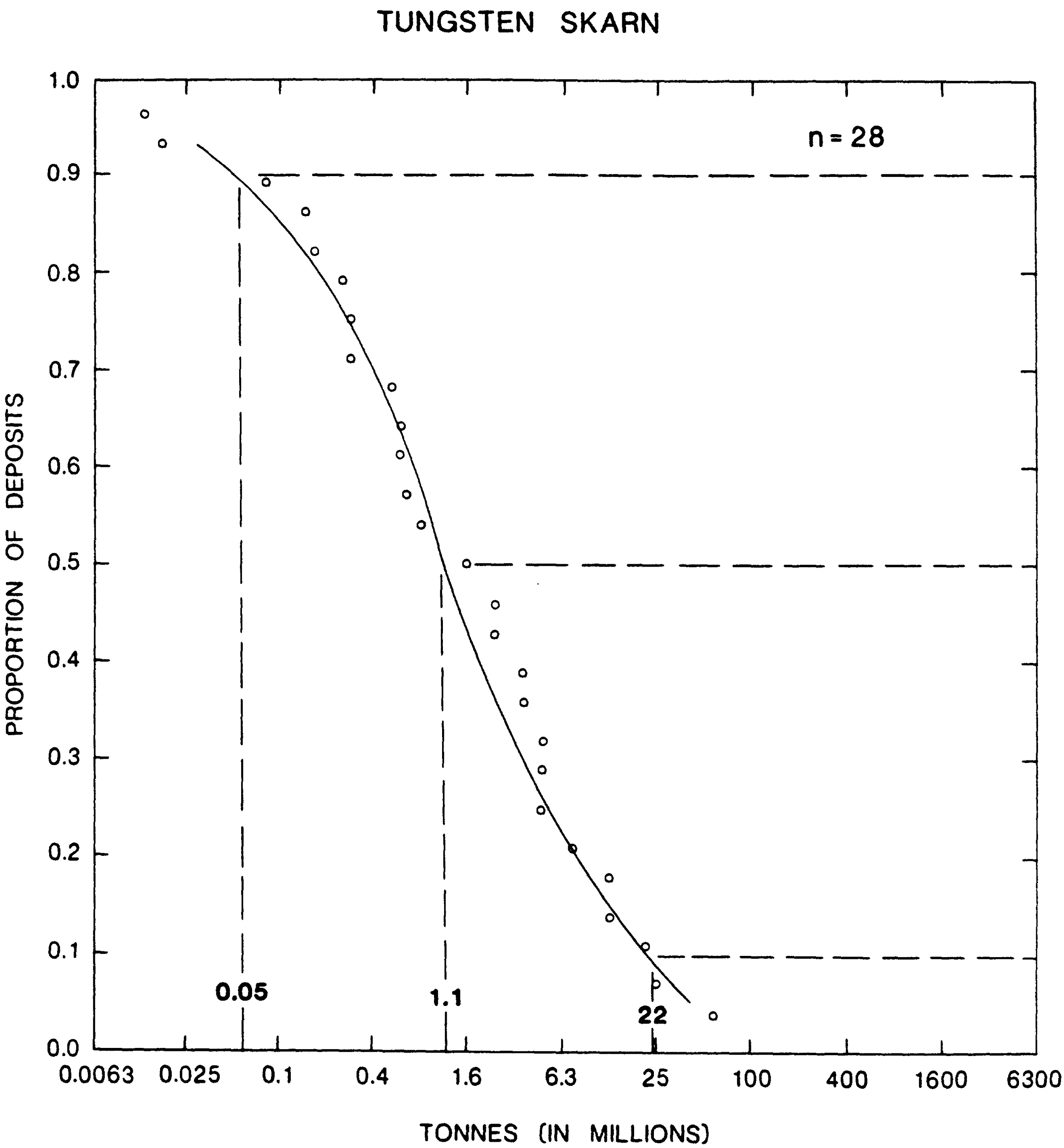
DEPOSIT TYPE Tungsten skarn MODEL NUMBER 2.8

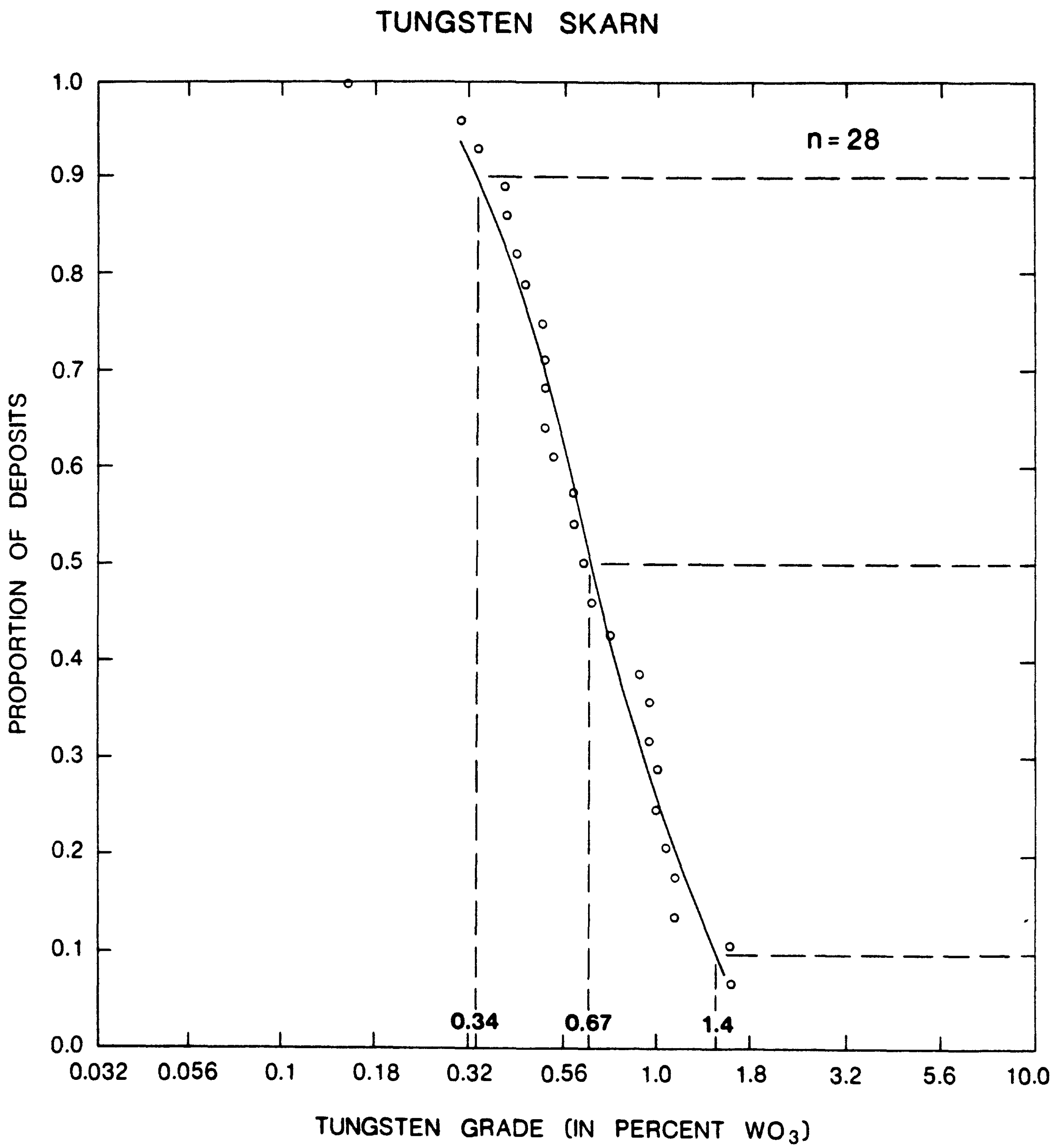
AUTHOR W. D. Menzie and G. M. Jones

COMMENTS Some of the data are from districts. Deposits were combined if they occurred in the same rock units within 10 km of each other.

DEPOSITS

Name	Country
Bailey	CNYT
Brejui	BRZL
Cab	CNYT
Calvert (Red Button)	USMT
Cantung	CNNT
Dublin Gulch (GSZ)	CNYT
Emerald-Dodger	CNBC
Iron Mountain	USNM
King Island	AUTS
Lost Creek	USMT
Lucky Mike	CNBC
Mactung	CNNT
Maykhura	URTD
Milford area	USUT
Nevada-Massachusetts	USNV
Nevada-Scheelite	USNV
Osgood Range	USNV
Pine Creek	USCA
Quixaba	BRZL
Ray Gulch	CNYT
Sang Dong	SKOR
Stormy Group	CNYT
Tem Piute district	USNV
Tyrny-Auz	URRS
Uludag	TRKY
Victory	CNBC
Yellow Pine district	USID
Ysxjoberg	SWDN


TUNGSTEN SKARN
n = 28
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.05
1.1
22
0.0063
0.025
0.1
0.4
1.6
6.3
25
100
400
1600
6300
TONNES (IN MILLIONS)



TUNGSTEN SKARN
n = 28
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PROPORTION OF DEPOSITS
0.34
0.67
1.4
0.032
0.056
0.1
0.18
0.32
0.56
1.0
1.8
3.2
5.6
10.0
TUNGSTEN GRADE (IN PERCENT WO3)

DEPOSIT TYPE Cyprus massive sulfide MODEL NUMBER 3.1

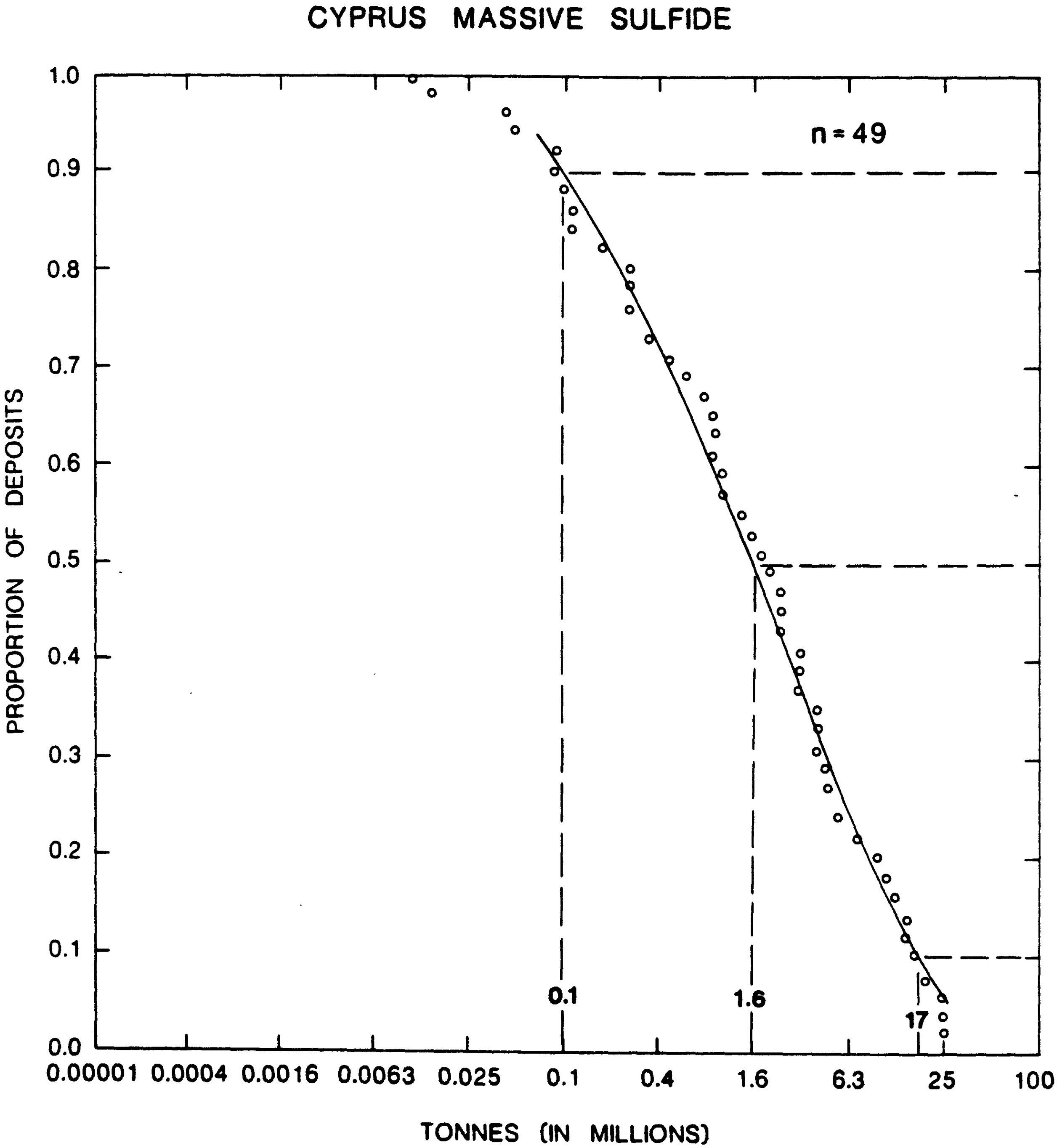
AUTHOR D. A. Singer and D. L. Mosier

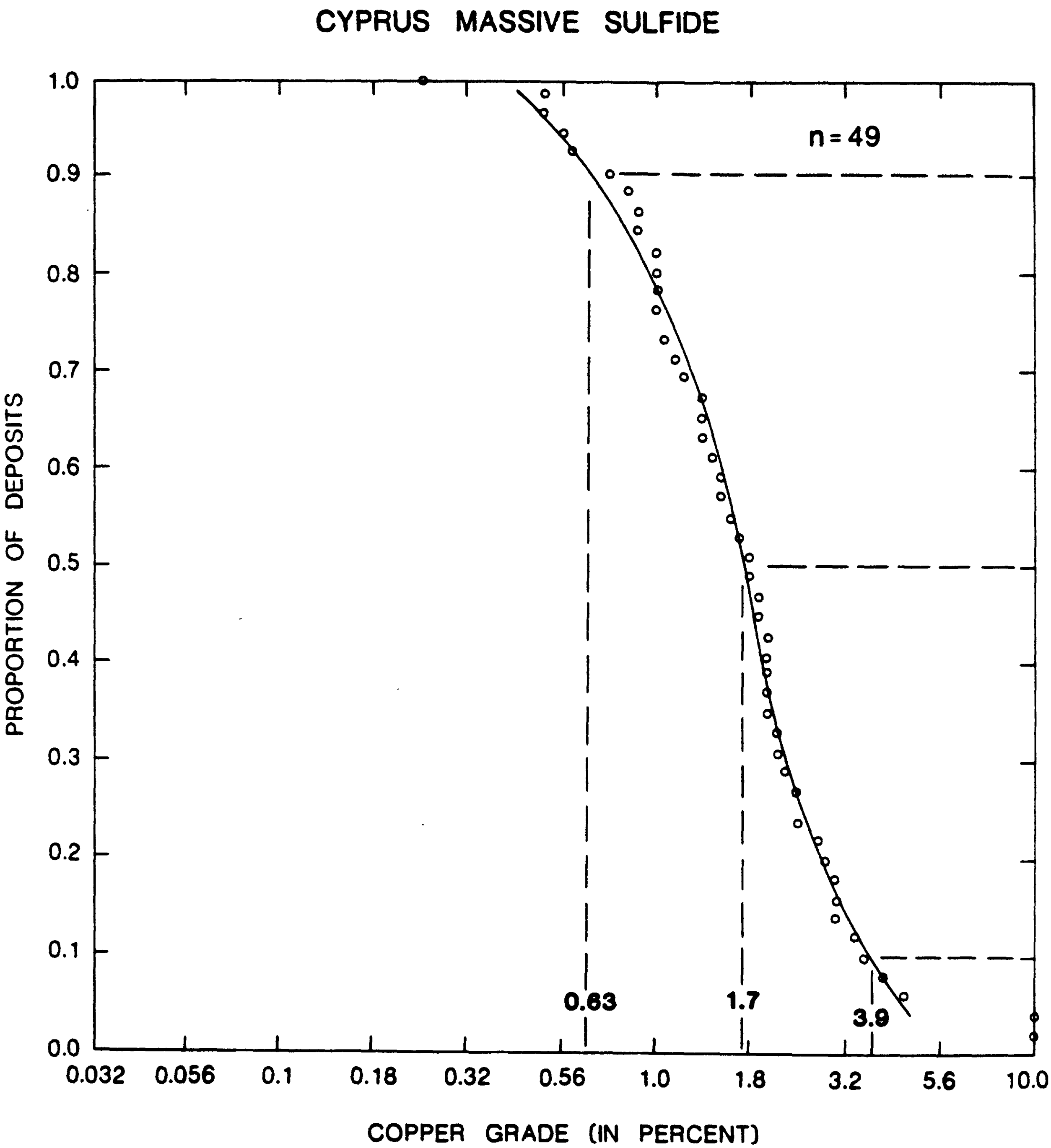
DATA REFERENCES Mosier and others, 1983.

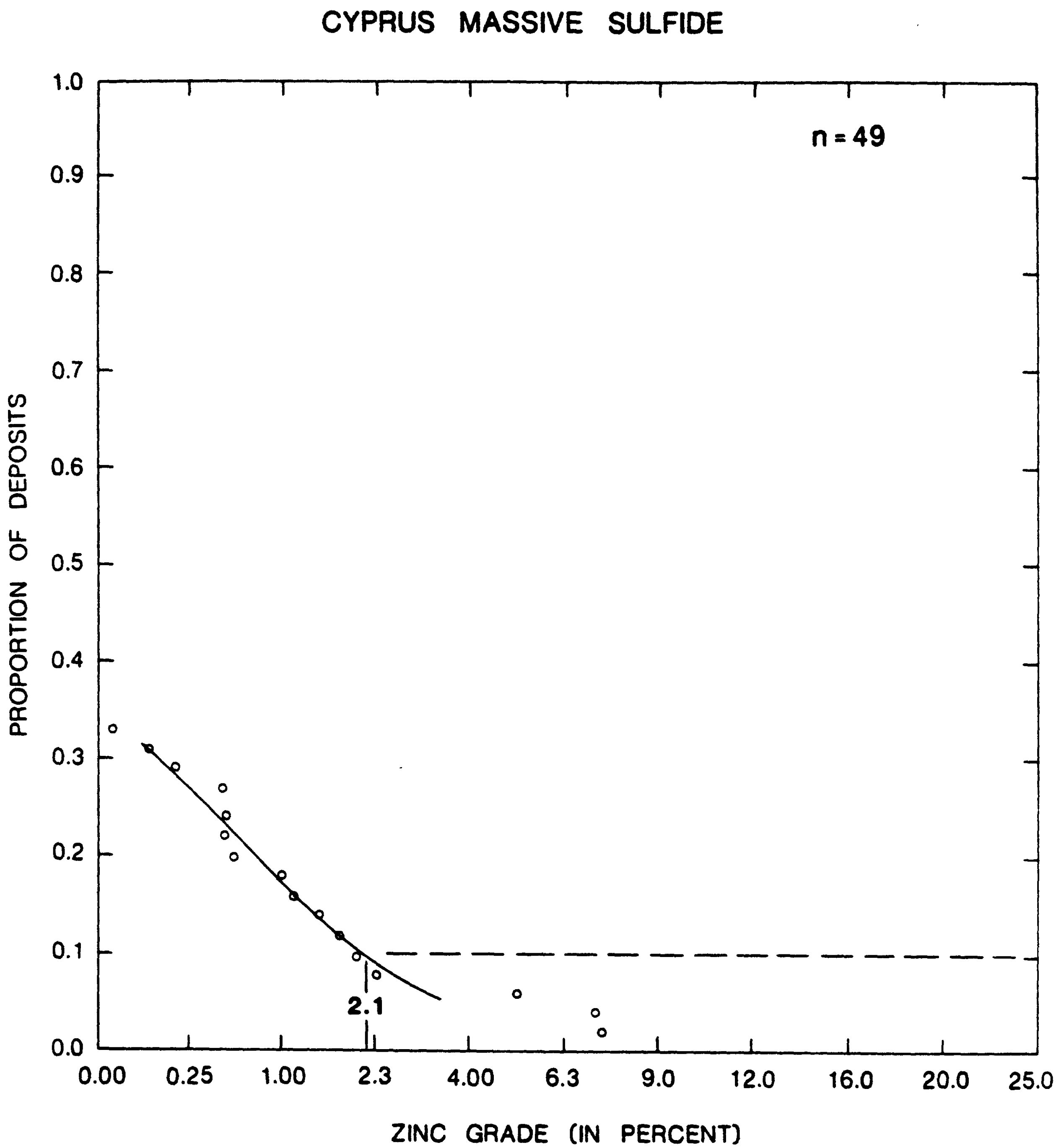
COMMENTS Massive sulfide deposits from Mosier and others (1983) which had only mafic or ultramafic rocks immediately above through 500 m below, and had either pillow basalt or diabase dikes in the sequence were included in these plots. Gold grade is correlated with tonnage at the five percent level (r = 0.29).

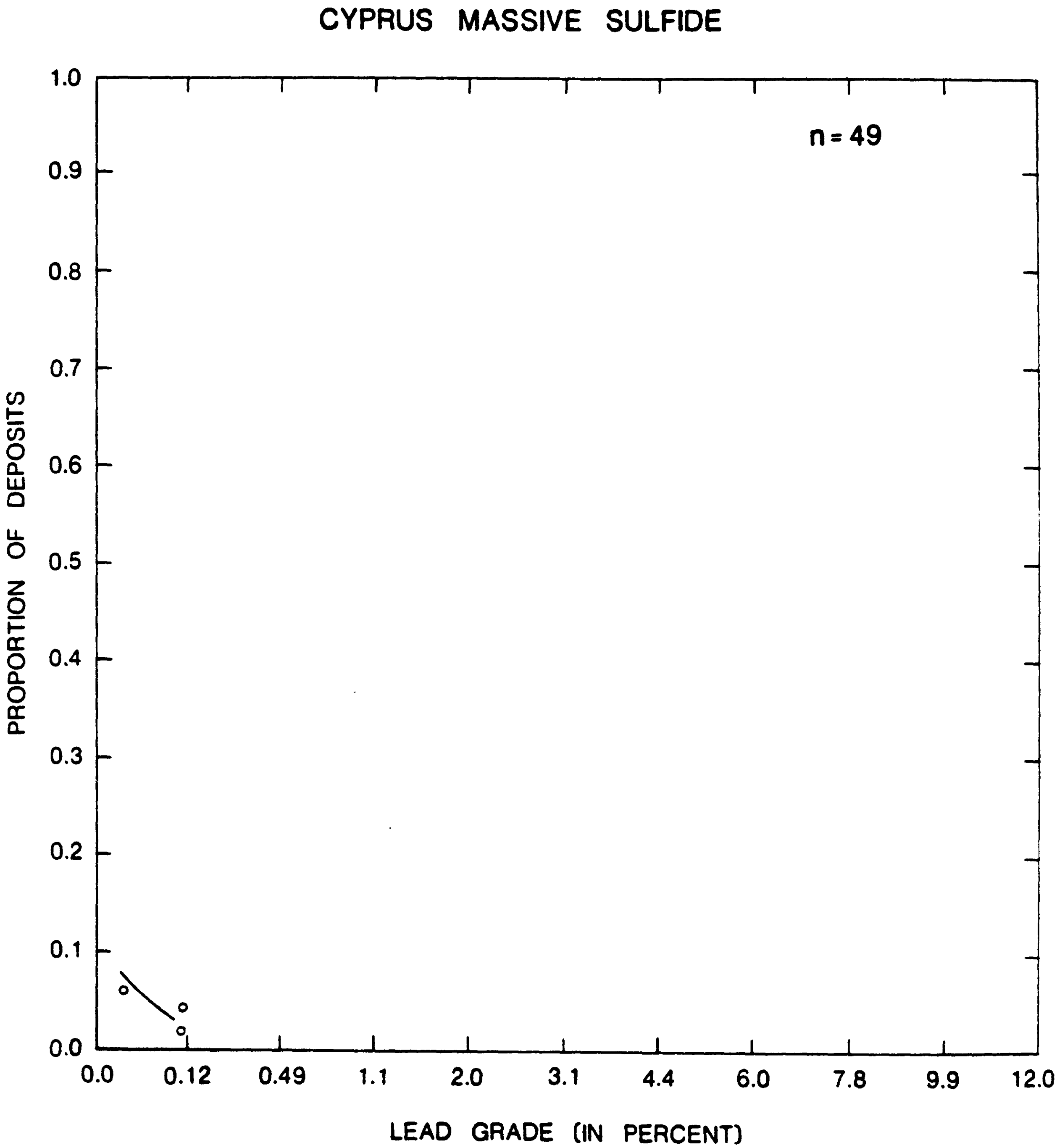
DEPOSITS

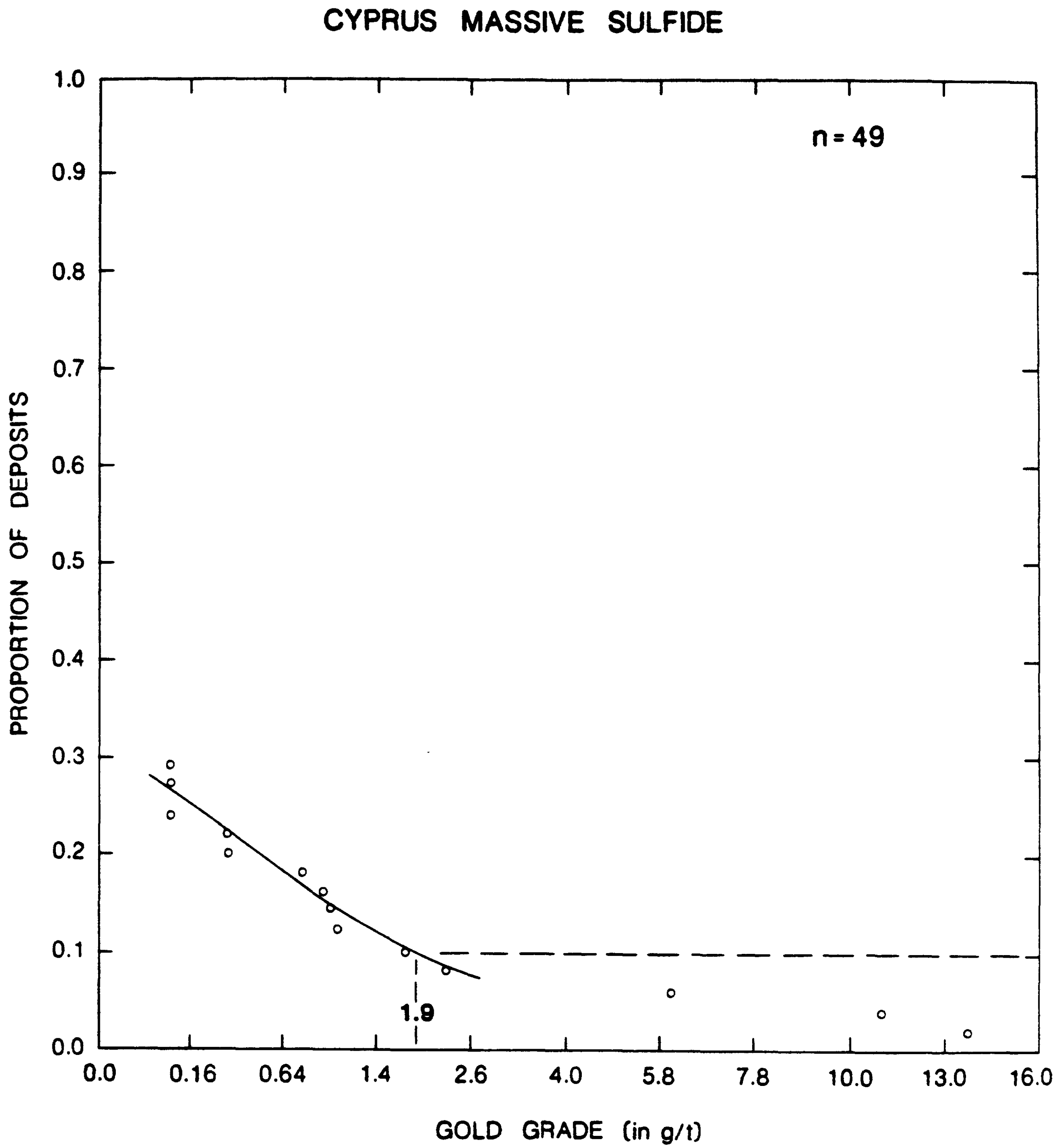
Name	Country	Name	Country
Aarja	OMAN	Lasail	OMAN
Agrokipia	CYPS	Limni	CYPS
Ambelikou	CYPS	Little Bay	CNNF
Ana Yatak-Ergani	TRKY	Lokken	NRWY
Apliki	CYPS	Lorraine	PLPN
Arinteiro	SPAN	Mathiati North	CYPS
Bama	SPAN	Mavrovouni	CYPS
Barlo	PLPN	Mousoulos-Kalavasos	CYPS
Bayda	OMAN	Ny Sulitjelma	NRWY
Betts Cove	CNNF	Oxec	GUAT
Big Mike	USNV	Peravasa	CYPS
Bonanza	CNBC	Platies	CYPS
Bongbongan	PLPN	Rendall-Jackson	CNNF
Carawison	PLPN	Rua Cove	USAK
Carmel	PLPN	Sha	CYPS
Colchester	CNNF	Siirt Madenkoy	TRKY
Fornas	SPAN	Skorovass	NRWY
Hand Camp	CNNF	Skouriotissa	CYPS
Huntingdon	CNQU	Svano	NRWY
Kapedhes	CYPS	Tilt Cove	CNNF
Kokkinoyia	CYPS	Troulli	CYPS
Kokkinopezoula	CYPS	Turner-Albright	USOR
Kure (Asikoy)	TRKY	Whalesback-Little Deer	CNNF
Kure (Bakibaba)	TRKY	York Harbour	CNNF
Kynousa	CYPS		


CYPRUS MASSIVE SULFIDE
n = 49
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.1
1.6
17
0.00001 0.0004 0.0016 0.0063 0.025 0.1 0.4 1.6 6.3 25 100
TONNES (IN MILLIONS)

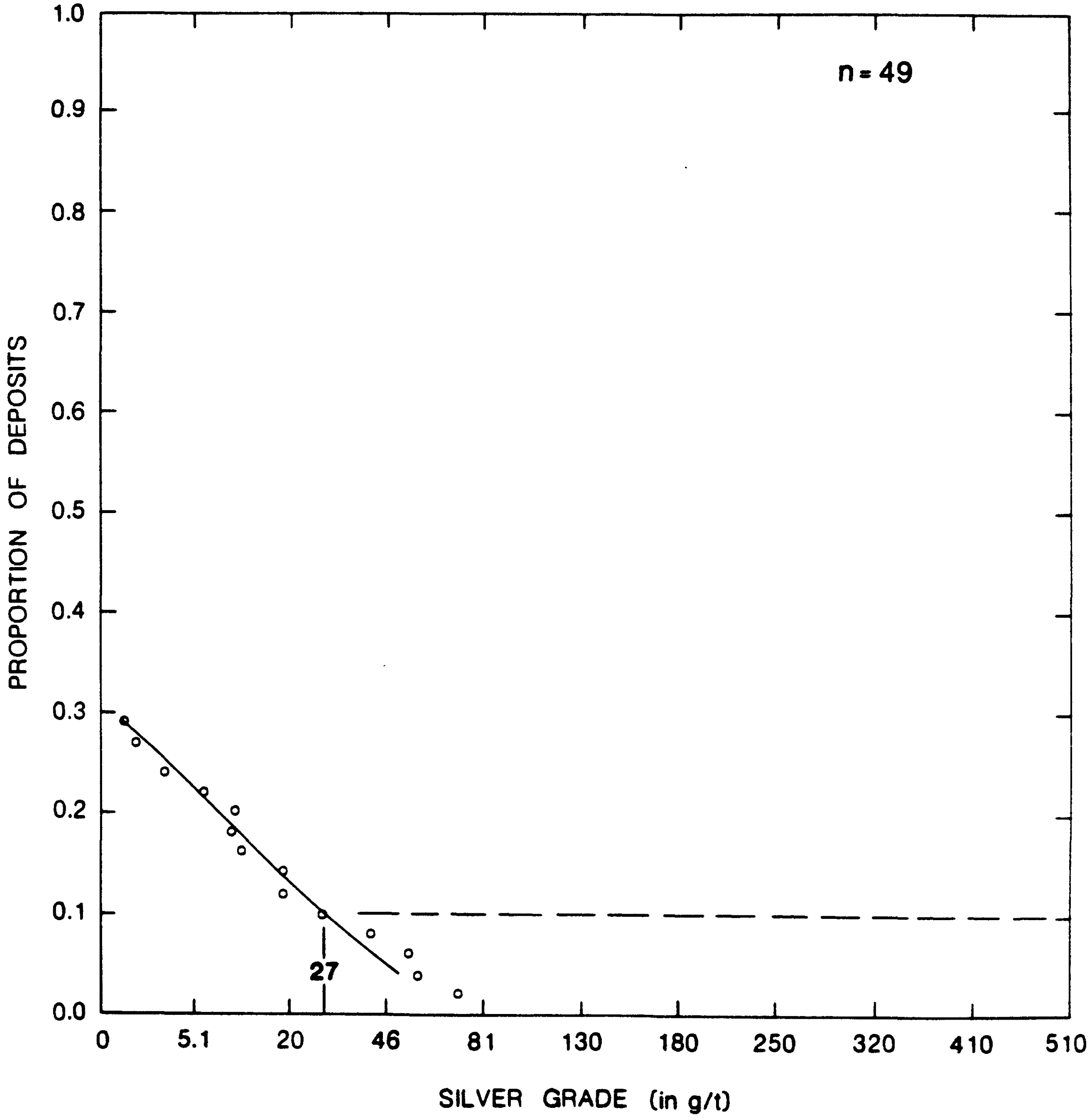

CYPRUS MASSIVE SULFIDE
n = 49
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.63
1.7
3.9
0.032
0.056
0.1
0.18
0.32
0.56
1.0
1.8
3.2
5.6
10.0
COPPER GRADE (IN PERCENT)


CYPRUS MASSIVE SULFIDE
n = 49
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2.1
0.00
0.25
1.00
2.3
4.00
6.3
9.0
12.0
16.0
20.0
25.0
ZINC GRADE (IN PERCENT)


CYPRUS MASSIVE SULFIDE
n = 49
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0
0.12
0.49
1.1
2.0
3.1
4.4
6.0
7.8
9.9
12.0
LEAD GRADE (IN PERCENT)


CYPRUS MASSIVE SULFIDE
n = 49
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1.9
0.0
0.16
0.64
1.4
2.6
4.0
5.8
7.8
10.0
13.0
16.0
GOLD GRADE (in g/t)

CYPRUS MASSIVE SULFIDE



DEPOSIT TYPE Felsic-intermediate massive sulfide MODEL NUMBER 3.2

AUTHOR D. A. Singer and D. L. Mosier

DATA REFERENCES Mosier and others, 1983

COMMENTS Includes all massive sulfides listed by Mosier and others (1983), except the Cyprus deposit type deposits and deposits with only mafic rocks 500 m above and below the deposit. Copper grade is correlated with tonnage at the one percent level (r = -0.17) and lead grade is correlated with zinc grade (r = 0.63).

DEPOSITS

Name	Country	Name	Country	Name	Country
Abeshiro (Sakura)	JAPN	Bailadores	VNZL	Bodennec	FRNC
Adak-Lindskold	SWDN	Balaklala	USCA	Boliden	SWDN
Afterthought	USCA	Bald Mountain	USME	Bomber	CNMN
Aijala	FNLD	Bandgan	PKTN	Bossmo	NRWY
Akarsen	TRKY	Barrett	USME	Britannia	CNBC
Akkoy	TRKY	Barrington Lake	CNMN	Bruce	USAZ
Akulla Vastra	SWDN	Barvallee-Mogador	CNQU	Brunswick No. 12	CNNB
Albert	CNQU	Baskoy	TRKY	Brunswick No. 6	CNNB
Aldermac	CNQU	Bathurst-Norsemines	CNNT	Buchans (LS-Roth)	CNNF
Allard River	CNQU	Bawdwin	BRMA	Buchans (McLean)	CNNF
Almagrera-Lapilla	SPAN	Beatson	USAK	Buchans (OB-Orient)	CNNF
Amulet A	CNQU	Bedford Hill	CNQU	Bully Hill-Rising St	USCA
Amulet F	CNQU	Bell Allard	CNQU	Bursi	NRWY
Anayatak-Cakmakkaya	TRKY	Bell Channel	CNQU	Campanario	SPAN
Anderson Lake	CNMN	Bidjovagge (A)	NRWY	Canadian Jamieson	CNON
Angelo	AUWA	Bidjovagge (B)	NRWY	Canoe Landing	CNNB
Anne	NRWY	Bidjovagge (C)	NRWY	Captain	CNNB
Antler	USAZ	Bidjovagge (D)	NRWY	Captains Flat	AUNS
Arctic	USAK	Big Bend	USCA	Caribou	CNNB
Armstrong (A)	CNNB	Big Hill	USME	Carpio	SPAN
As Safra	SAAR	Binghampton	USAZ	Castillo Buitron	SPAN
Asen-east	SWDN	Birch Lake	CNSK	Castro Verde	PORT
Asen-west	SWDN	Bjorkasen	NRWY	CC	CNBC
Ash Shizm	SAAR	Bjurfors	SWDN	Centennial	CNMN
Austin Brook	CNNB	Bjurliden	SWDN	Chestatee	USGA
Avoca	IRLD	Bjurtrask	SWDN	Chester	CNNB
Aznacollar	SPAN	Blue Ledge	USCA	Chisel Lake	CNMN
Bagacay	PLPN	Blue Moon	USCA	Clinton	CNQU

(continued on next page)

DEPOSIT TYPE Felsic-intermediate massive sulfide MODEL NUMBER 3.2

DEPOSITS (continued)

Name	Country	Name	Country	Name	Country
Conception	SPAN	Flexar	CNSK	Hood River	CNNT
Conigo	CNQU	Flin Flon	CNMN	Horne-Quemont	CNQU
Copper Crown	CNBC	Fonnfjell	NRWY	Hunter	CNQU
Copper George	AUWA	Fox	CNMN	HW	CNBC
Copper Hill	USCA	Freddie Wells	AUNS	Hyers Island	CNMN
Corbet	CNQU	Fretais	PORT	Iron Dyke	USOR
Coronation	CNSK	Frotet Lake	CNQU	Iron King	USAZ
Crandon	USWI	Fukazawa	JAPN	Iron Mountain	USCA
Cronin	CNBC	Furuhaugen	NRWY	Irsahan	TRKY
Cueva de la Mora	SPAN	Furutobe-Ainai	JAPN	Iso-Magusi-New Insco	CNQU
Cupra D'Estrie	CNQU	Gamle Folldal	NRWY	Israil	TRKY
Cuprus	CNMN	Garon Lake	CNQU	Iwami east	JAPN
Davis	USMS	Gaviao	PORT	Iwami west	JAPN
Deer Isle	USME	Gelvenakko	SWDN	Izok Lake	CNNT
Delbridge	CNQU	George Copper	CNBC	Jabal Sayid	SAAR
Despina	CNQU	Ghost Lake	CNMN	Jakobsbakken	NRWY
Detour	CNQU	Giken-Charlotta	NRWY	Jameland	CNON
Devils Elbow	CNNB	Girilambone	AUNS	Jerome	USAZ
Dickstone	CNMN	Gjersvik	NRWY	Joanne	CNMN
Don Jon	CNMN	Golden Grove	AUWA	Joliet	CNQU
Double Ed	CNBC	Goodenough	CNMN	Josselin	CNQU
Dumagami	CNQU	Gray Eagle	USCA	Joutel	CNQU
Dumont Bourlamque	CNQU	Green Coast	CNON	Kalkanli	TRKY
Dunraine	CNQU	Greens Creek	USAK	Kam Kotia	CNON
Duthie	CNBC	Gullbridge	CNNF	Kamikita (Kominosawa)	JAPN
Dyce Siding	CNMN	Hacan	TRKY	Kankberg	SWDN
Early Bird	USCA	Half Mile Lake (SG)	CNNB	Kelly-Desmond	CNQU
East Sullivan	CNQU	Halliwell	CNQU	Key Anacon	CNNB
Ego	CNON	Hanaoka (Doy-Tsut)	JAPN	Keystone	USCA
Embury Lake	CNMN	Hanaoka (Mats-Sha)	JAPN	Keystone-Union	USCA
Emerson	USME	Hanawa (Aket-Osak)	JAPN	Khans Creek	AUNS
Empire Le Tac	CNQU	Hanson Lake	CNSK	Khnaiguiyah	SAAR
Errington	CNON	Harkoy	TRKY	Kidd Creek	CNON
Estacao	PORT	Heath Steele (A-C-D)	CNNB	Killingdal	NRWY
Eulaminna	AUWA	Heath Steele (B)	CNNB	Kimheden	SWDN
Eustis	CNQU	Heath Steele (E-F)	CNNB	Kittelgruvan	SWDN
F Group	CNON	Heimtjonnho	NRWY	Kizilkaya	TRKY
Farewell Lake	CNMN	Hercules	AUTS	Koff Zone	CNMN
Filon Sur-Esperanza	SPAN	Herrerias	SPAN	Koprubasi	TRKY
Fjeldgruve	NRWY	Hersjo	NRWY	Kosaka (Motoyama)	JAPN
FL & DH	CNMN	High Lake	CNNT	Kosaka (Uch-Uwa)	JAPN
Flambeau	USWI	Hixbar	PLPN	Kostere	TRKY
Flat Landing	CNNB	Hoidal	NRWY	Kristineberg	SWDN

(continued on next page)

DEPOSIT TYPE Felsic-intermediate massive sulfide MODEL NUMBER 3.2

DEPOSITS (continued)

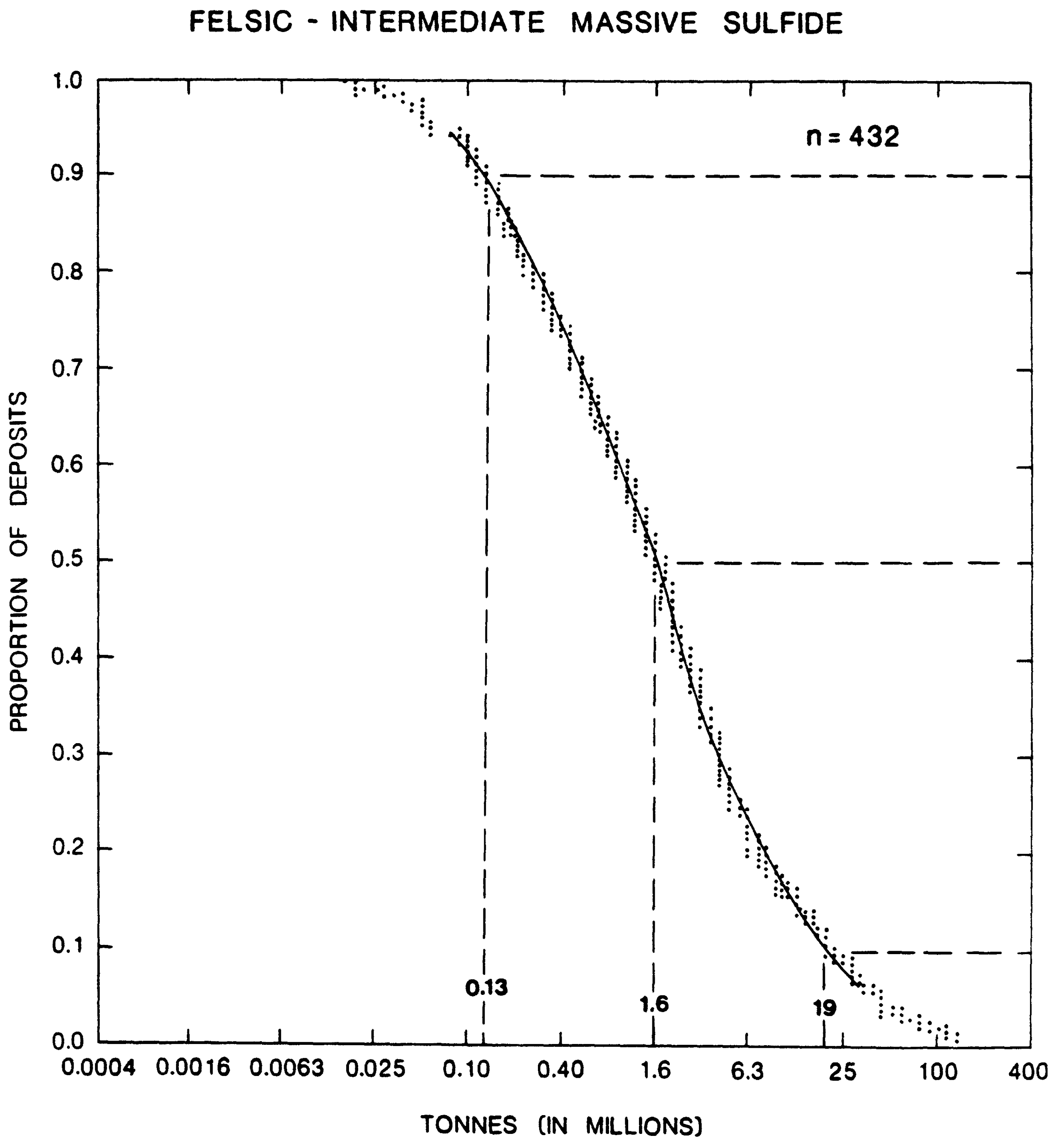
Name	Country	Name	Country	Name	Country
Kunitomi (3-4-6)	JAPN	Moleon Lake	CNQU	Pelican	USWI
Kunitomi (7-8)	JAPN	Monpas	CNQU	Penn	USCA
Kunitomi (1-5-1N-Fud)	JAPN	Mons Cupri	AUWA	Perrunal	SPAN
Kurosawa	JAPN	Mordey	CNON	Phelps Dodge	CNQU
Kutcho Creek	CNBC	Mos	NRWY	Pilleys Island	CNNF
Kutlular	TRKY	Moskogaissa	NRWY	Pine Bay	CNMN
Kuvarshan	TRKY	Moulton Hill	CNQU	Piray	PLPN
La Joya	SPAN	Mount Bulga	AUNS	Point Leamington	CNNF
La Torrera	SPAN	Mount Chalmers	AUQL	Poirier	CNQU
La Zarza	SPAN	Mount Lyell	AUTS	Port Aux Moines	FRNC
Lagunazo	SPAN	Mount Morgan	AUQL	Pot Lake	CNMN
Lahanos	TRKY	Mount Mulcahy	AUWA	Price	CNBC
Lake Dufault	CNQU	Murgul	TRKY	Pyhasalmi	FNLD
Lancha	SPAN	Murray Brook	CNNB	Que River	AUTS
Langdal	SWDN	Myra Falls-Lynx	CNBC	Quebec Manitou	CNQU
Langsele	SWDN	Nasliden	SWDN	Radiore E	CNQU
Lenora-Twin J	CNBC	Nepisiguit	CNNB	Rail Lake	CNMN
Levi	SWDN	New Bay Pond	CNNF	Rakkejaur	SWDN
Lillebo	NRWY	New Hosco	CNQU	Rambler-Ming	CNNF
Lost Lake	CNMN	Newton	USCA	Ramsey	CNSK
Lousal	PORT	Nine Mile Brook	CNNB	Ravliden	SWDN
Louvem	CNQU	Nordre Gjetryggen	NRWY	Ravlidmyran	SWDN
Lyndhurst	CNQU	Norita	CNQU	Rosebery-Read	AUTS
Lynx	CNQU	Normetal	CNQU	Red Wing	CNBC
Lyon Lake	CNON	North Boundary	CNNB	Reed Lake	CNMN
MacBride Lake	CNMN	North Keystone	USCA	Renstrom	SWDN
Madenkoy	TRKY	North Star	CNMN	Rieppe	NRWY
Malaiba	PLPN	Northair	CNBC	Rio Tinto	SPAN
Mamie	CNBC	Nuqrah	SAAR	Rocky Turn	CNNB
Mammoth	USCA	Old Waite	CNQU	Rod	CNMN
Mandy	CNMN	Orange Point	USAK	Rodhammeren	NRWY
Mankayan	PLPN	Orchan	CNQU	Rodkleiv	NRWY
Marcos	PLPN	Orijarvi	FNLD	Romanera	SPAN
Mattabi	CNON	Osbourne Lake	CNMN	Romerito	SPAN
Mattagami Lake	CNQU	Oshio	JAPN	Rostvangen	NRWY
McMaster	CNNB	Ostra Hogkulla	SWDN	Rudtjebacken	SWDN
Metsamonttu	FNLD	Pabineau River	CNNB	Ruttan	CNMN
Mic Mac	CNQU	Paronen	FNLD	Sabetjok	NRWY
Millenbach	CNQU	Parys Mountain	GRBR	Sagmo	NRWY
Mobrun	CNQU	Pasuquin	PLPN	Sain Bel	FRNC
Mofjell	NRWY	Pater	CNON	San Antonio	SPAN
Moinho	PORT	Paymogo	SPAN	San Domingos	PORT
Mokoman Lake	CNSK	Pecos	USNM	San Guillermo-Sierra	SPAN

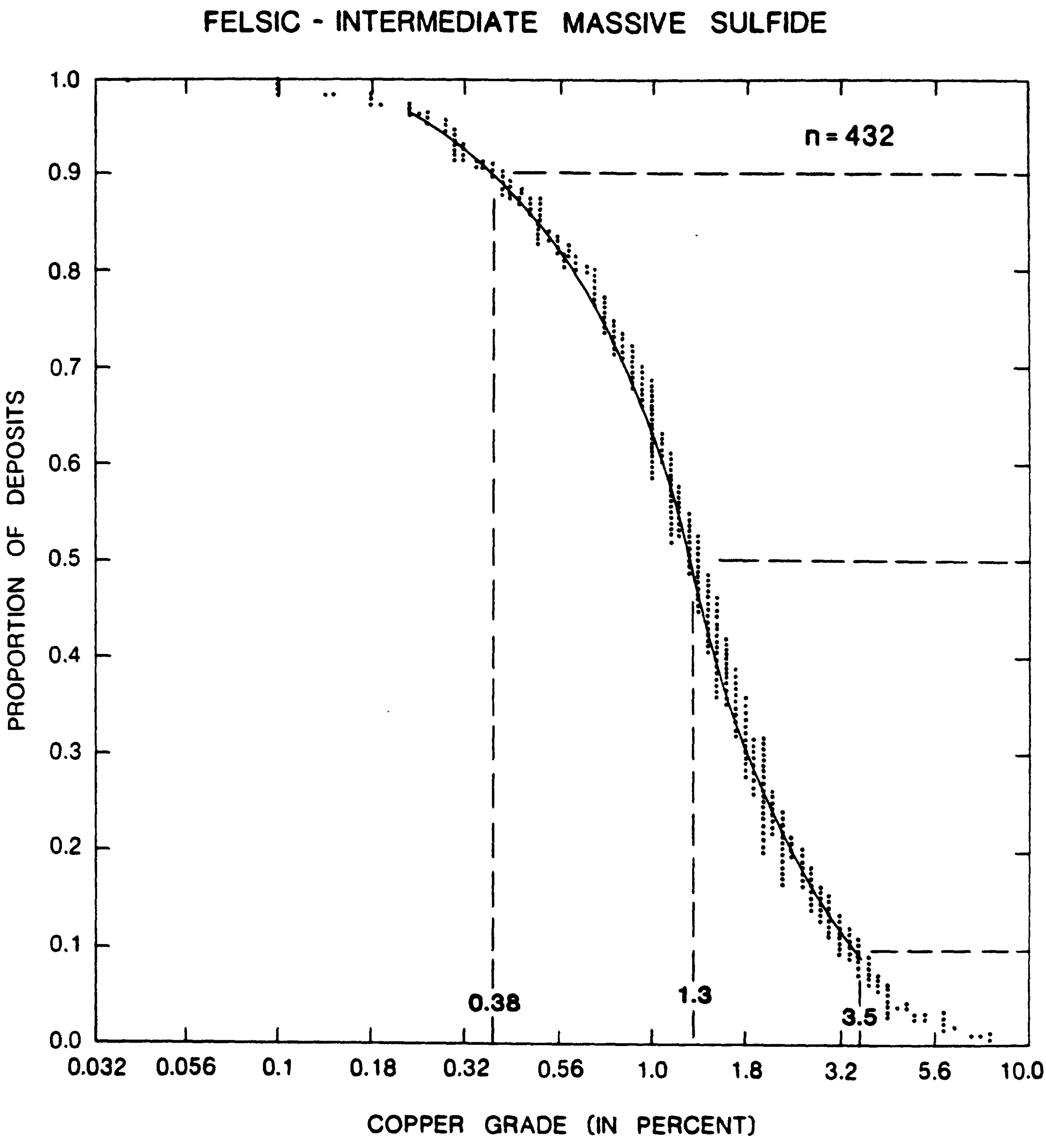
(continued on next page)

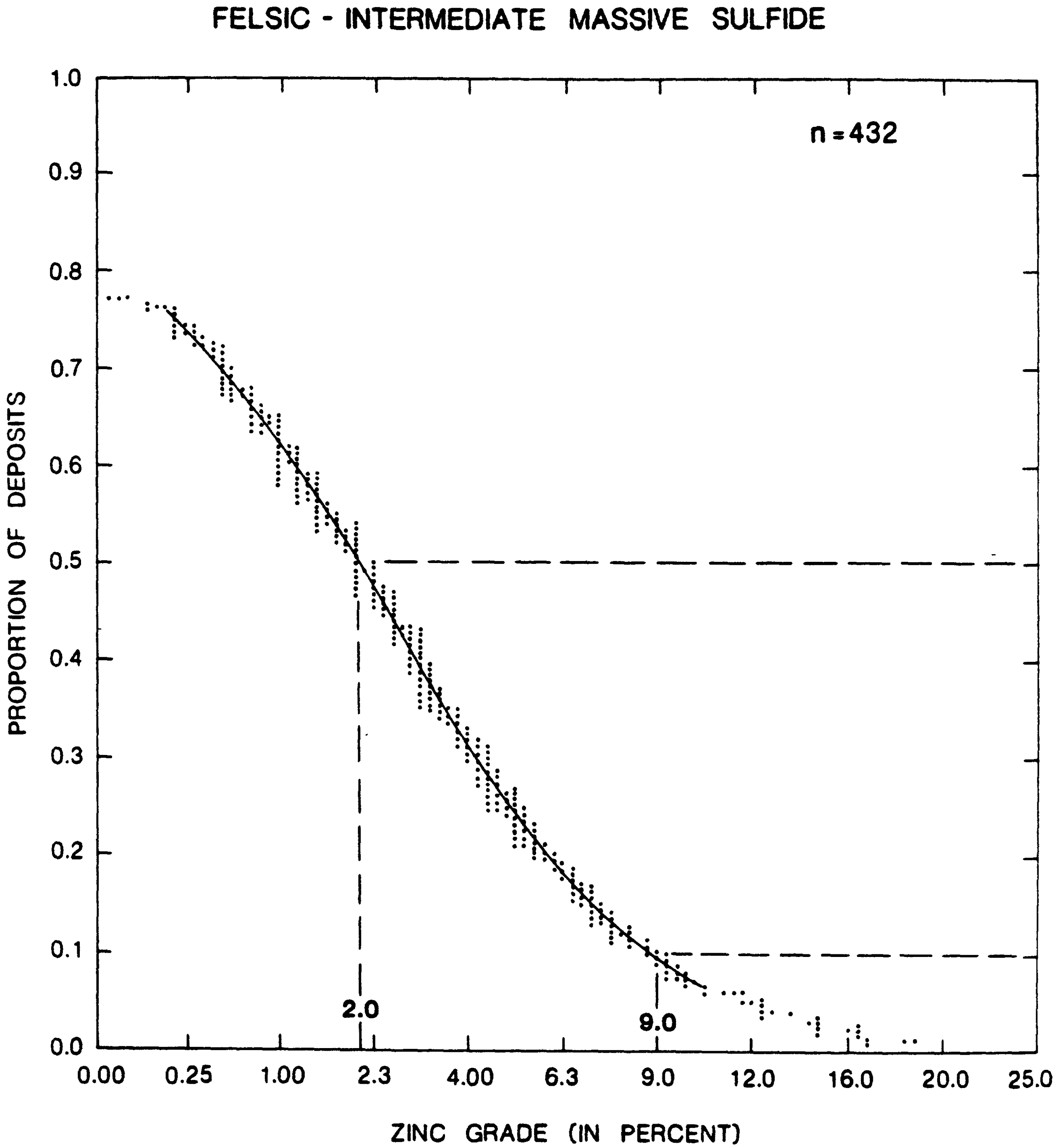
DEPOSIT TYPE Felsic-intermediate massive sulfide MODEL NUMBER 3.2

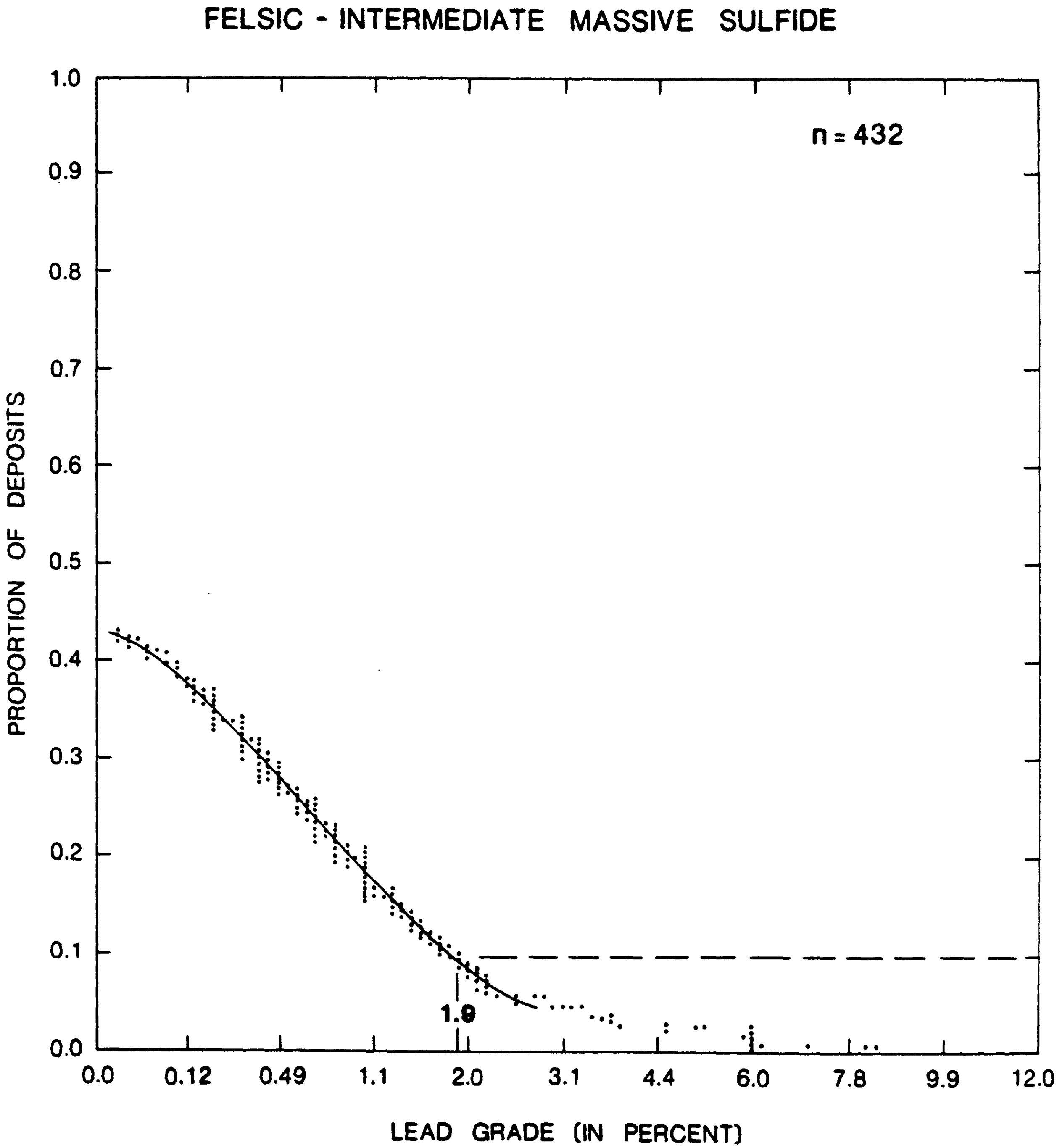
DEPOSITS (continued)

Name	Country	Name	Country
San Mateo	PLPN	Third Portage	CNNB
San Pedro	SPAN	Tjokkola	SWDN
San Platon	SPAN	Tomogonops	CNNB
San Telmo	SPAN	Trinity	CNQU
Santa Rosa	SPAN	Trout Bay	CNON
Schist Lake	CNMN	Tsuchihata (Hatabira)	JAPN
Selco-Scott	CNQU	Tsuchihata (Honniozaw)	JAPN
Shasta King	USCA	Tsuchihata (Shiratsuc)	JAPN
Shunsby	CNON	Tsuchihata (Uenono-Ok)	JAPN
Sierrecilla	SPAN	Tsuchihata (Washinosu)	JAPN
Silver Queen	CNBC	Tulk's Pond	CNNF
Skaide	NRWY	Tulsequah	CNBC
Solbec	CNQU	Tunca	TRKY
Sotiel	SPAN	Tverrfjellet	NRWY
Sourdough Bay	CNMN	Uchi	CNON
South Dufault	CNQU	Udden	SWDN
South Rusty Hill	CNQU	Undu	FIJI
Spenceville	USCA	Vaddas	NRWY
Spruce Point	CNMN	Vamp	CNMN
Stall Lake	CNMN	Vauze	CNQU
Stekenjokk	SWDN	Vermillion	CNON
Stirling	CNNS	Vigsnes	NRWY
Stowell	USCA	Viscaria	SWDN
Stralak	CNON	Waden Bay	CNSK
Stratmat	CNNB	Waite East	CNQU
Sturgeon Lake	CNON	Wallaroo	AUWA
Suffield	CNQU	Wedge	CNNB
Sulat	PLPN	Weedon	CNQU
Sun	CNMN	Weiss	TRKY
Sunshine	CNBC	West McDonald	CNQU
Susu Lake	CNNT	Westarm	CNMN
Sutro	USCA	Whim Creek	AUWA
Tache Lake	CNQU	White Lake	CNMN
Taisho (Nishimata)	JAPN	Whundo	AUWA
Takijug Lake	CNNT	Wildcat	PLPN
Taknar I	IRAN	Willecho	CNON
Taknar II	IRAN	Wim	CNMN
Tapley	USME	Windy	CNBC
Tashiro	JAPN	Woodlawn	AUQL
Taslica	TRKY	Yava	CNNT
Teahan	CNNB	Yoichi	JAPN
Tedi	CNBC	Yokota (Motoyama-Hama)	JAPN
Terra Nova	CNNF	Yoshino (Hisaka)	JAPN
Teutonic Bore	AUWA	Yoshino (Main)	JAPN
Texas	CNNB	Z	CNMN

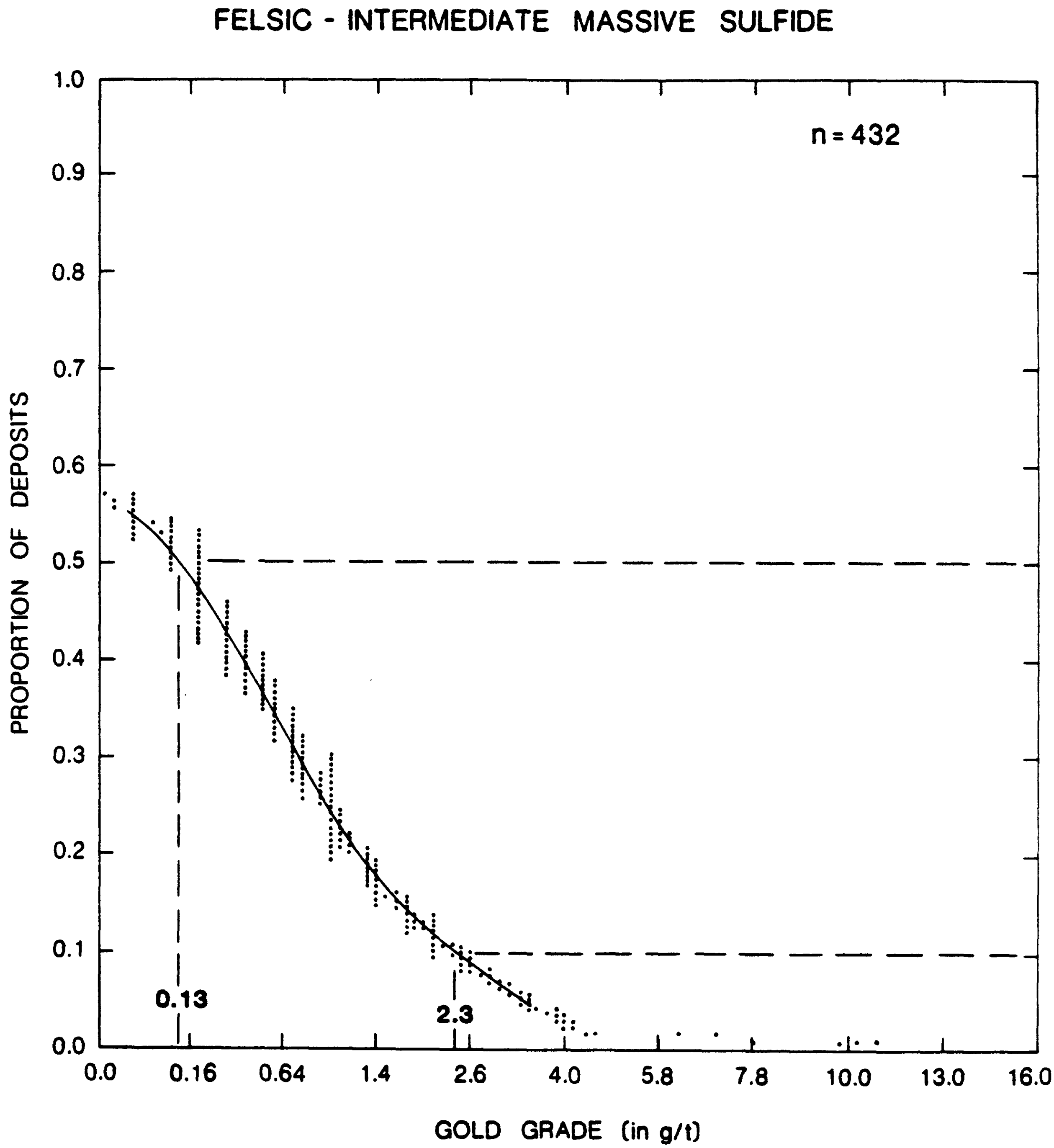

FELSIC - INTERMEDIATE MASSIVE SULFIDE
n = 432
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.13
1.6
19
0.0004
0.0016
0.0063
0.025
0.10
0.40
1.6
6.3
25
100
400
TONNES (IN MILLIONS)

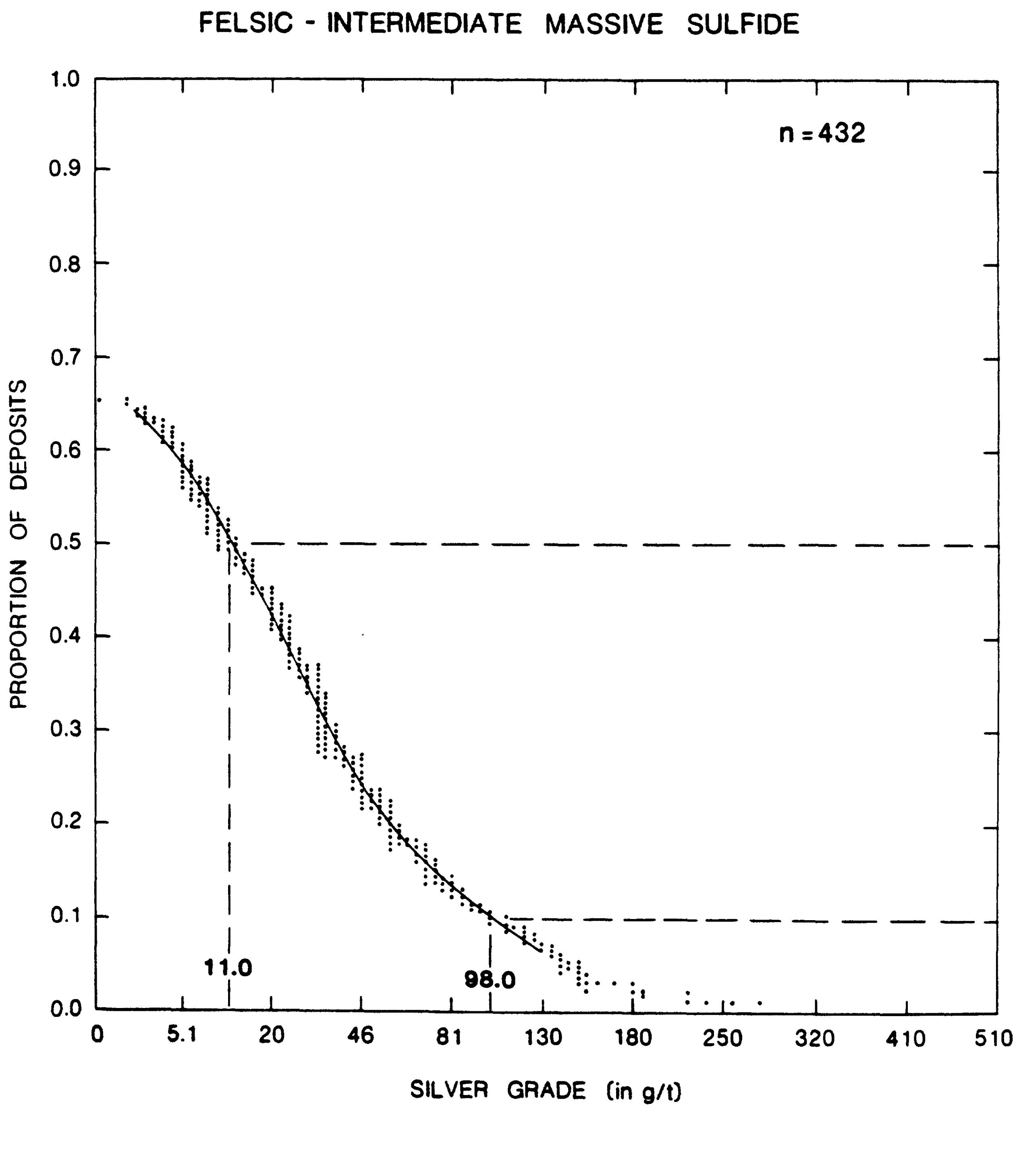

FELSIC - INTERMEDIATE MASSIVE SULFIDE
n=432
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.38
1.3
3.5
0.032
0.056
0.1
0.18
0.32
0.56
1.0
1.8
3.2
5.6
10.0
COPPER GRADE (IN PERCENT)


FELSIC - INTERMEDIATE MASSIVE SULFIDE
n = 432
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2.0
9.0
0.00
0.25
1.00
2.3
4.00
6.3
9.0
12.0
16.0
20.0
25.0
ZINC GRADE (IN PERCENT)



FELSIC - INTERMEDIATE MASSIVE SULFIDE
n = 432
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1.9
0.0
0.12
0.49
1.1
2.0
3.1
4.4
6.0
7.8
9.9
12.0
LEAD GRADE (IN PERCENT)


FELSIC - INTERMEDIATE MASSIVE SULFIDE
n = 432
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.13
2.3
0.0
0.16
0.64
1.4
2.6
4.0
5.8
7.8
10.0
13.0
16.0
GOLD GRADE (in g/t)


FELSIC - INTERMEDIATE MASSIVE SULFIDE
n = 432
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
11.0
98.0
0
5.1
20
46
81
130
180
250
320
410
510
SILVER GRADE (in g/t)

DEPOSIT TYPE Volcanogenic gold MODEL NUMBER 3.3

AUTHOR D. L. Mosier

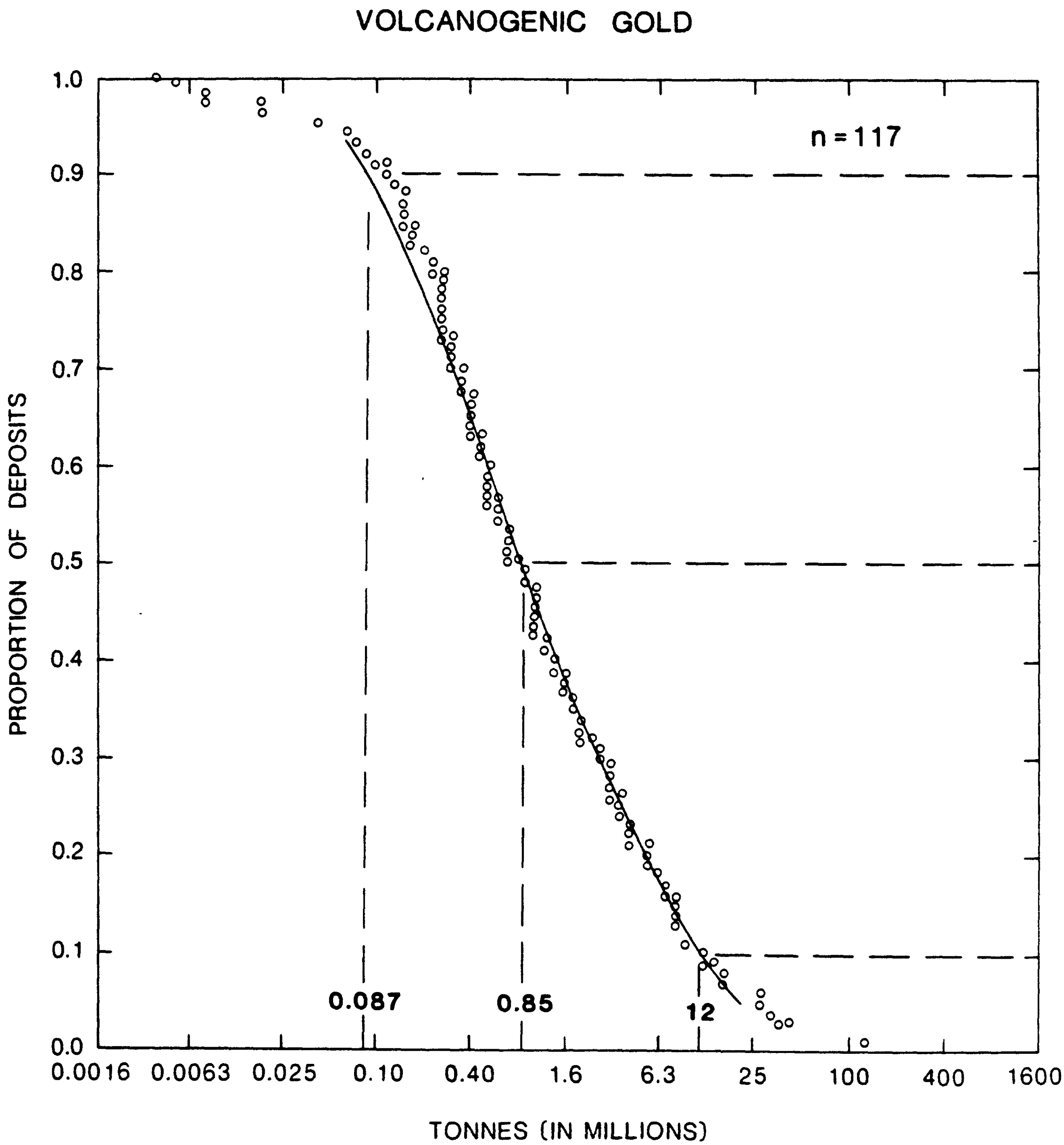
COMMENTS Deposits were combined when they occur within one mile of each other.

DEPOSITS

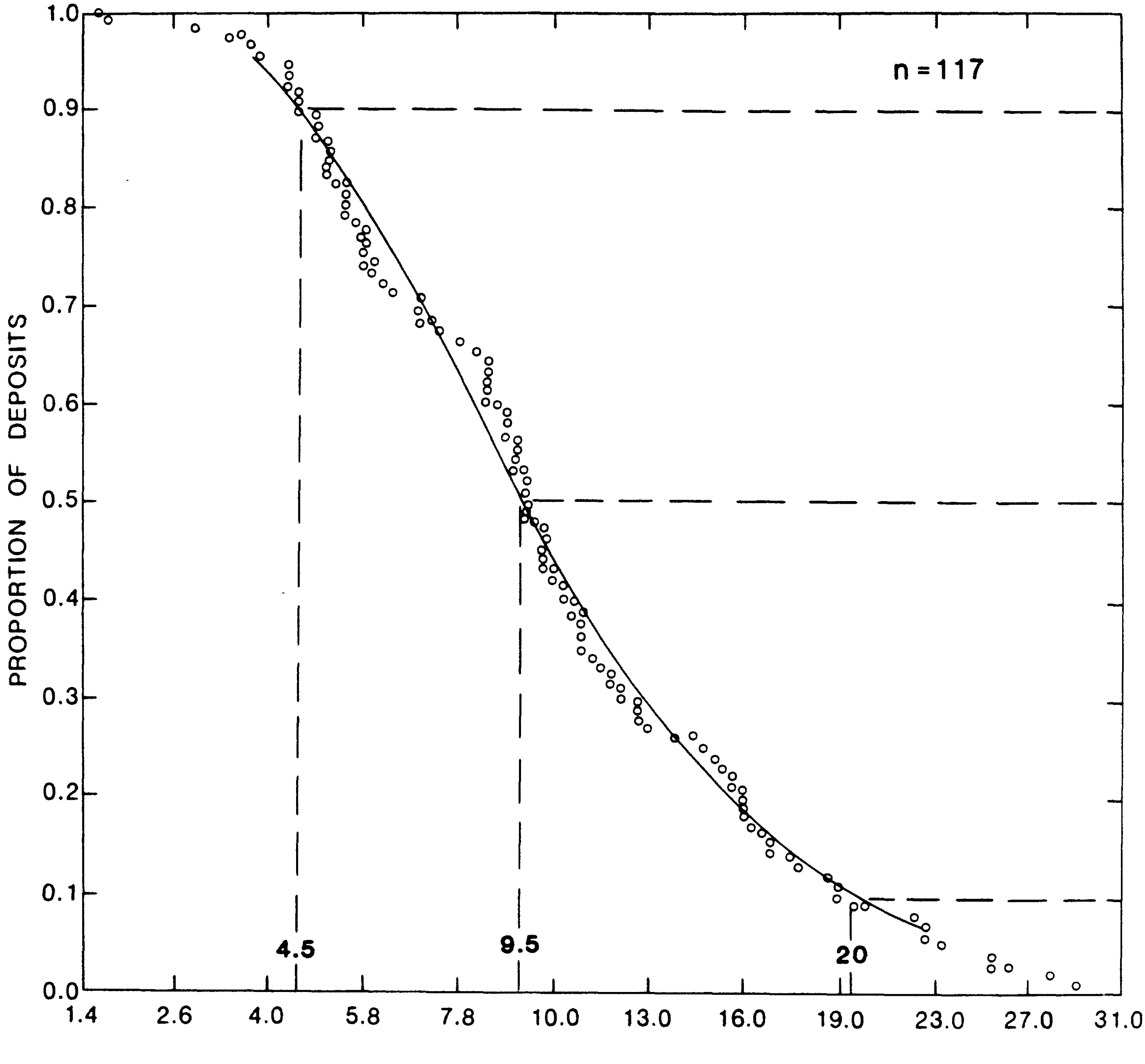
Name	Country	Name	Country
Agassiz	CNMN	Geita	TNZN
Albino	CNON	Gimlet-Slippery	AUWA
Ankerite-Aunor-Delnite	CNON	Gladstome-Sand Queen	AUWA
Arrowhead	CNQU	God's Lake	CNMN
Ashley	CNON	Gold Eagle-McKenzie	CNON
Bankfield-Tombill	CNON	Gold Hawk	CNON
Barbara-Surprise	AUWA	Gold Hill	CNON
Barber-Larder	CNON	Golden Ridge	AUWA
Barberton	SAFR	Gongo Socco	BRZL
Barry Hollinger	CNON	Gurney	CNMN
Bellevue	AUWA	Hard Rock-McLeod-Cockshutt	CNON
Bidgood-Moffatt-Hall	CNON	Hasaga-Howey	CNON
Big Bell	AUWA	Hollinger and others	CNON
Black Range-Oroya	AUWA	Homestake	USSD
Bob	ZIMB	Hutti	INDA
Bonnievale	AUWA	Ida H.	AUWA
Bouscadillac and others	CNON	Island Lake	CNMN
Broulan and others	CNON	Jason	CNON
Buffalo Red Lake	CNON	Jerome	CNON
Burbanks	AUWA	Kerr Addison	CNON
Calder-Bousquet	CNQU	Kiabakari	TNZN
Campbell Red Lake-Dickenson	CNON	Kilo-Moto	CNGO
Carshaw-Tommy Burns	CNON	Kolar	INDA
Cathroy Larder	CNON	Laguerre	CNON
Central Manitoba	CNMN	Lancefield	AUWA
Central Patricia	CNON	Lapa Cadillac	CNQU
Cheminis-Fernland-Omega	CNON	Leitch-Sand River	CNON
Chesterville	CNON	Lingman	CNON
Connemara	ZIMB	Little Long Lac	CNON
Coolgardie	AUWA	Madsen	CNON
Copperhead	AUWA	Magnet Cons.	CNON
Cosmopolitan	AUWA	Marble Bar	AUWA
Cullaton Lake	CNNT	Martin-Bird	CNON
Davidson	CNON	Matachewan Cons. & others	CNON
Day Dawn-Main Line	AUWA	Matona-Stairs	CNON
De Santis	CNON	McFinley	CNON
Dome-Paymaster-Preston	CNON	McMarmac	CNON
Edna May	AUWA	McWatters	CNQU
Emu-Great Eastern	AUWA	Menzies	AUWA
Fraser's	AUWA	Minto-Tyranite	CNON
Fuller-Tisdale	CNON	Morris-Kirkland	CNON

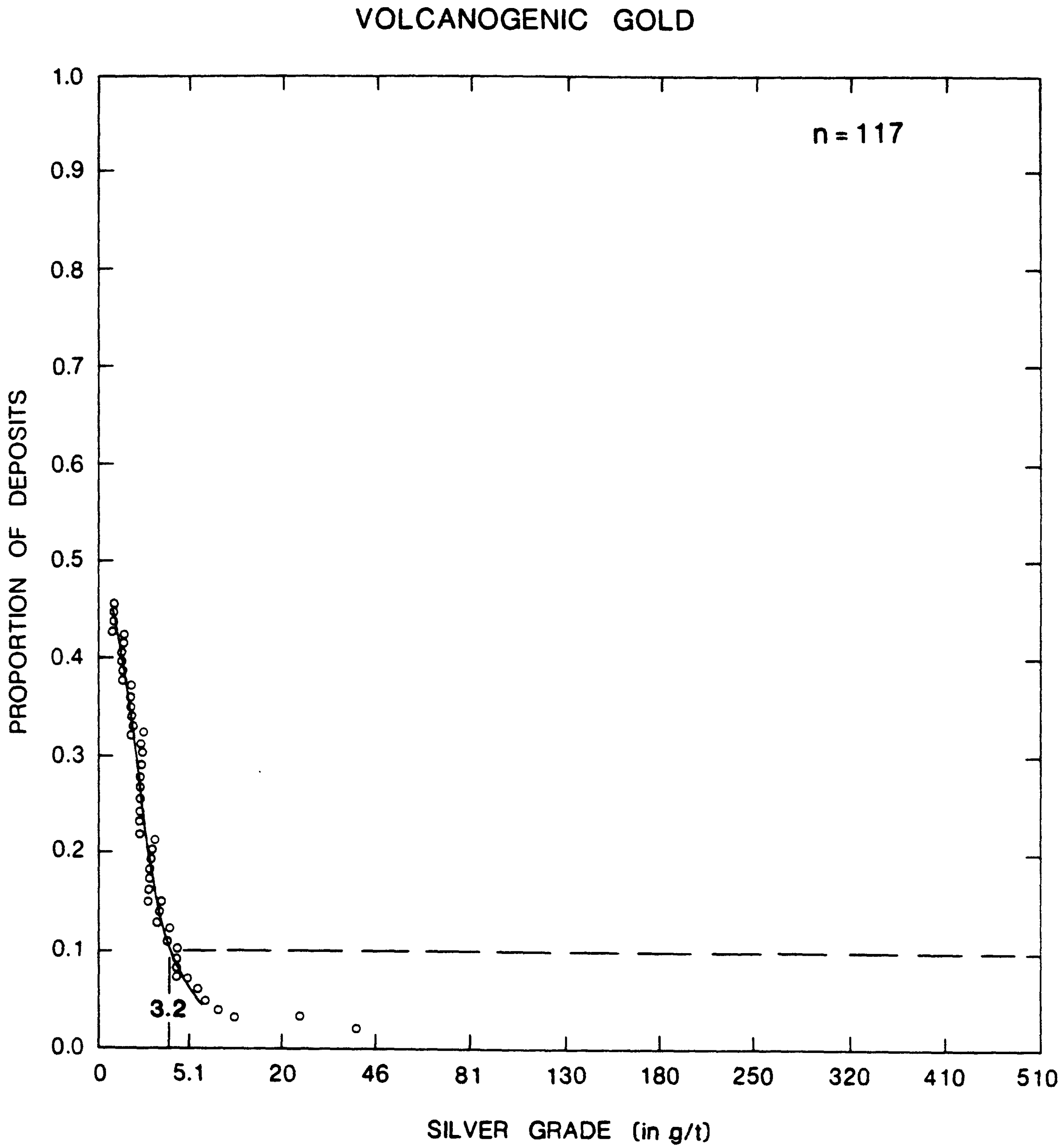
DEPOSITS (Continued)

Name	Country
Morro Velho	BRZL
Mt. Magnet	AUWA
Mt. Morgans	AUWA
Naybob	CNON
Nobles Nob	AUWA
Norseman-Dundas	AUWA
Orpit	CNON
Paddy's Flat	AUWA
Palmer's Find	AUWA
Passagem	BRZL
Pickle Crow	CNON
Queenston	CNON
Raposos	BRZL
Red Crest	CNON
Red Lake Gold Shore	CNON
Ross	CNON
Rouyn Merger	CNQU
Sanshaw	CNON
Shamva-Cymric Gp.	ZIMB
Son of Gwalia	AUWA
Stadacona	CNQU
Starratt-Olsen	CNON
Talmora Longlac	CNON
Thompson Bousquet	CNQU
Timoni	AUWA
Triton	AUWA
Uchi	CNON
Upper Beaver	CNON
Upper Canada	CNON
Wasa Lake	CNQU
White Feather	AUWA
Wilmar and others	CNON
Wiluna-Moonlight	AUWA
Youanmi	AUWA


VOLCANOGENIC GOLD
n = 117
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.087
0.85
12
0.0016 0.0063 0.025 0.10 0.40 1.6 6.3 25 100 400 1600
TONNES (IN MILLIONS)

VOLCANOGENIC GOLD




VOLCANOGENIC GOLD
n = 117
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
3.2
0
5.1
20
46
81
130
180
250
320
410
510
SILVER GRADE (in g/t)

DEPOSIT TYPE Komatiitic nickel MODEL NUMBER 3.4

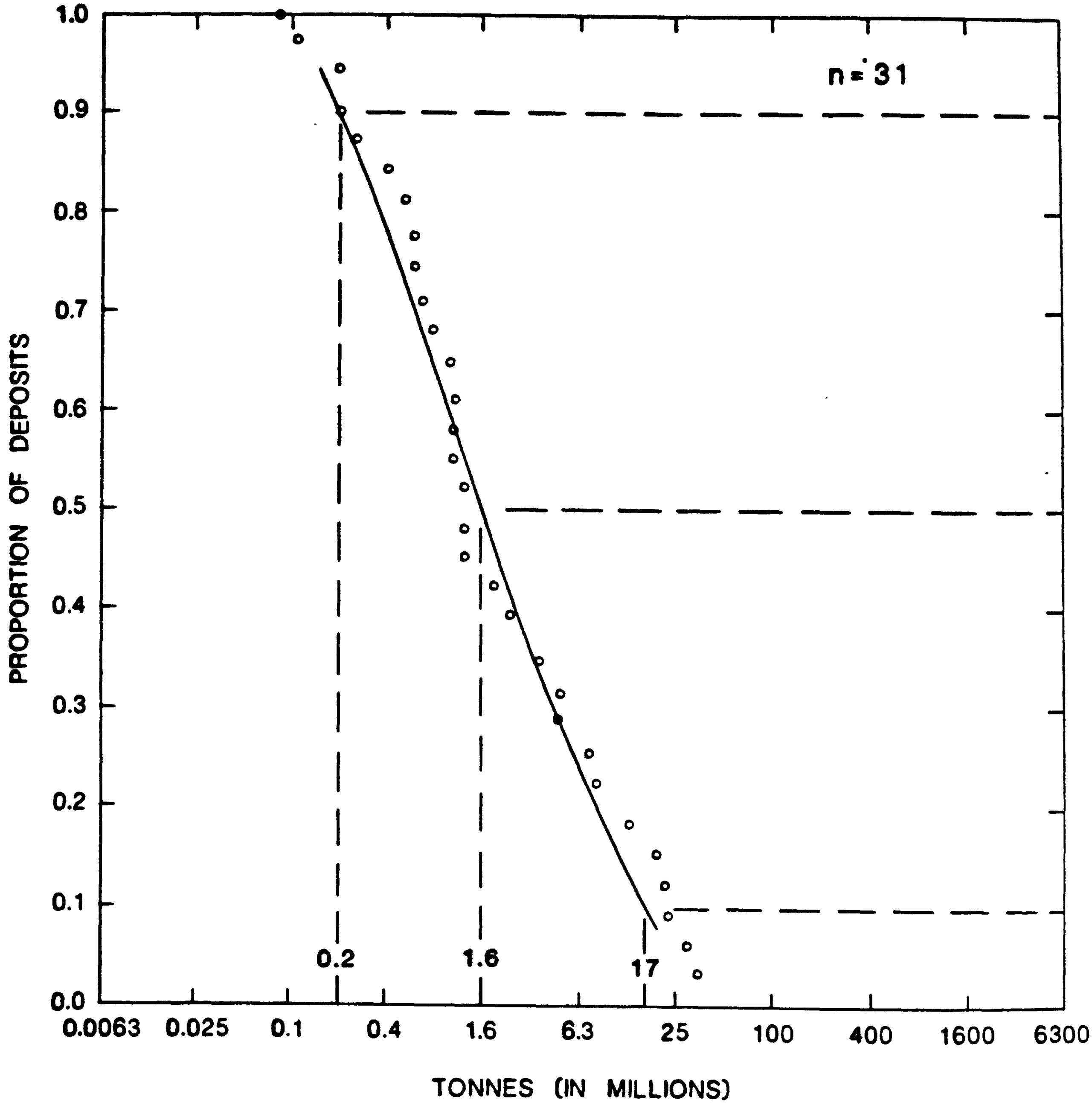
AUTHOR D. A. Singer, N. J Page, and W. D. Menzie

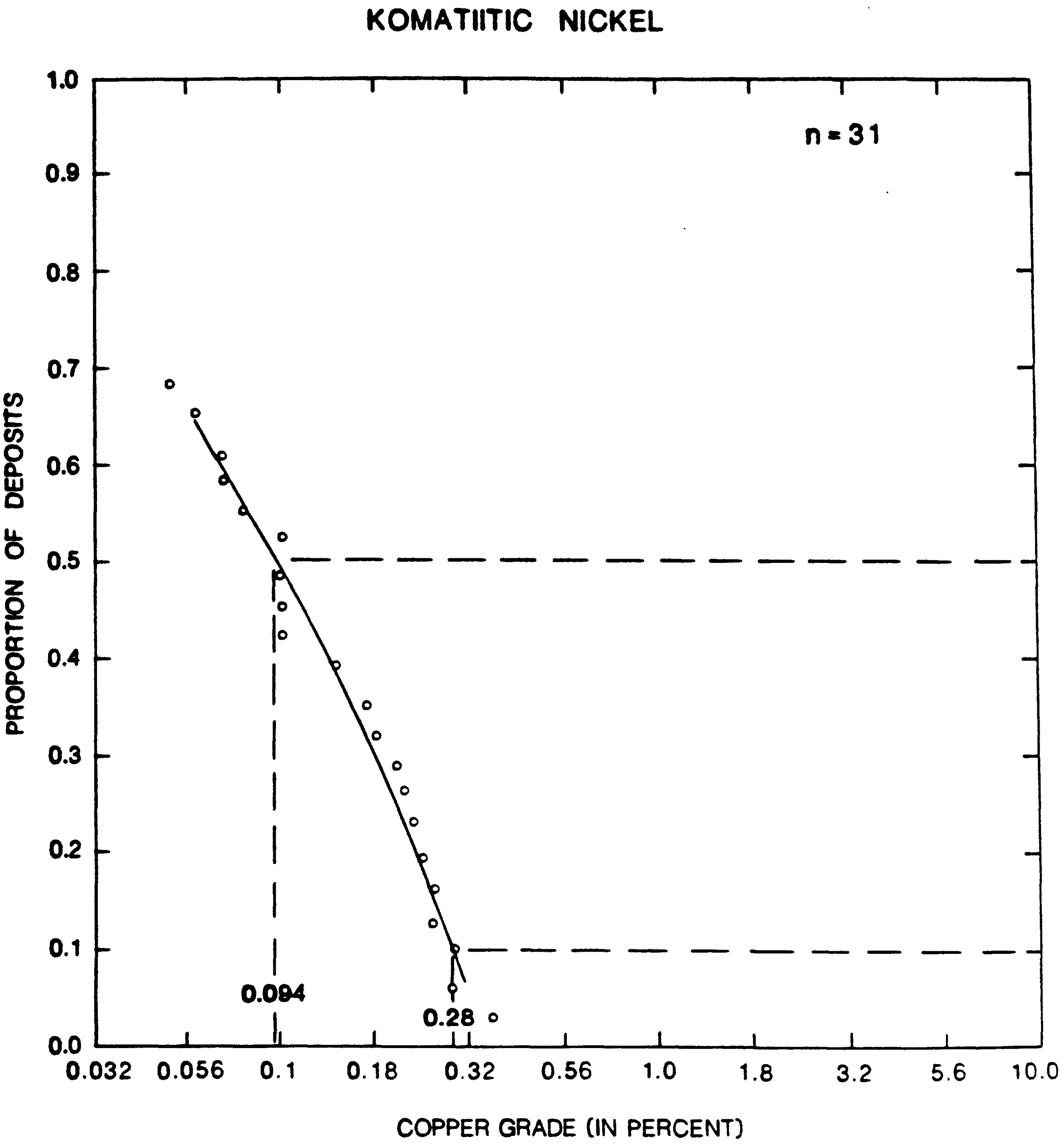
COMMENTS Nickel grade is correlated with tonnage (r=-0.47) and with copper grade (r=0.59).

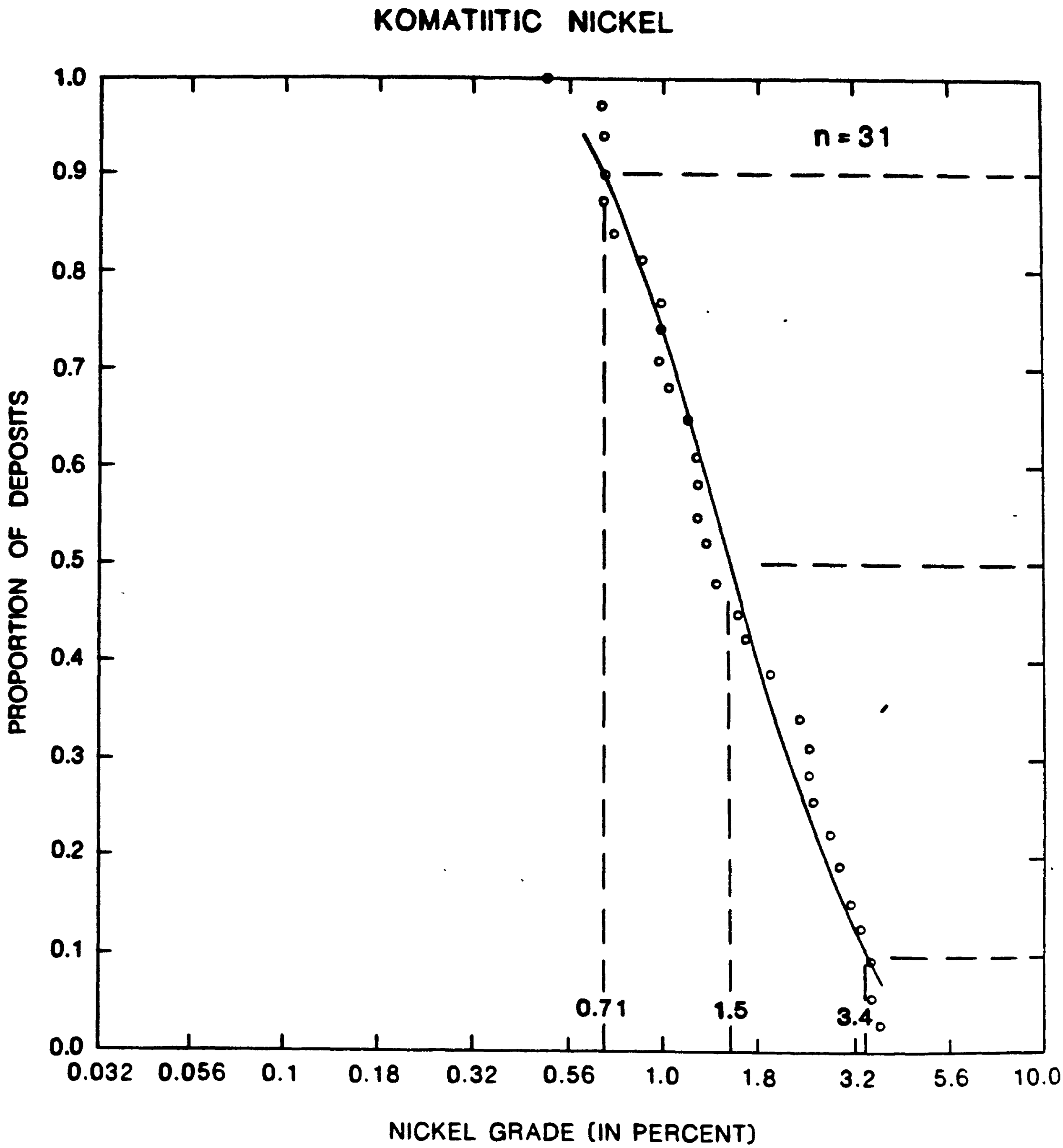
DEPOSITS

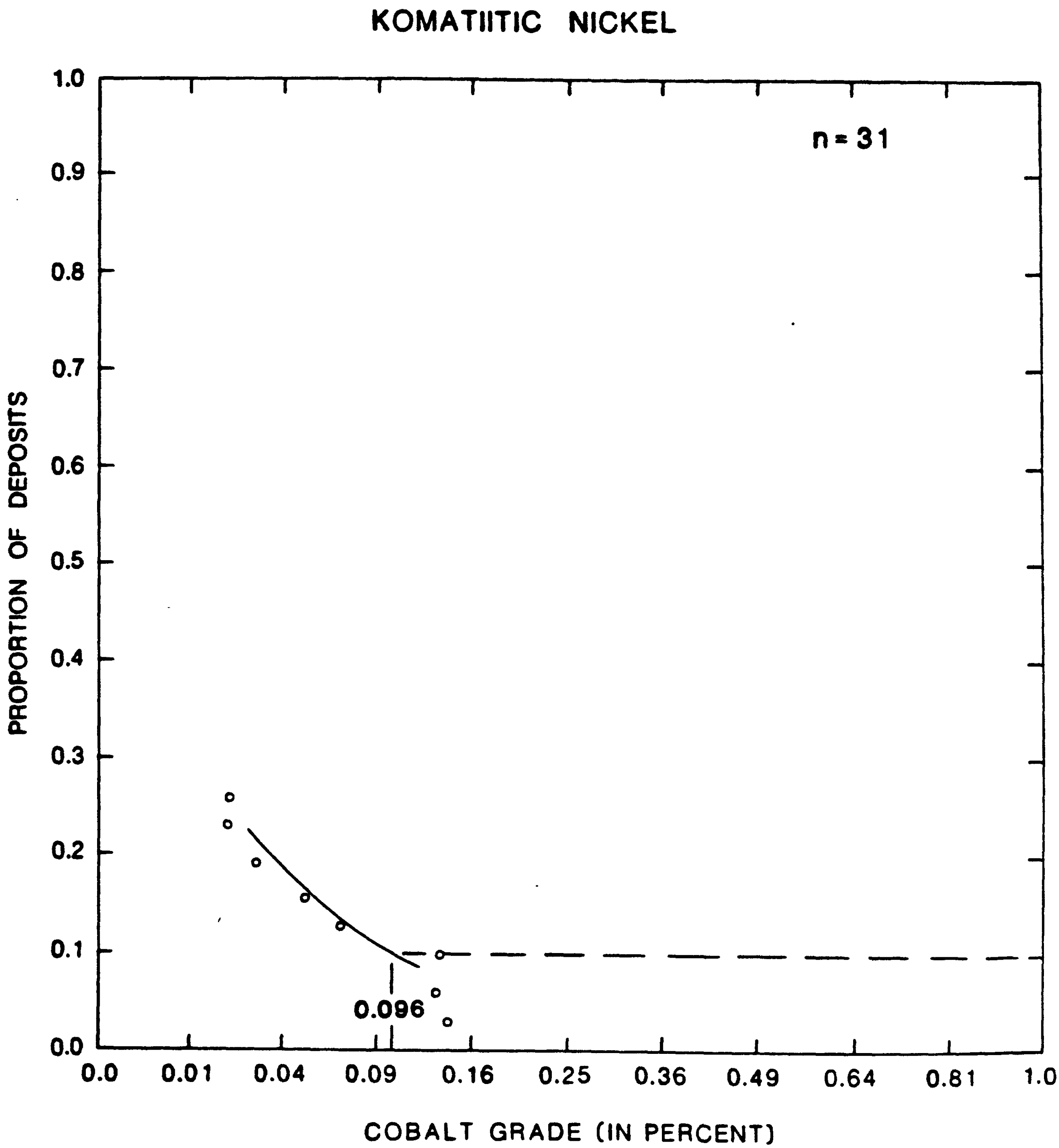
Name	Country
Carnilya E.	AUWA
Carnilya Hill	AUWA
Damba	ZIMB
Epoch	ZIMB
E. Scotia	AUWA
Hitura	FNLD
Huntersroad	ZIMB
Kambalda	AUWA
Kotalahti	FNLD
Langmuir 1	CNON
Langmuir 2	CNON
Marbridge	CNQU
McWatters	CNON
Miriam	AUWA
Mt. Edwards	AUWA
Mt. Windarra	AUWA
Munda	AUWA
Nepean	AUWA
Perserverance	ZIMB
Rankin Inlet	CNNT
Redross	AUWA
Scotia	AUWA
Selukwe	ZIMB
Shangani	ZIMB
Sothman Twp.	CNON
Spargonville	AUWA
S. Windarra	AUWA
Textmont	CNON
Trojan	ZIMB
Wannaway	AUWA
Wigie 3	AUWA

KOMATIITIC NICKEL

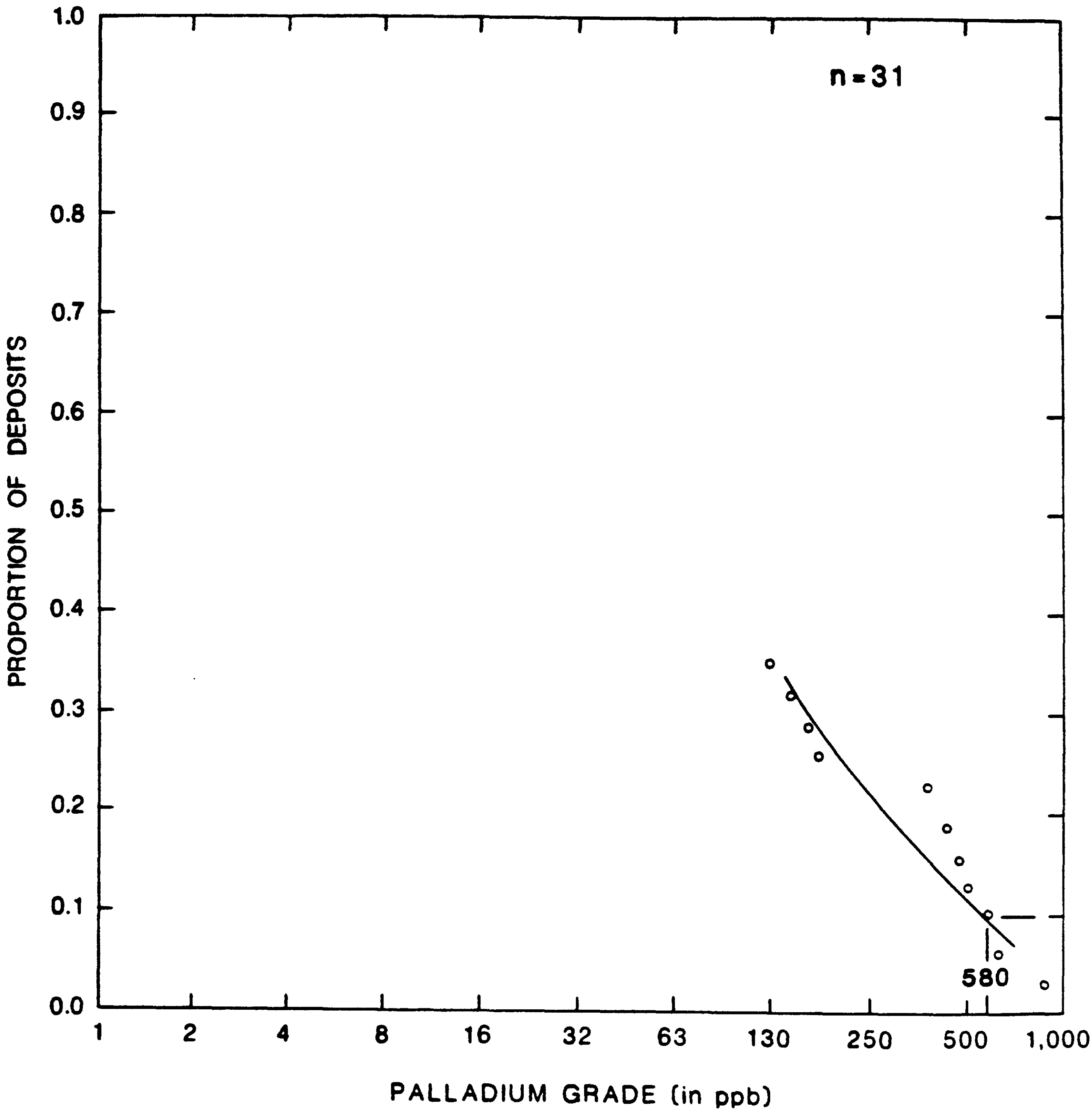


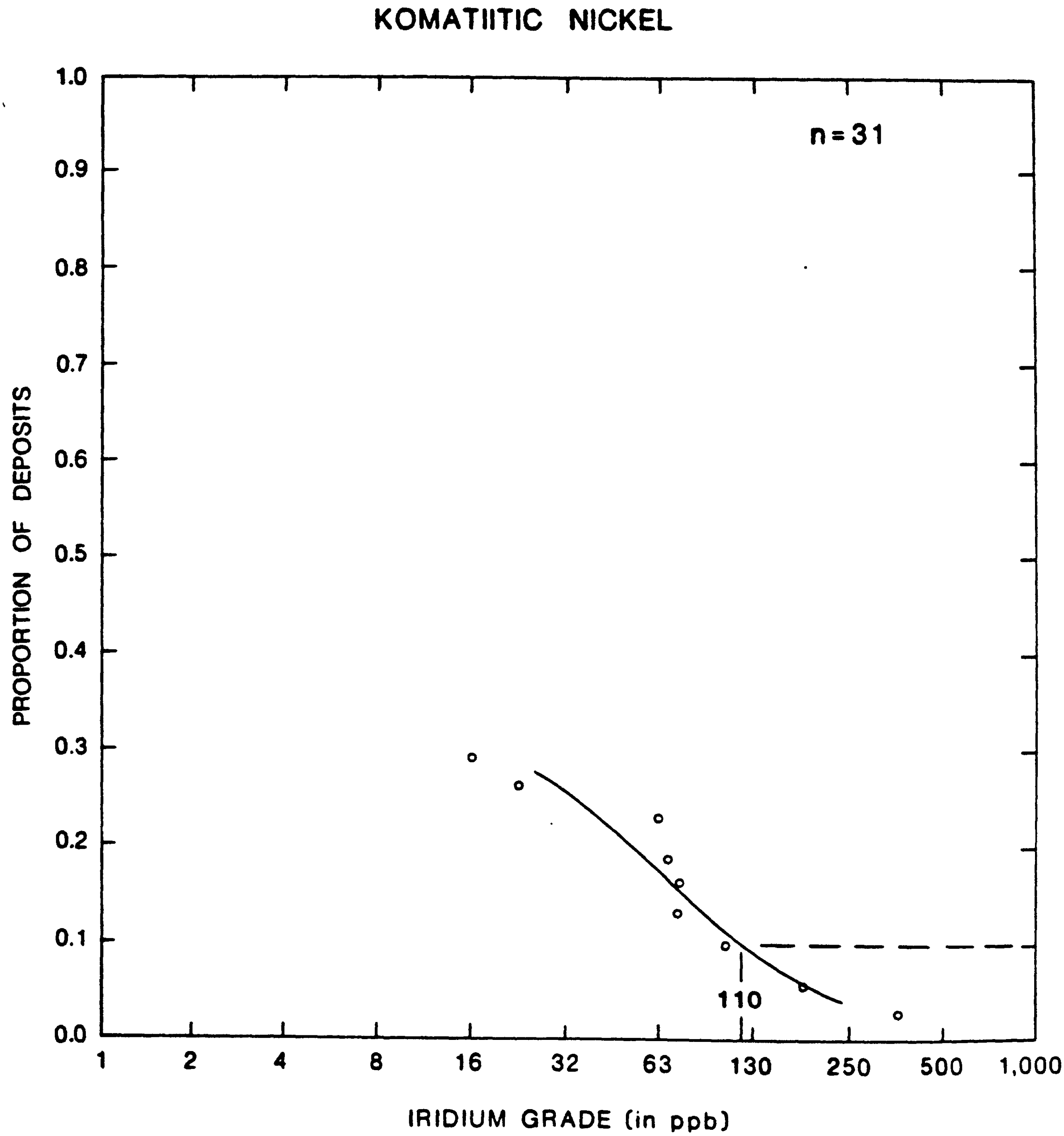

KOMATIITIC NICKEL
n = 31
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.094
0.28
0.032
0.056
0.1
0.18
0.32
0.56
1.0
1.8
3.2
5.6
10.0
COPPER GRADE (IN PERCENT)

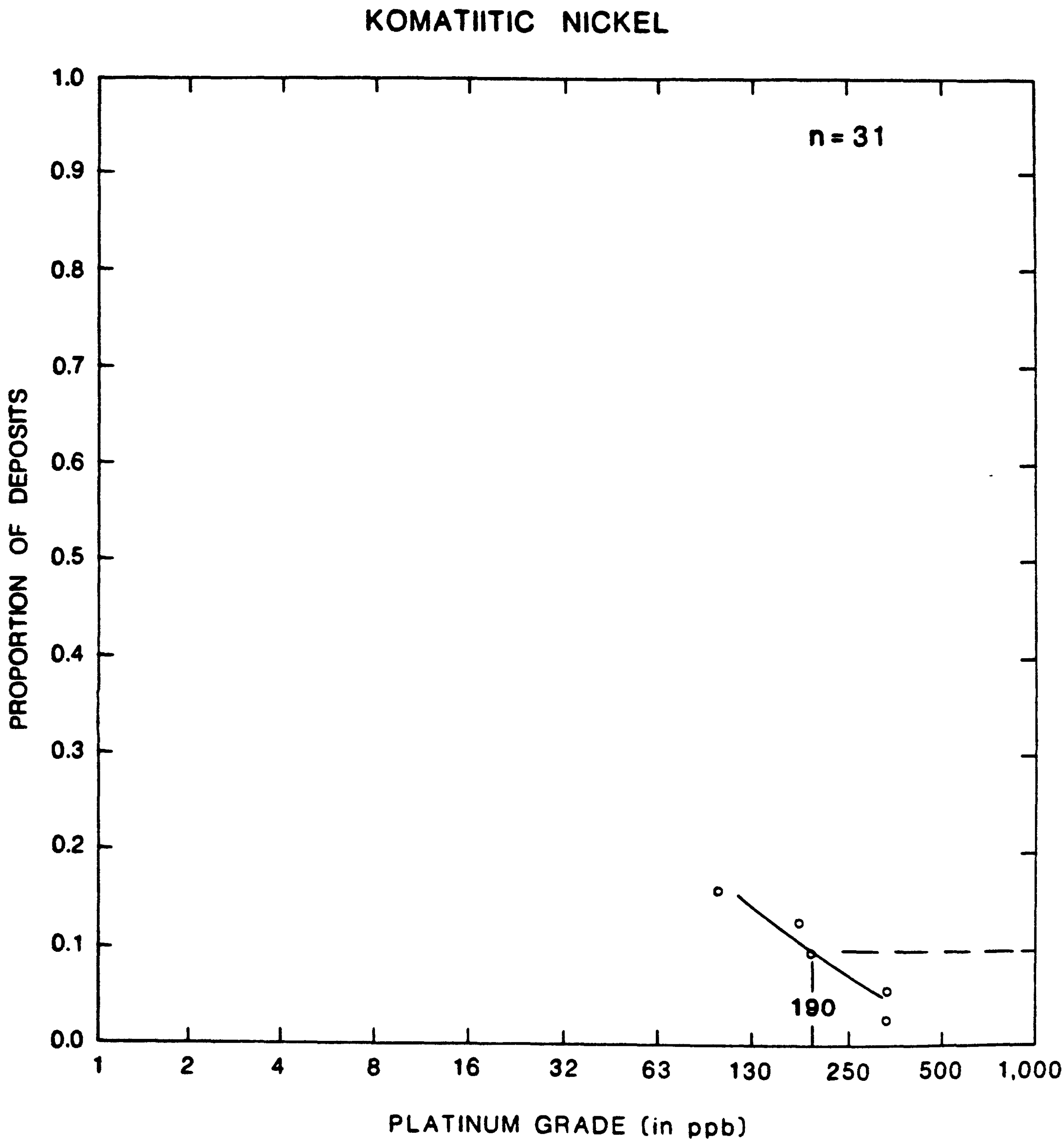

KOMATIITIC NICKEL
n = 31
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PROPORTION OF DEPOSITS
0.71
1.5
3.4
0.032
0.056
0.1
0.18
0.32
0.56
1.0
1.8
3.2
5.6
10.0
NICKEL GRADE (IN PERCENT)

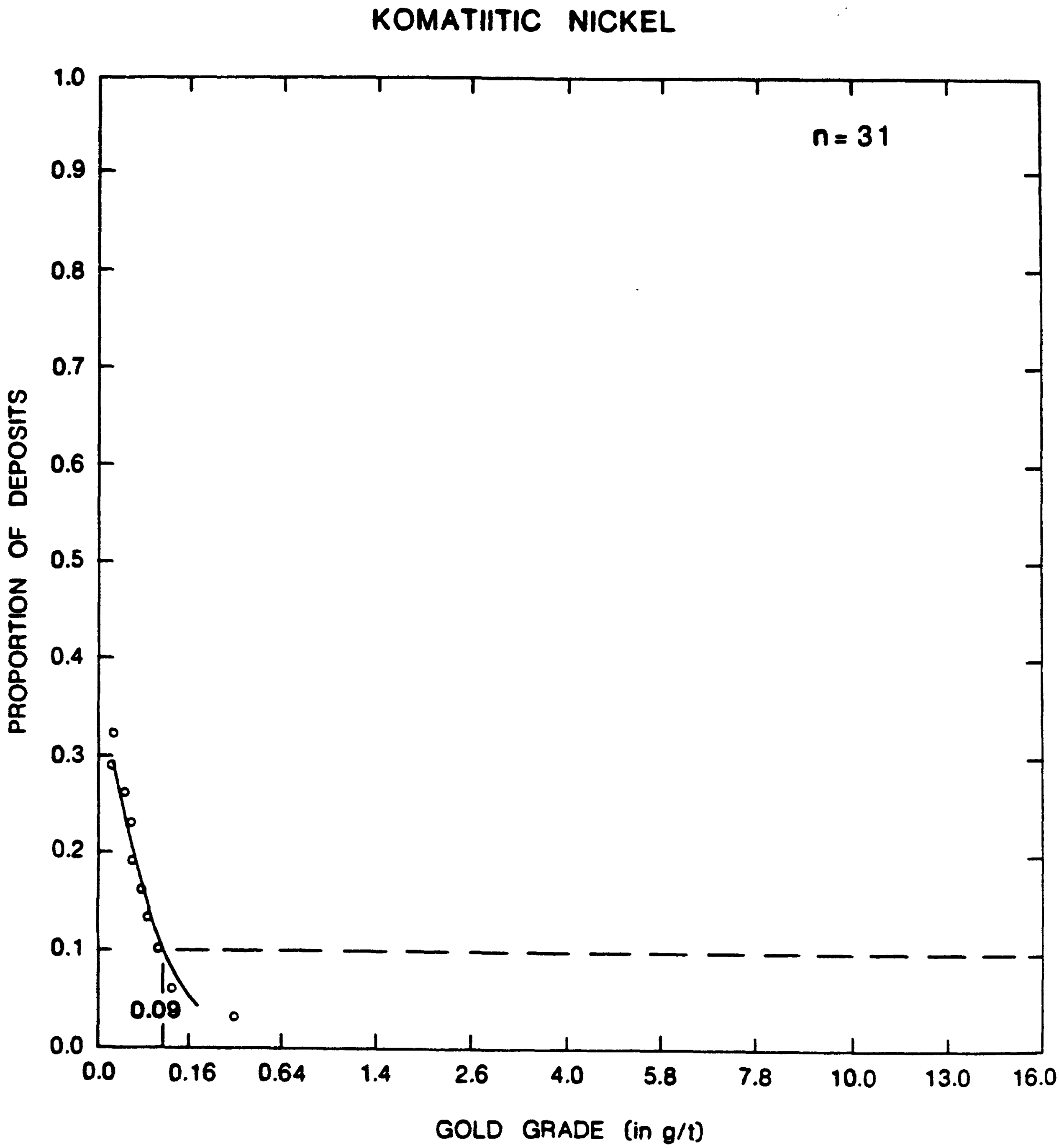

KOMATIITIC NICKEL
n = 31
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.096
0.0
0.01
0.04
0.09
0.16
0.25
0.36
0.49
0.64
0.81
1.0
COBALT GRADE (IN PERCENT)

KOMATIITIC NICKEL




KOMATIITIC NICKEL
n=31
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PROPORTION OF DEPOSITS
110
1
2
4
8
16
32
63
130
250
500
1,000
IRIDIUM GRADE (in ppb)


KOMATIITIC NICKEL
n = 31
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PROPORTION OF DEPOSITS
190
1
2
4
8
16
32
63
130
250
500
1,000
PLATINUM GRADE (in ppb)


KOMATIITIC NICKEL
n = 31
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.09
0.0
0.16
0.64
1.4
2.6
4.0
5.8
7.8
10.0
13.0
16.0
GOLD GRADE (in g/t)

DEPOSIT TYPE Volcanogenic manganese MODEL NUMBER 3.5

AUTHOR D. L. Mosier

COMMENTS Manganese grade is correlated with tonnage at the 1% level (r=-0.33).

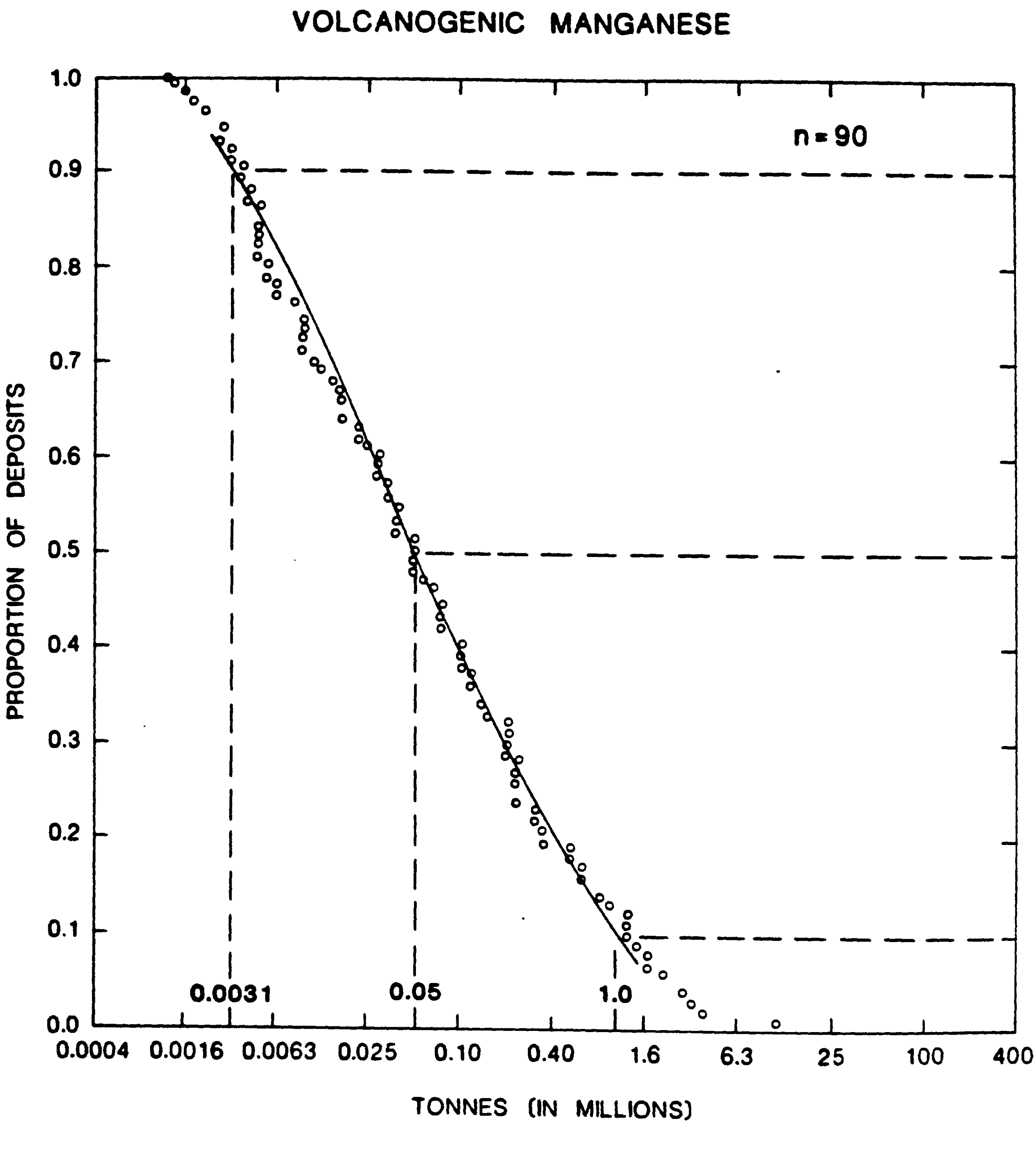
DEPOSITS

Name	Country	Name	Country
Abuhemsin (Abiulya)	TRKY	Gloria-Elvira-Polaris	CUBA
Abundancia	TRKY	Gocek Koyu	TRKY
Akcakilise Topkirazlar	TRKY	Guanaba Group	CUBA
Akoluuk	TRKY	Gunbasi (Akcakese)	TRKY
Akseki Gokceovacik	TRKY	Hyatt No. 1	PANA
Antonio	CUBA	Idikel	MRCO
Augusto Luis & others	CUBA	Ilave	CUBA
Avispa	CUBA	Jo7	NCAL
Black Diablo	USNV	Jutinicu	CUBA
Blue Jay	USCA	Komurluk Koyunun	TRKY
Boston Group	CUBA	Korucular	TRKY
Briseida Group & others	CUBA	La Calanesa	SPAN
Buckeye	USCA	Ladd	USCA
Bueycito	CUBA	Lagnokaha	UVOL
Buritirama	BRZL	Lasbela	PKTN
Cadiz	CUBA	La Unica	CUBA
Castillode Palanco	SPAN	Laverton-Mt. Lucky	AUWA
Cavdarli-Komurluk	TRKY	Liberty	USCA
Cayirli Koy	TRKY	Lucia (Generosa)	CUBA
Charco Redondo-Casualidad	CUBA	Lucifer	MXCO
Crescent	USWA	Magadalena	CUBA
Cubenas	CUBA	Manacas Group	CUBA
Cubuklu Koyu	TRKY	Manuel	CUBA
Cummings	USCA	Montenegro-Adriana	CUBA
Curiol-Playa Real-Pavones	CORI	Mrima	KNYA
Dassoumble	IVCO	Pirki	TRKY
Djebel Guettara	ALGR	Piskala	TRKY
Durnovskoe	URRS	Ponupo	CUBA
El Cuervo	SPAN	Ponupo de Manacal	CUBA
Esperancita	CUBA	Pozo Prieto	CUBA
Estrella-Sopresa	CUBA	Progreso	CUBA
Fabian	USCA	Quarzazate	MRCO
Faucogney	FRNC	Quinto	CUBA
Foster Mountain	USCA	Raymond	NCAL
Glib en Nam	MRCO	Rhiw	GRBR

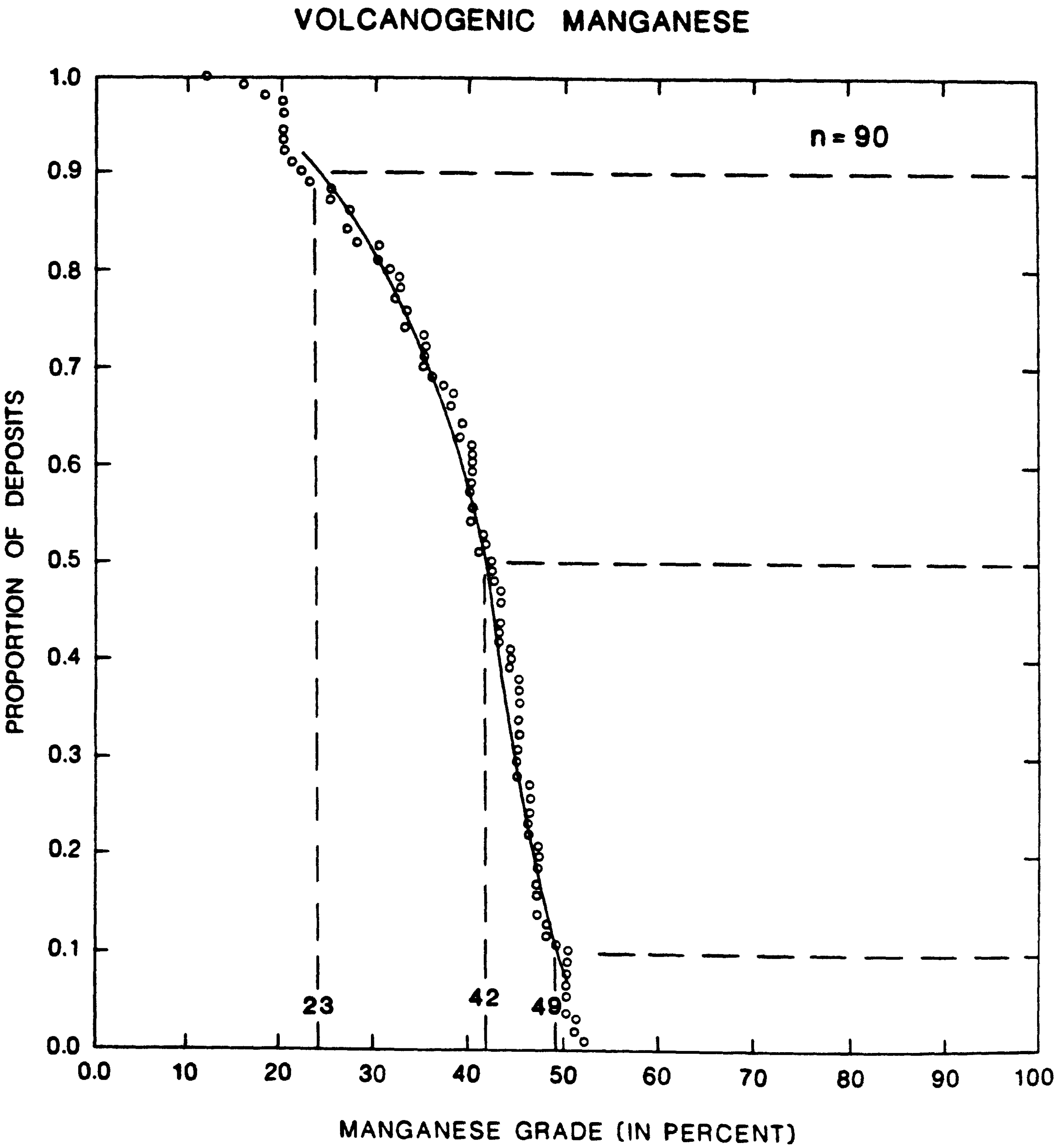
DEPOSIT TYPE Volcanogenic manganese MODEL NUMBER 3.5

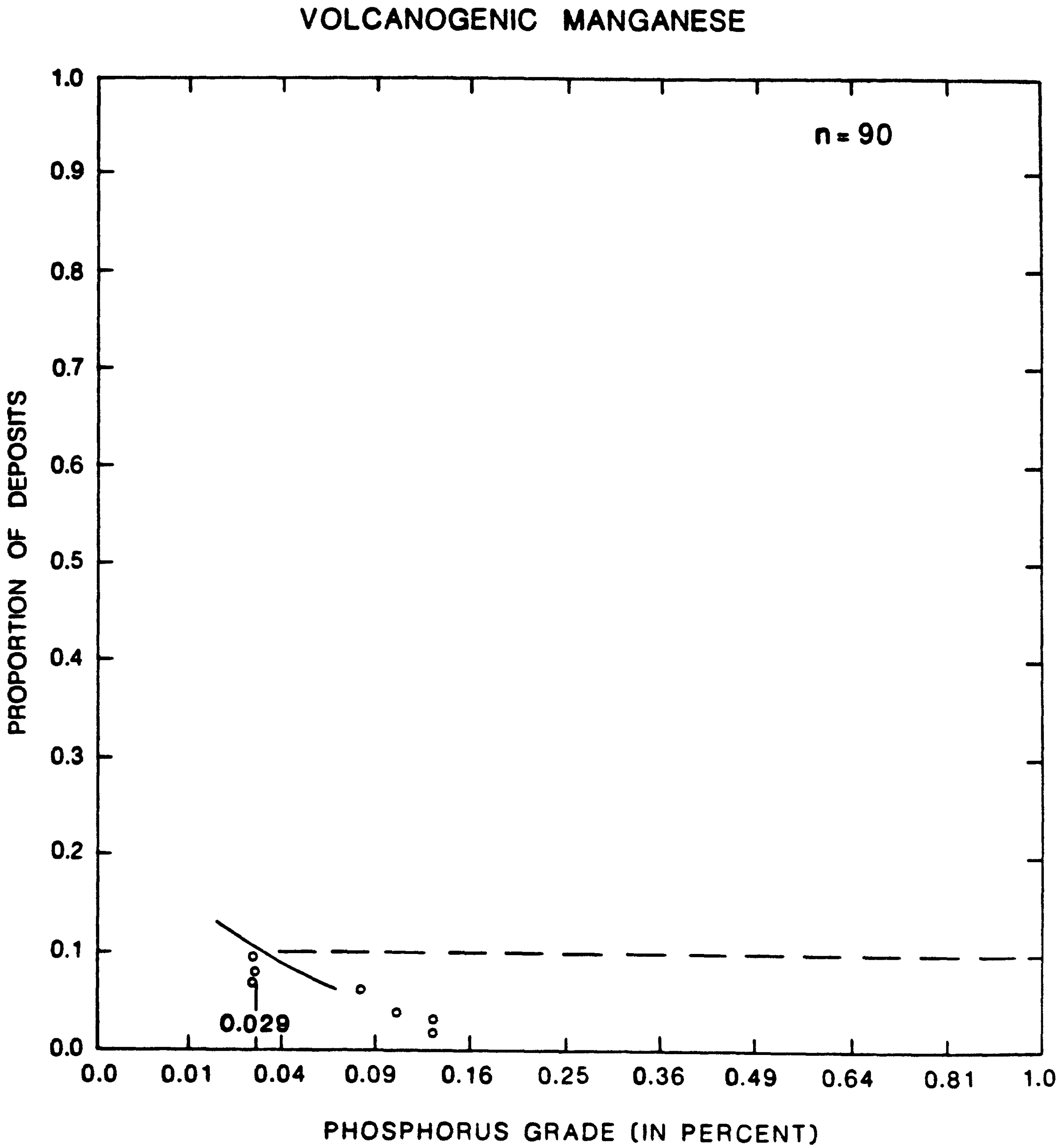
DEPOSITS (continued)

Name	Country	Name	Country
Sabanilla	CUBA	Tiere	UVOL
Sapalskoe	URRS	Tiouine	MRCO
Sereno	BRZL	Tokoro	JAPN
Sigua	CUBA	Topkirozlar	TRKY
Soloviejo	SPAN	Toscana (Cerchiara)	ITLY
South Thomas	USCA	Tutunculer	TRKY
Taratana	CUBA	Valle de Manganeso	CUBA
Taritipan	INDS	Welch	USCA
Thatcher Creek	USCA	Woody Woody	AUWA
Thomas	USCA	Yeya	CUBA



VOLCANOGENIC MANGANESE
n = 90
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0031
0.05
1.0
0.0004
0.0016
0.0063
0.025
0.10
0.40
1.6
6.3
25
100
400
TONNES (IN MILLIONS)


VOLCANOGENIC MANGANESE
n = 90
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
23
42
49
0.0
10
20
30
40
50
60
70
80
90
100
MANGANESE GRADE (IN PERCENT)



VOLCANOGENIC MANGANESE
n = 90
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.029
0.0 0.01 0.04 0.09 0.16 0.25 0.36 0.49 0.64 0.81 1.0
PHOSPHORUS GRADE (IN PERCENT)

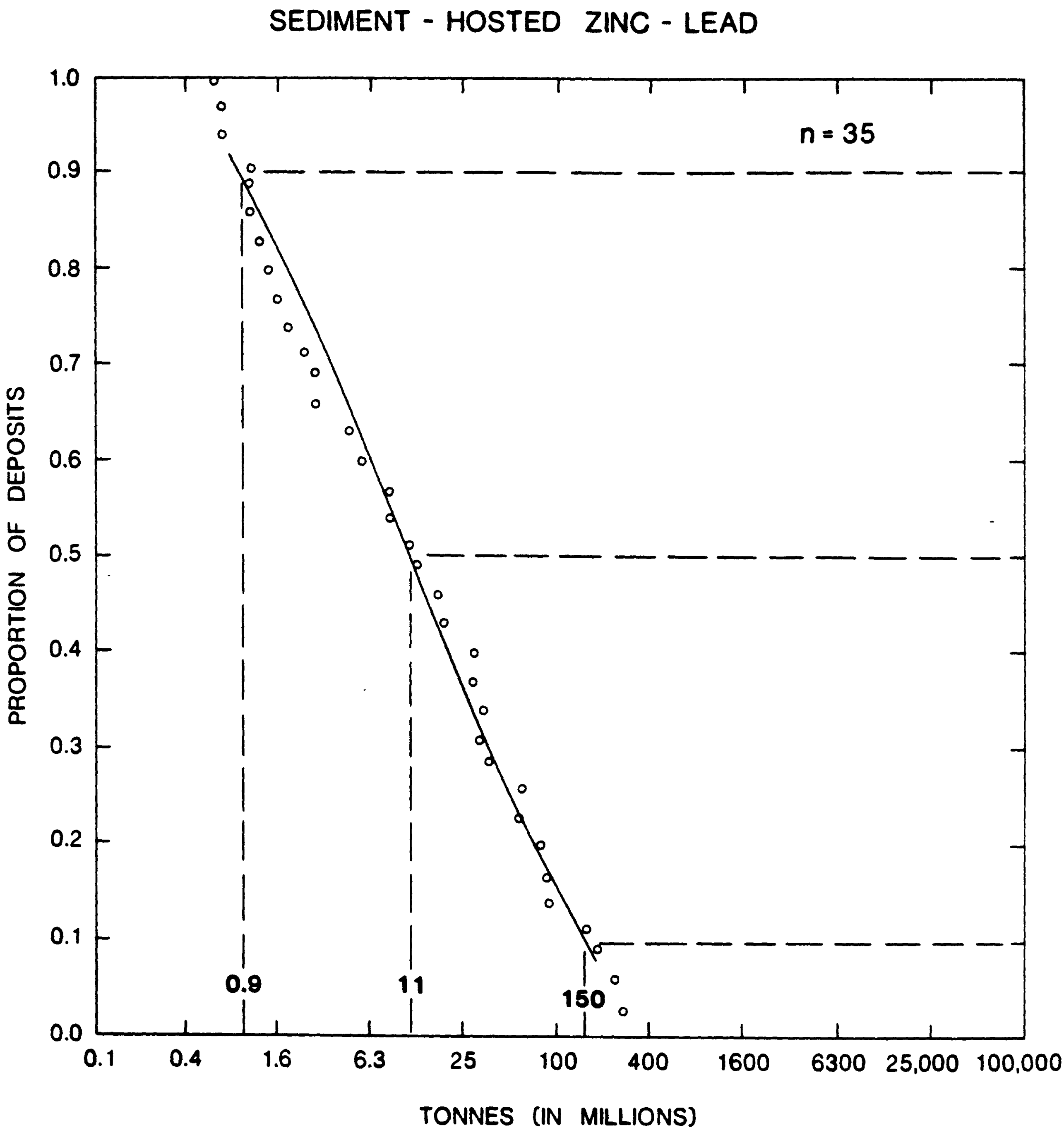
DEPOSIT TYPE Sediment-hosted exhalative zinc-lead MODEL NUMBER 4.5

AUTHOR W. D. Menzie and D. L. Mosier

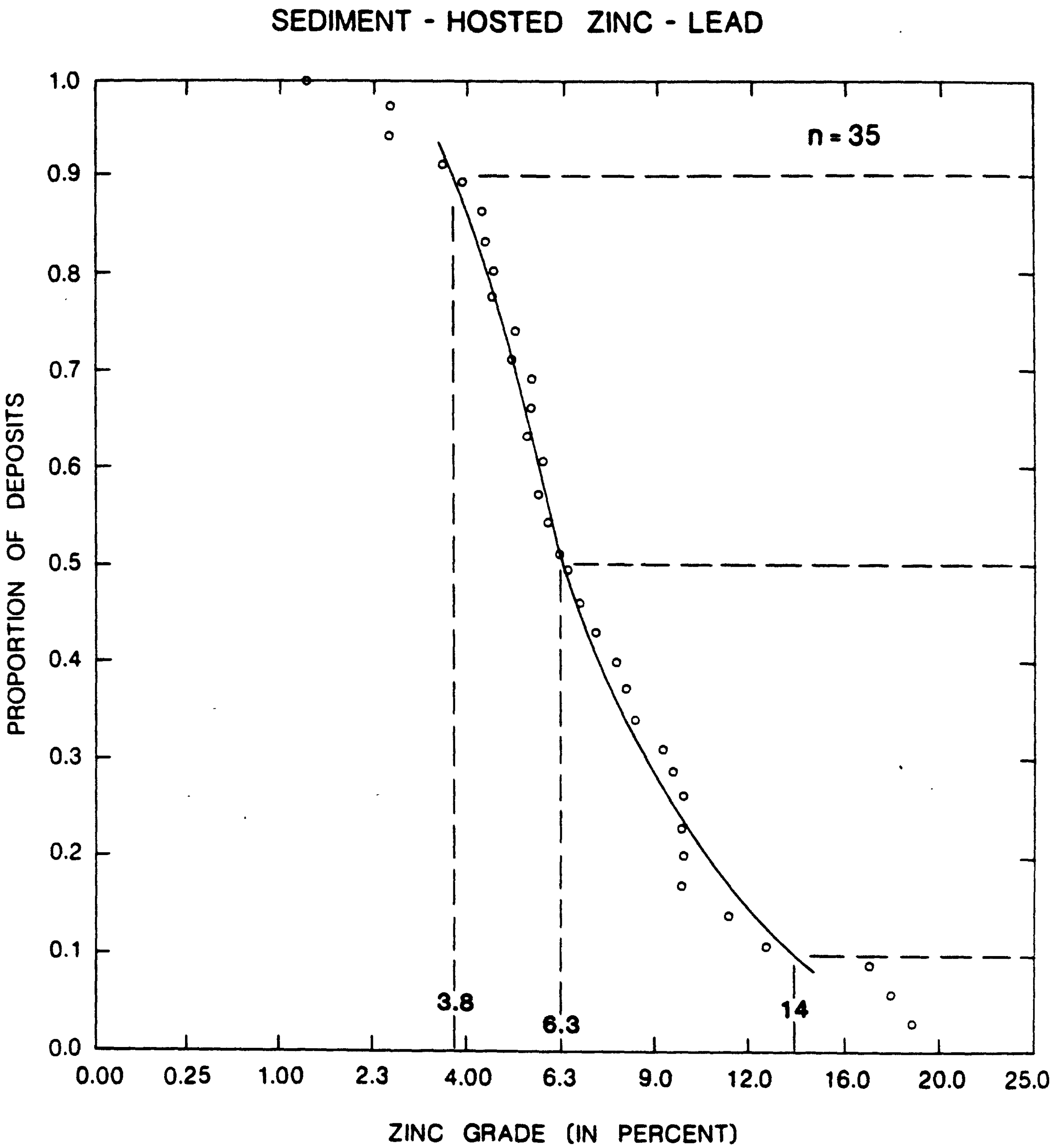
COMMENTS Lead grades are significantly correlated with silver grades (r = 0.76).

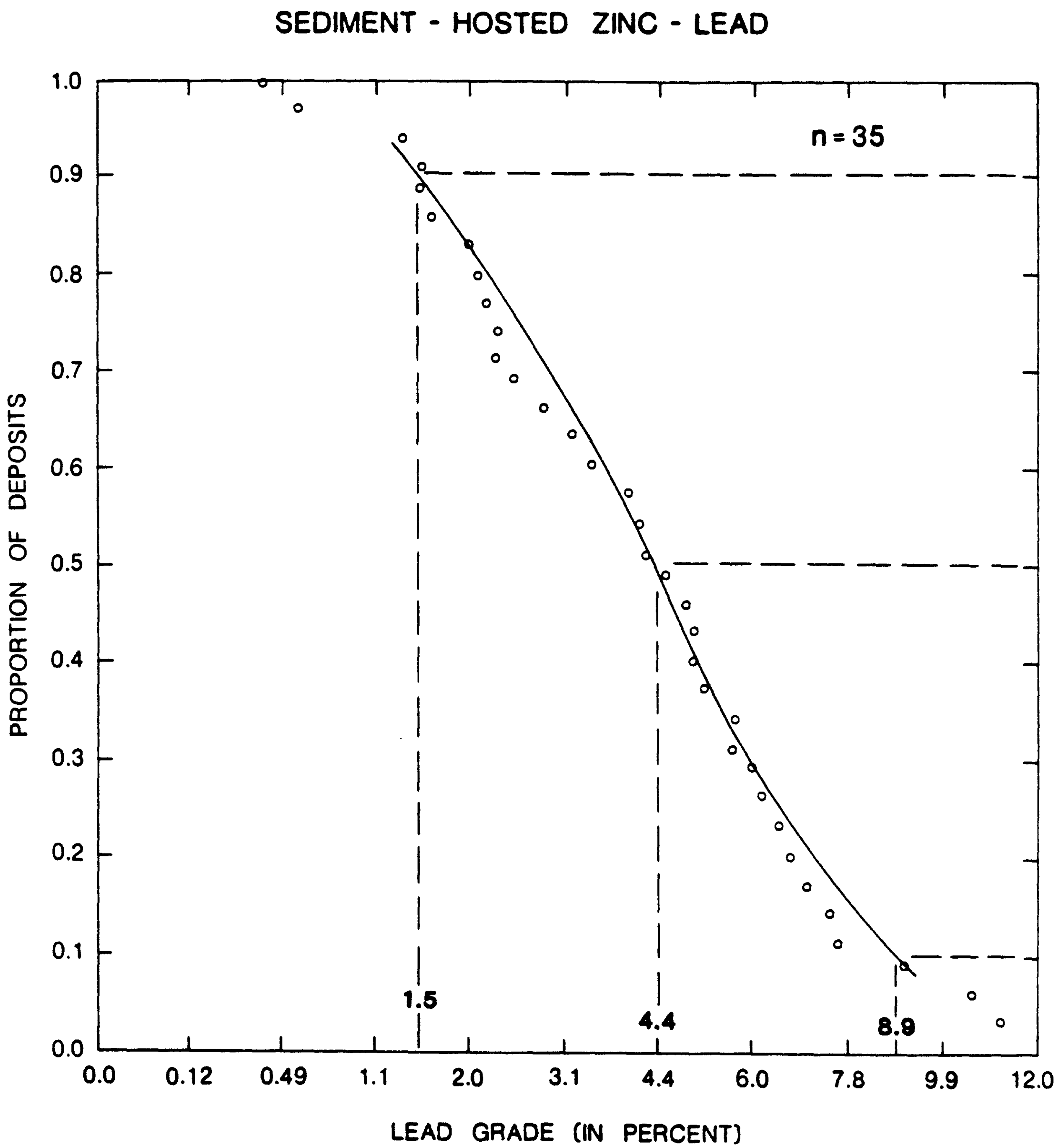
DEPOSITS

Name	Country
Abbeytown	IRLD
Broken Hill	AUNS
Cirque	CNBC
Cotton Belt	CNBC
Dugald River	AUQL
Elura	AUNS
Faro	CNYT
Fx	CNBC
Grum	CNYT
Hilton	AUQL
Homestake	CNBC
Howards Pass	CNYT
King Fissure	CNBC
Lady Loretta	AUQL
MacMillan	CNYT
Matt Berry	CNYT
McArthur	AUNT
Meggen	GRMY
Mel	CNYT
Mineral King	CNBC
Mount Isa	AUQL
Navan	IRLD
Rammelsberg	GRMY
Red Dog	USAK
River Jordan	CNBC
Rosh Pinah	SAFR
St. Eugene	CNBC
Silvermines	IRLD
Squirrel Hills	AUQL
Sullivan	CNBC
Swim Lake	CNYT
Tom	CNYT
Tynagh	IRLD
Vangorda	CNYT
Woodcutters	AUNT

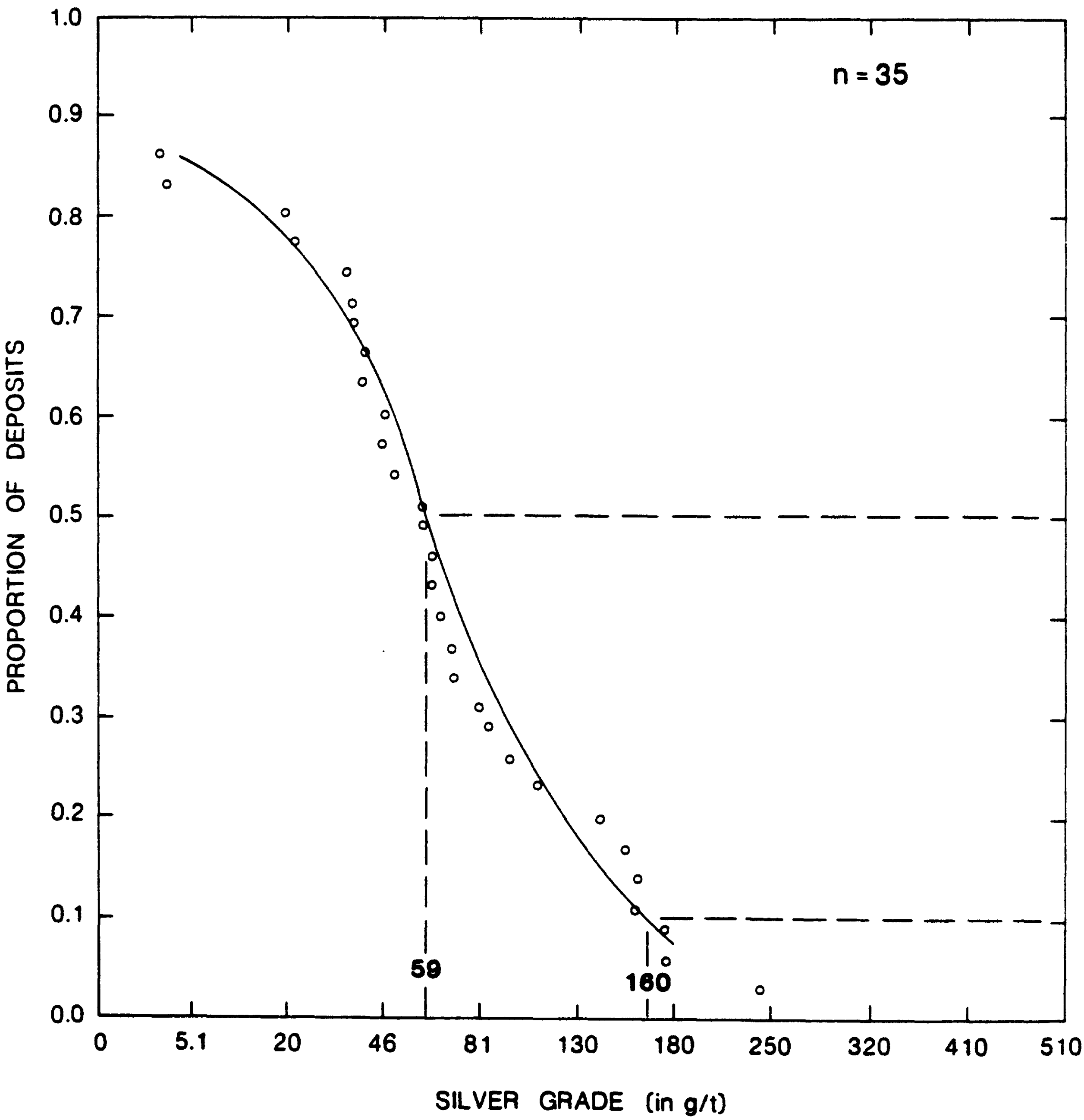


SEDIMENT - HOSTED ZINC - LEAD
n = 35
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.9
11
150
0.1
0.4
1.6
6.3
25
100
400
1600
6300
25,000
100,000
TONNES (IN MILLIONS)


SEDIMENT - HOSTED ZINC - LEAD
n = 35
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
3.8
6.3
14
0.00
0.25
1.00
2.3
4.00
6.3
9.0
12.0
16.0
20.0
25.0
ZINC GRADE (IN PERCENT)


SEDIMENT - HOSTED ZINC - LEAD
n = 35
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1.5
4.4
8.9
0.0
0.12
0.49
1.1
2.0
3.1
4.4
6.0
7.8
9.9
12.0
LEAD GRADE (IN PERCENT)

SEDIMENT - HOSTED ZINC - LEAD



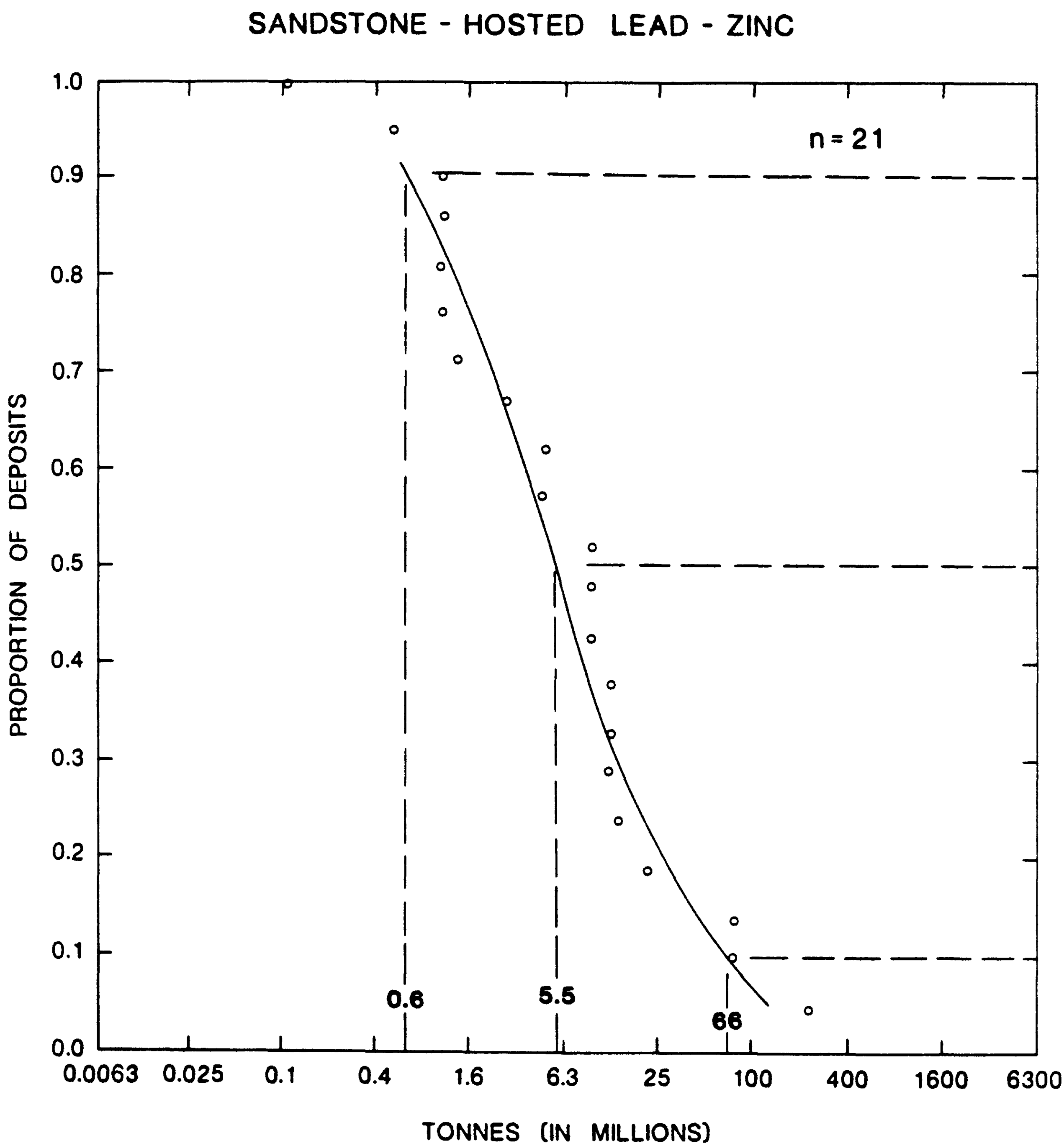
DEPOSIT TYPE Sandstone-hosted lead-zinc MODEL NUMBER 4.8

AUTHOR D. L. Mosier

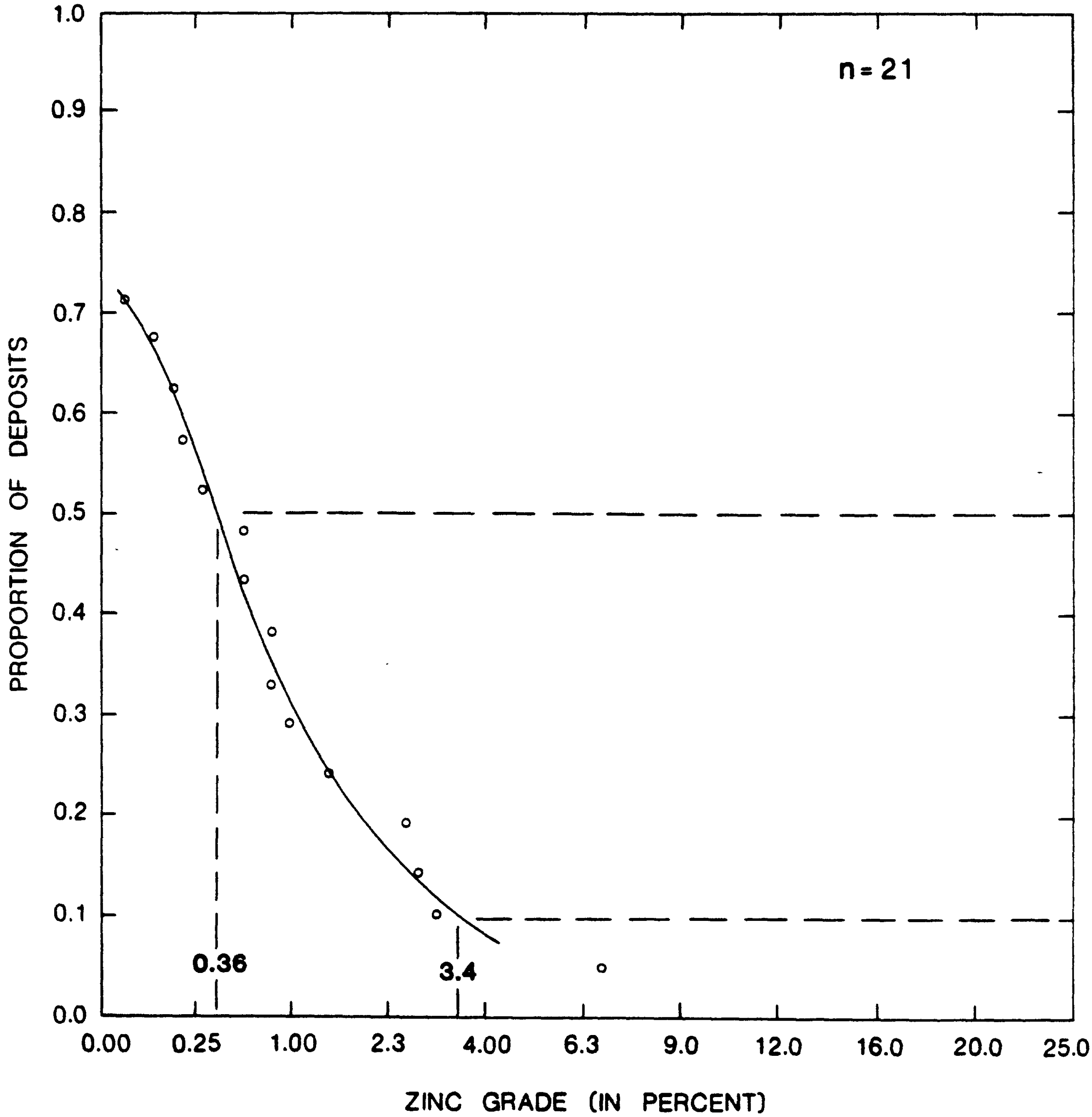
COMMENTS none

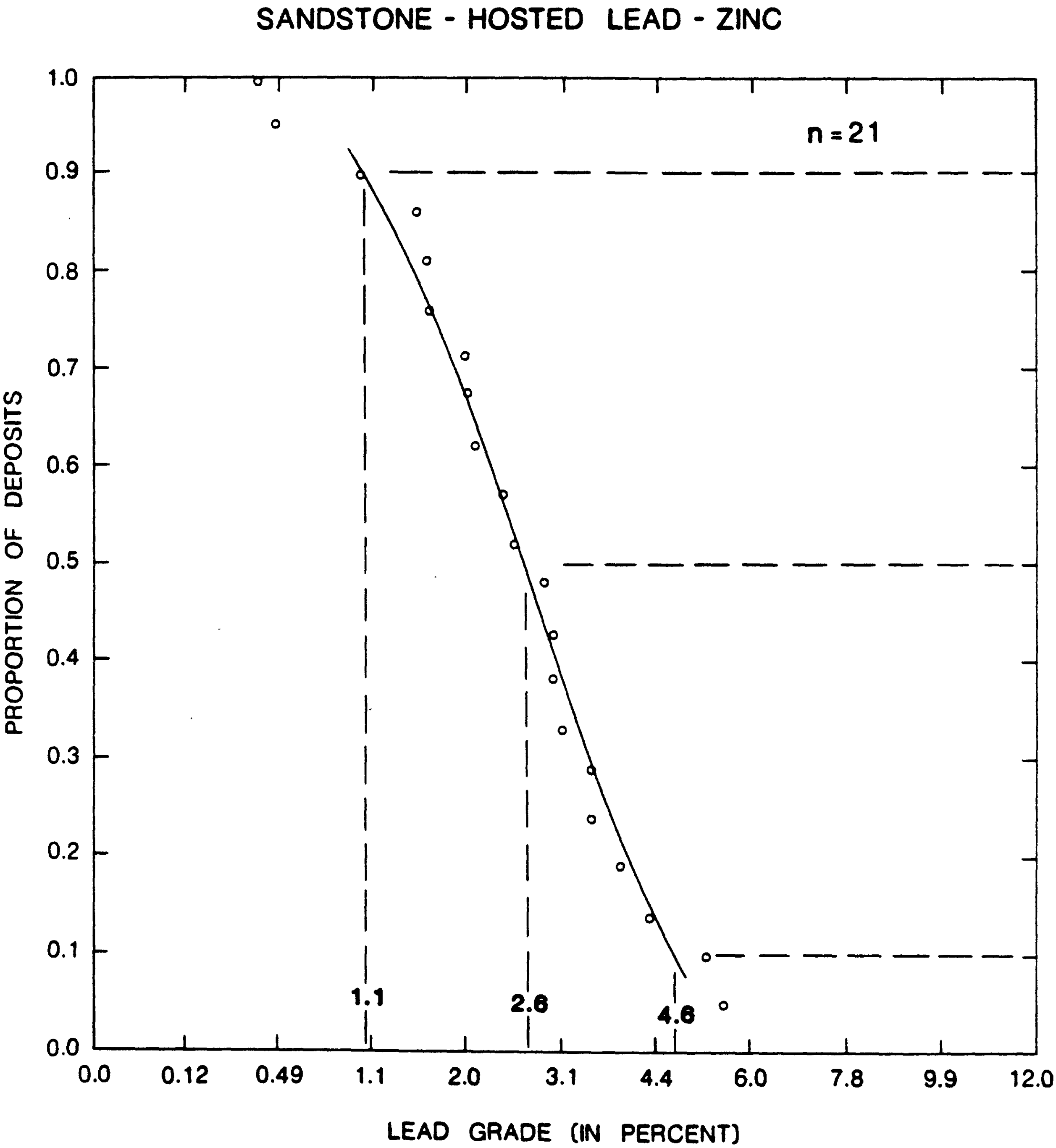
DEPOSITS

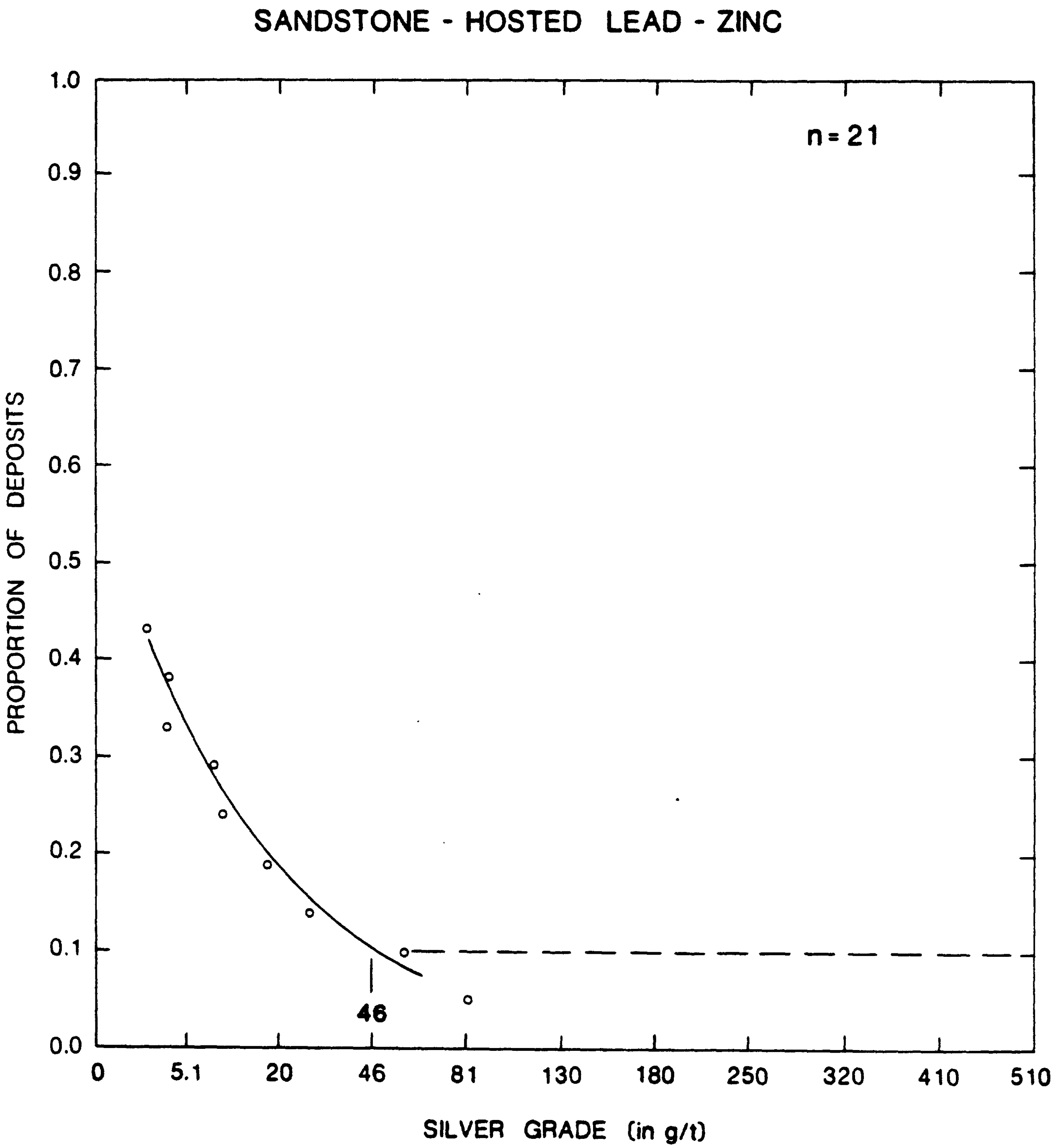
Name	Country
Belokany-Laura	URUR
Bou Mia	MRCO
Boylen	CNQU
George Lake	CNSK
Guttusjon	SWDN
Laisvall	SWDN
Largentiere	FRNC
Lovstrand	SWDN
Majva	SWDN
Masua	ITLY
Maubacher	GRMY
Mechernich	GRMY
Oberpfalz	GRMY
Osen	NRWY
Sagliden	SWDN
Shertingdal	NRWY
Smithfield	CNNS
Tregioivo	ITLY
Vassbo	SWDN
Yava (Silvermine)	CNNS
Zeida	MRCO


SANDSTONE - HOSTED LEAD - ZINC
n = 21
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.6
5.5
66
0.0063 0.025 0.1 0.4 1.6 6.3 25 100 400 1600 6300
TONNES (IN MILLIONS)

SANDSTONE - HOSTED LEAD - ZINC




SANDSTONE - HOSTED LEAD - ZINC
n = 21
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1.1
2.6
4.6
0.0
0.12
0.49
1.1
2.0
3.1
4.4
6.0
7.8
9.9
12.0
LEAD GRADE (IN PERCENT)


SANDSTONE - HOSTED LEAD - ZINC
n = 21
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
46
0
5.1
20
46
81
130
180
250
320
410
510
SILVER GRADE (in g/t)

DEPOSIT TYPE Bedded barite

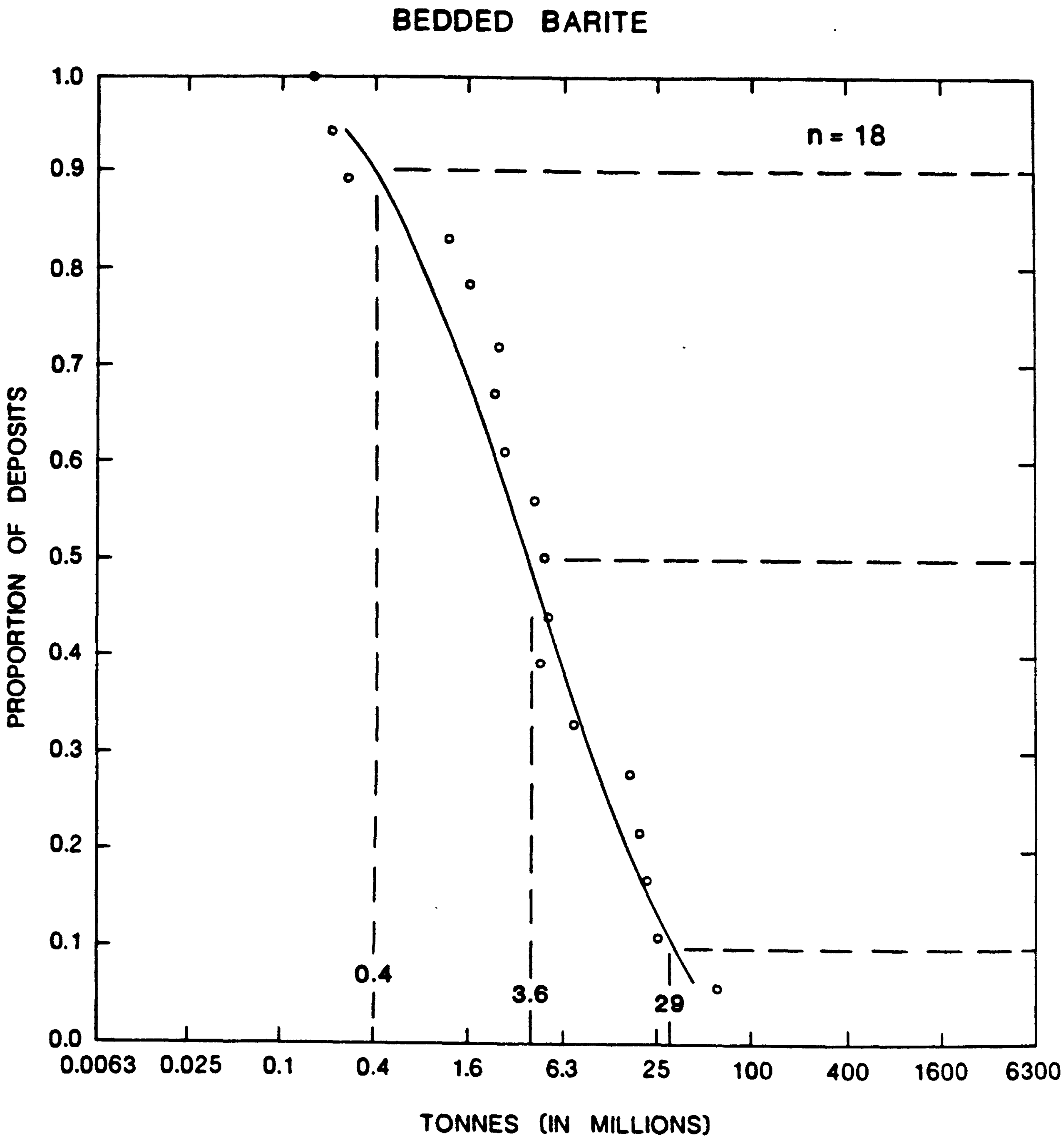
MODEL NUMBER 4.9

AUTHOR G. Orris

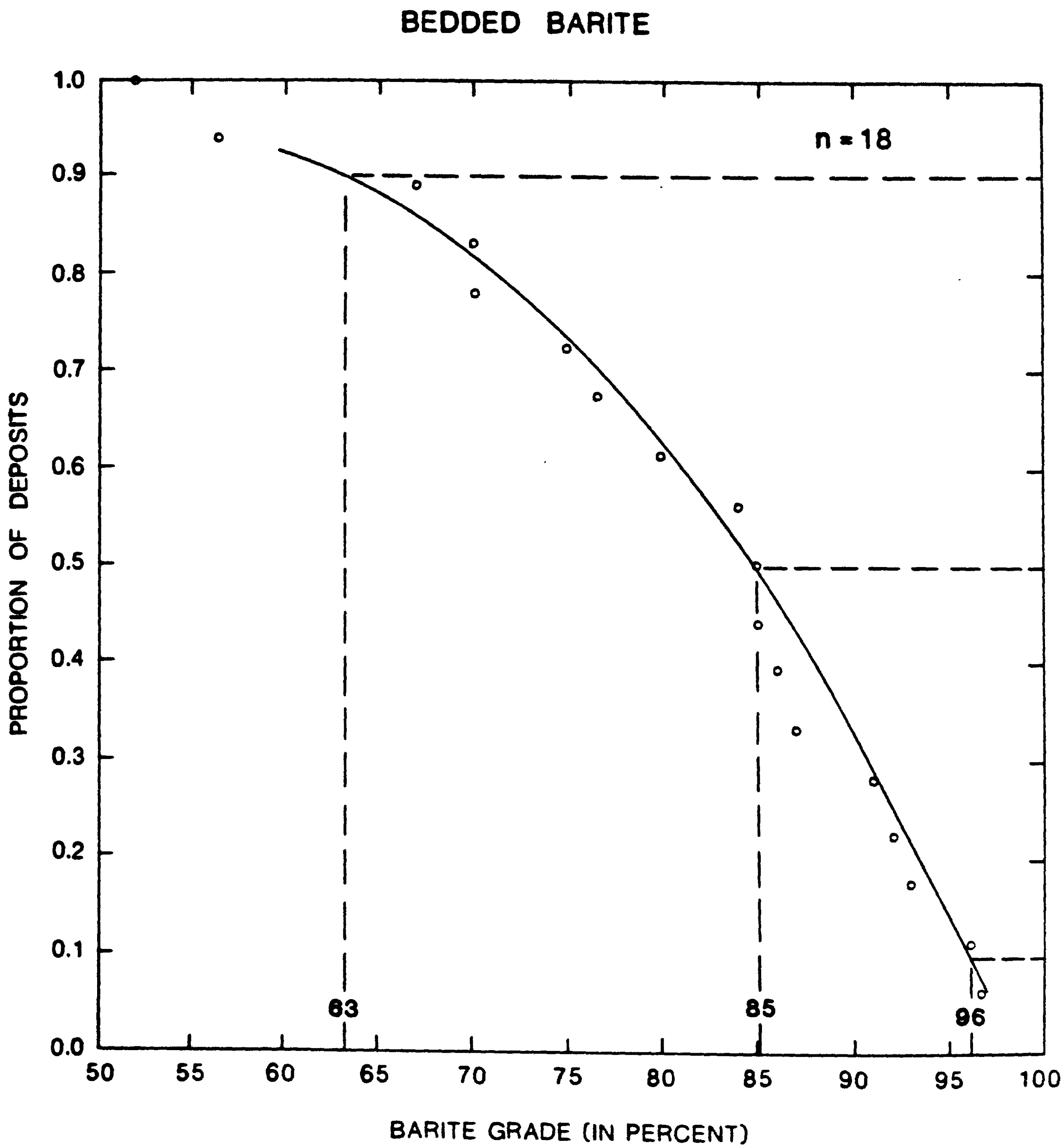
COMMENTS

DEPOSITS

Name	Country
Balleynoe	IRLD
Barite (Mouse)	CNYT
Barite Valley	SWAZ
Baw Hin Khao	THLD
Brookfield	CNNS
Cirque	CNBC
Khuzdar	PKTN
Magcobar	IRLD
Magnet Cove	USAR
Mangampetta N.	INDA
Mangampetta S.	INDA
Meggen	GRMY
Mel	CNYT
Nimiuktuk	USAK
Rammelsberg	GRMY
Snake Mountain	USNV
Tea	CNYT
Uribe	USWA



BEDDED BARITE
n = 18
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.4
3.6
29
0.0063
0.025
0.1
0.4
1.6
6.3
25
100
400
1600
6300
TONNES (IN MILLIONS)


BEDDED BARITE
n = 18
PROPORTION OF DEPOSITS
BARITE GRADE (IN PERCENT)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
50
55
60
65
70
75
80
85
90
95
100
63
85
96

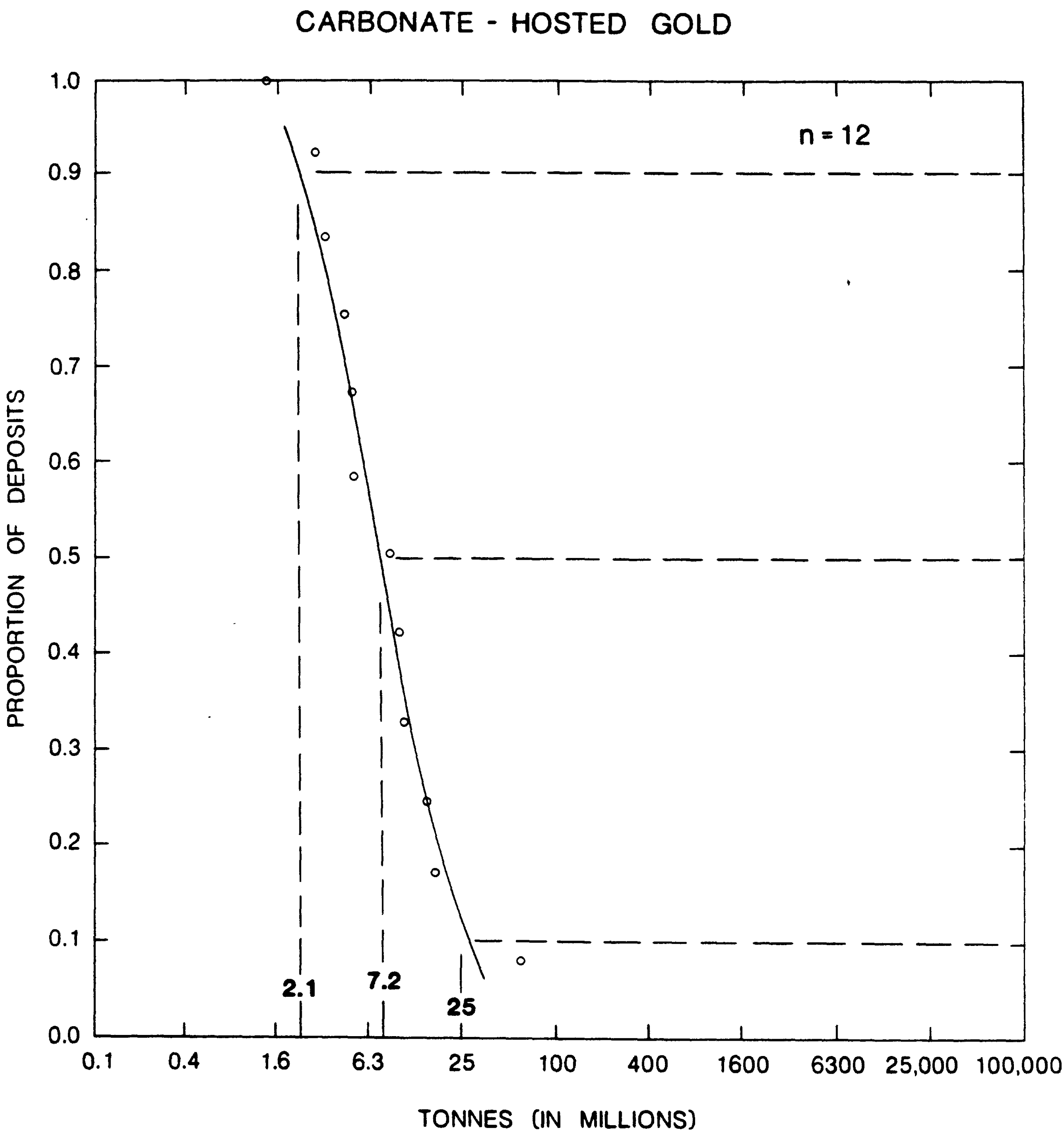
DEPOSIT TYPE Carbonate-hosted gold MODEL NUMBER 5.2

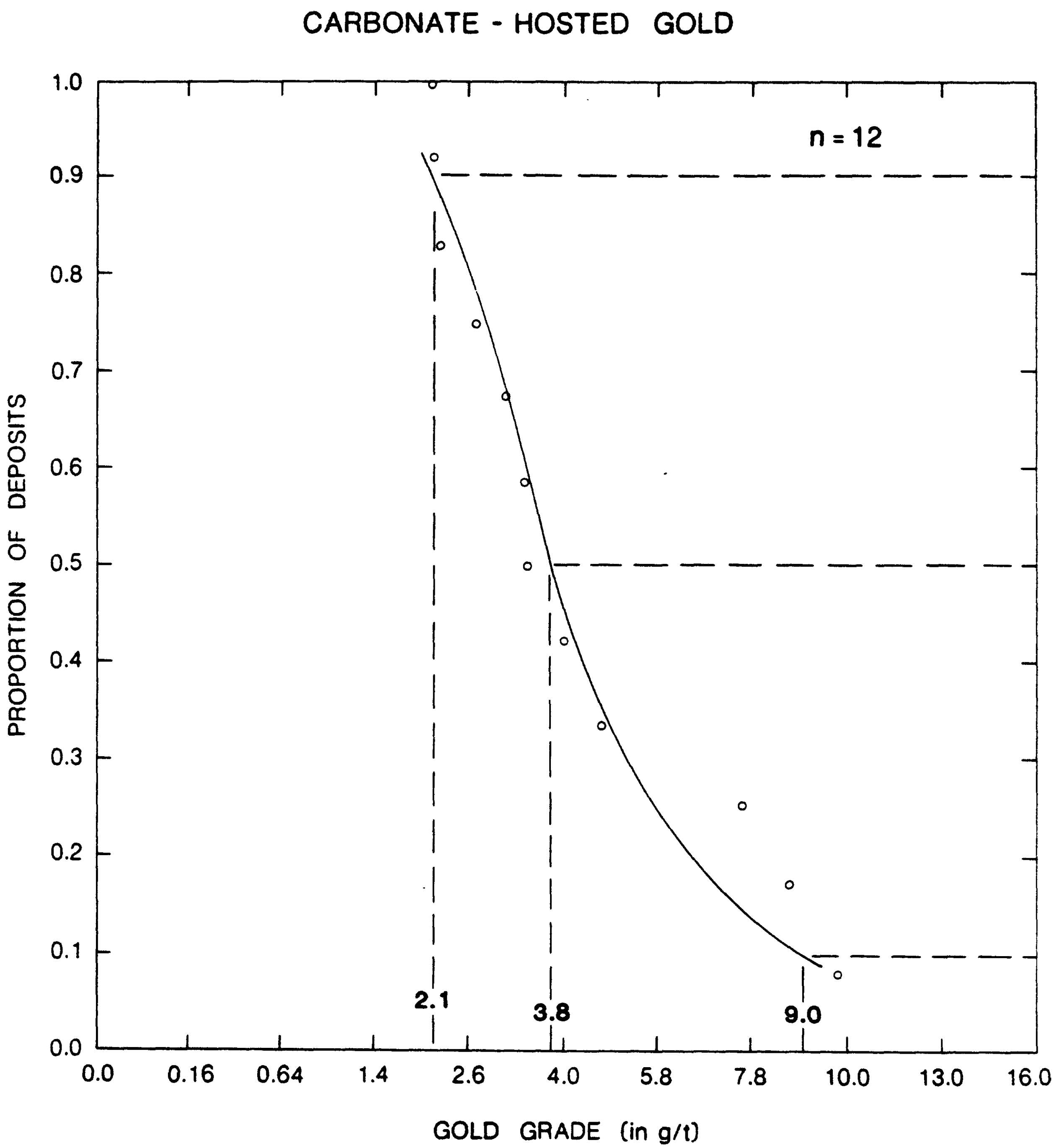
AUTHOR W. D. Menzie, D. L. Mosier, and D. A. Singer

COMMENTS none

DEPOSITS

Name	Country
Alligator Ridge	USNV
Carlin	USNV
Cortez	USNV
Getchell	USNV
Gold Quarry	USNV
Jerritt Canyon	USNV
Maggie Creek	USNV
Mercur	USUT
Northumberland	USNV
Pinson	USNV
Preble	USNV
Santa Fe	USNV


CARBONATE - HOSTED GOLD
n = 12
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2.1
7.2
25
0.1
0.4
1.6
6.3
25
100
400
1600
6300
25,000
100,000
TONNES (IN MILLIONS)



CARBONATE - HOSTED GOLD
n = 12
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PROPORTION OF DEPOSITS
2.1
3.8
9.0
0.0
0.16
0.64
1.4
2.6
4.0
5.8
7.8
10.0
13.0
16.0
GOLD GRADE (in g/t)

DEPOSIT TYPE Low-sulfide quartz gold   Model Number 5.3

AUTHOR J. Bliss

COMMENTS All deposits in the model are from the Mother Lode of California. All mines within one mile were combined and only deposits containing more than 100 tonnes are included. Gold grade is significantly correlated with tonnage (r = -0.40)

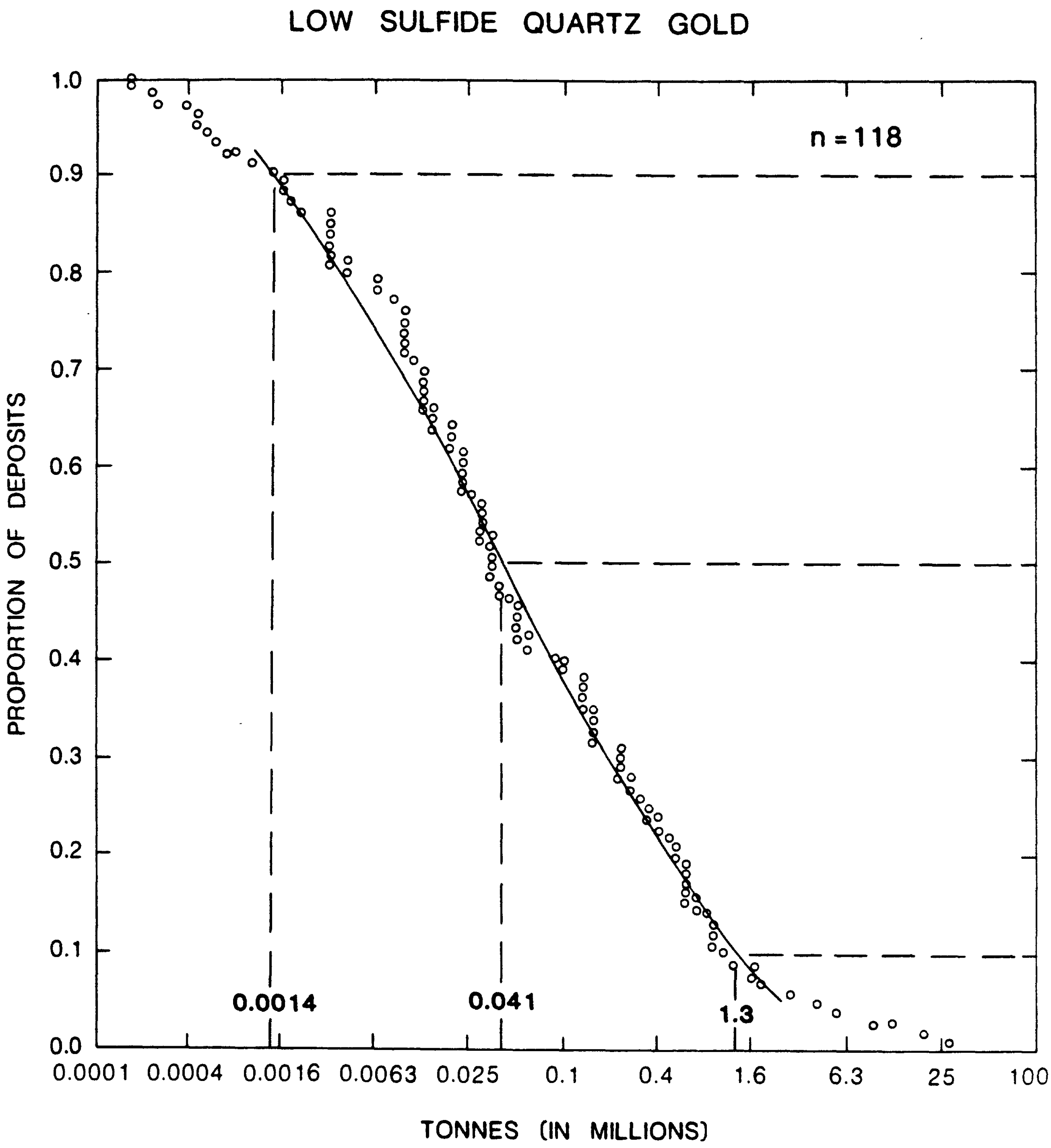
DEPOSITS

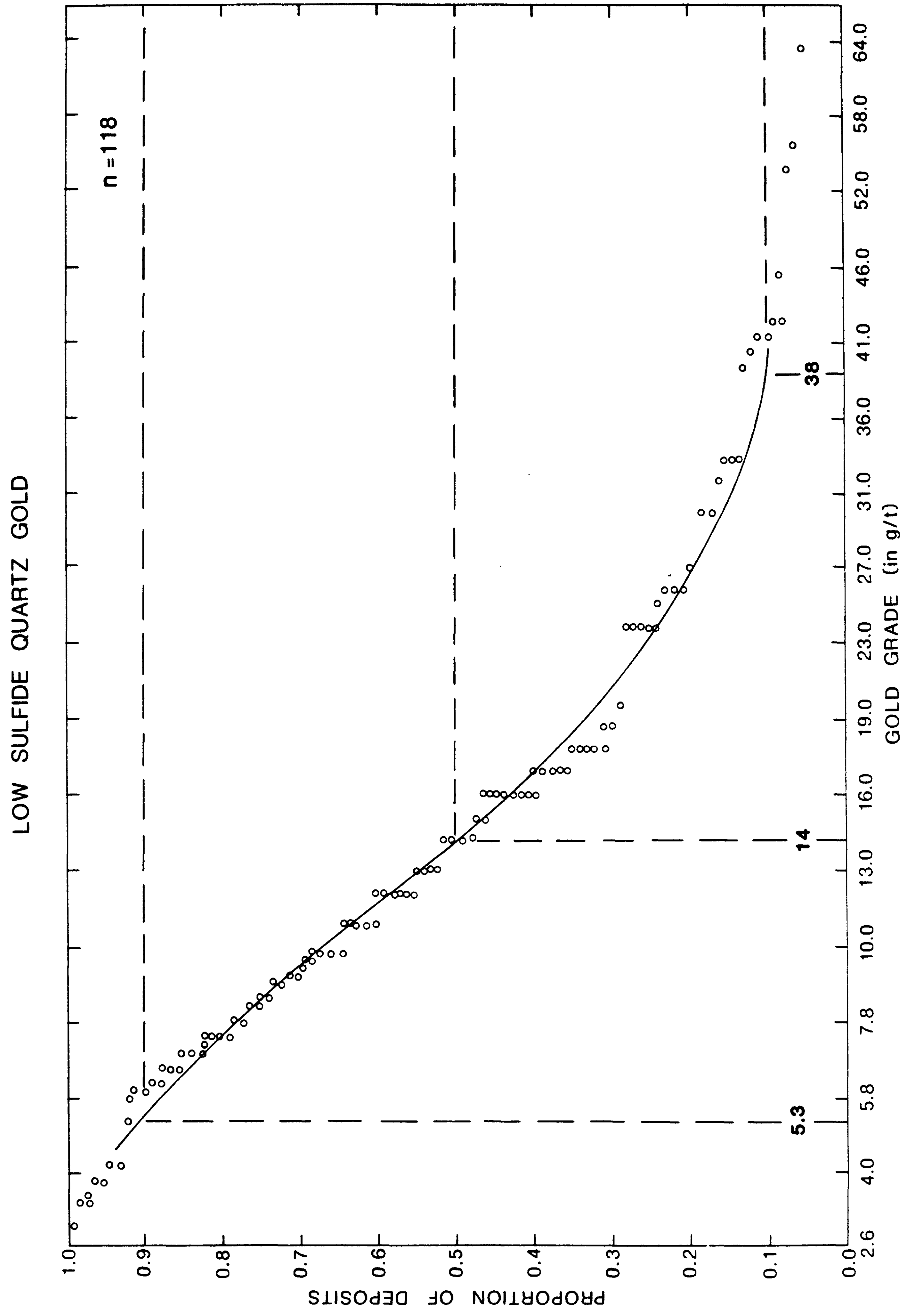
Name	Country	Name	Country
Alice	USCA	Finney	USCA
Alleghany East	USCA	Forbestown	USCA
Alleghany West	USCA	Ford	USCA
Alto	USCA	Fourth Cross	USCA
Amador City	USCA	French	USCA
American Bar	USCA	Gambetta	USCA
Angels-Carson	USCA	Gem	USCA
Argo	USCA	Gem Olive	USCA
Atlas	USCA	German Bar	USCA
Bagby	USCA	Giant Grass V.	USCA
Bagby North	USCA	Glencoe-Woudhouse	USCA
Bear Valley	USCA	Gold Bug	USCA
Bear Valley South	USCA	Golden Chariot	USCA
Belden	USCA	Gold Point	USCA
Berry Creek	USCA	Golden-Eldorado	USCA
Big Oak Flat	USCA	Grand Victory	USCA
Blackstone	USCA	Granite King	USCA
Blue Mountain	USCA	Greater Grass V.	USCA
Bondurant	USCA	Green-Excelsior	USCA
Coarsegold	USCA	Gwynne	USCA
Colfax	USCA	Ham-Birney	USCA
Colombo	USCA	Herman	USCA
Confidence	USCA	Hornitos	USCA
Coulterville	USCA	Horseshoe I	USCA
Coulterville South	USCA	Hunter Valley	USCA
Cove	USCA	Iconoclast	USCA
Damascus	USCA	Jacksonville W.	USCA
Defender	USCA	Jamestown	USCA
Demarest	USCA	Joe Walker	USCA
Dinero	USCA	Julian-Banner	USCA
Eagle Shawmut	USCA	Kelsey	USCA
Early-Sweetwater	USCA	Kelsey N.	USCA
Eclipse No. 1	USCA	Kinsley	USCA
El Dorado	USCA	Kinsley N.	USCA
El Portal	USCA	Lamphear	USCA
Enterprise	USCA	Locarno	USCA
Esmeralda	USCA	Lone Mary	USCA
Experimental	USCA	Mammoth	USCA
Felicianna	USCA	Mariposa	USCA
Fifty-Fifty	USCA	Mokelumne	USCA
Fine Gold	USCA	Moore's Flat	USCA

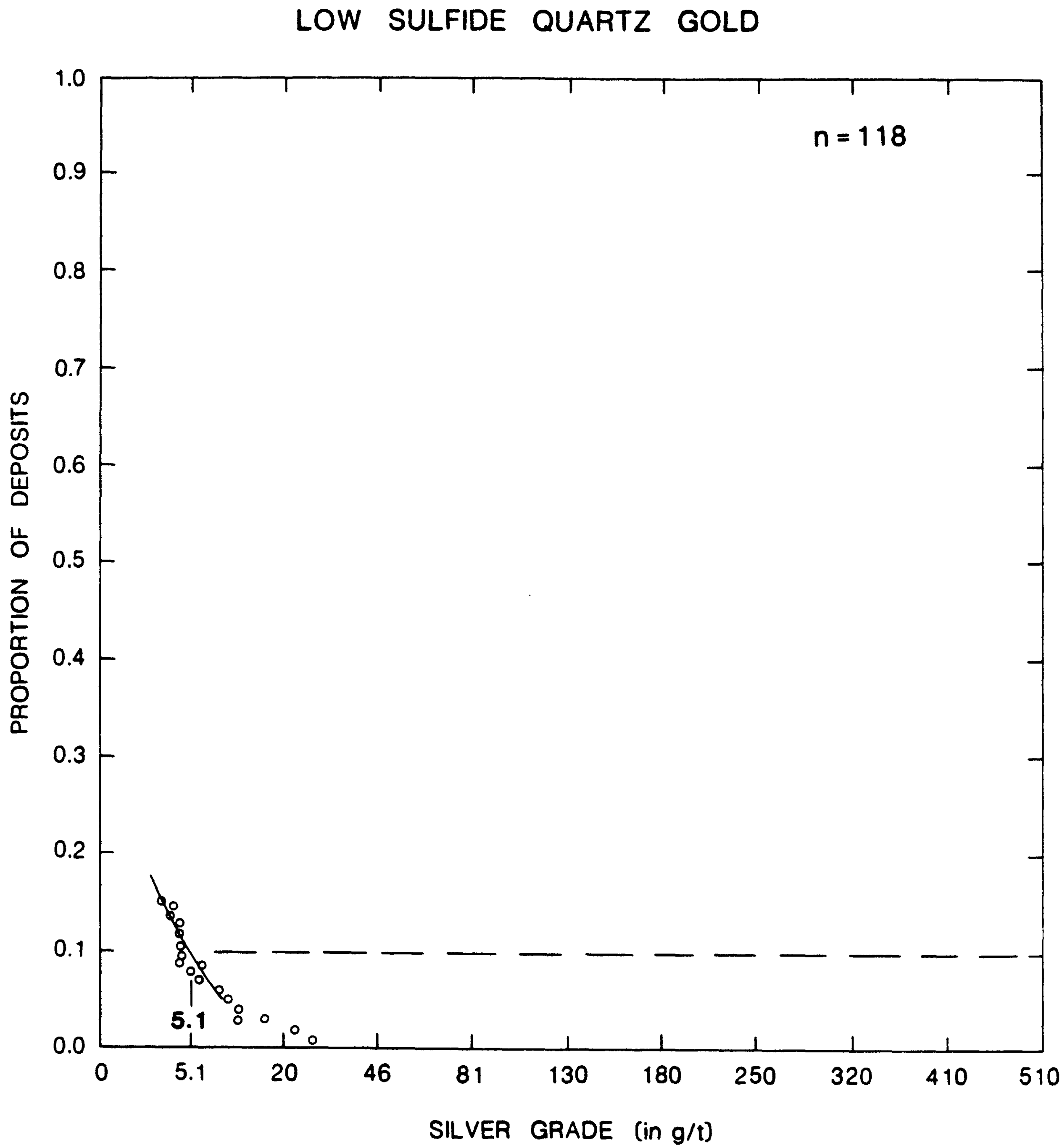
DEPOSIT TYPE Low sulfide quartz gold MODEL NUMBER 5.3

DEPOSITS (Continued)

Name	Country
Mormon Bar	USCA
Morris Ravine	USCA
Mount Bullion	USCA
Mount Gaines	USCA
Mountain King	USCA
Mt. Pleasant	USCA
Murphy N.	USCA
Nashville S.	USCA
Ophir	USCA
Paloma Gwin	USCA
Patrick	USCA
Penryn	USCA
Phoenix	USCA
Placerville	USCA
Pyramid	USCA
Rainbow	USCA
Ranch	USCA
Rich	USCA
Rich Gulch	USCA
Rindge No. 1	USCA
Royal Mt. King	USCA
R.R. Flat S.	USCA
Ryan	USCA
Sheep Ranch	USCA
Sliger	USCA
Soulsbyville	USCA
Sutter Creek	USCA
Taylor	USCA
Valley View	USCA
Washington	USCA
Whitlock E.	USCA
Whitlock W.	USCA
Wilshire-Bishop	USCA
Yankee Hill	USCA
Zeila	USCA


LOW SULFIDE QUARTZ GOLD
n = 118
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0014
0.041
1.3
0.0001
0.0004
0.0016
0.0063
0.025
0.1
0.4
1.6
6.3
25
100
TONNES (IN MILLIONS)


LOW SULFIDE QUARTZ GOLD
n = 118
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
GOLD GRADE (in g/t)
2.6
4.0
5.8
7.8
10.0
13.0
16.0
19.0
23.0
27.0
31.0
36.0
41.0
46.0
52.0
58.0
64.0
5.3
14
38


LOW SULFIDE QUARTZ GOLD
n = 118
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
5.1
0
5.1
20
46
81
130
180
250
320
410
510
SILVER GRADE (in g/t)

DEPOSIT TYPE Epithermal gold, quartz-adularia type MODEL NUMBER 5.4

AUTHOR D. L. Mosier and W. D. Menzie

COMMENTS Some of the data represent districts rather than individual deposits. The change in slope of silver grade at 40 g/t suggests the possibility of multiple populations. Lead grade is correlated with zinc grade (r = 0.83), gold grade is correlated with silver grade (r = 0.24), and gold grade is correlated with tonnage (r = -0.37).

DEPOSITS

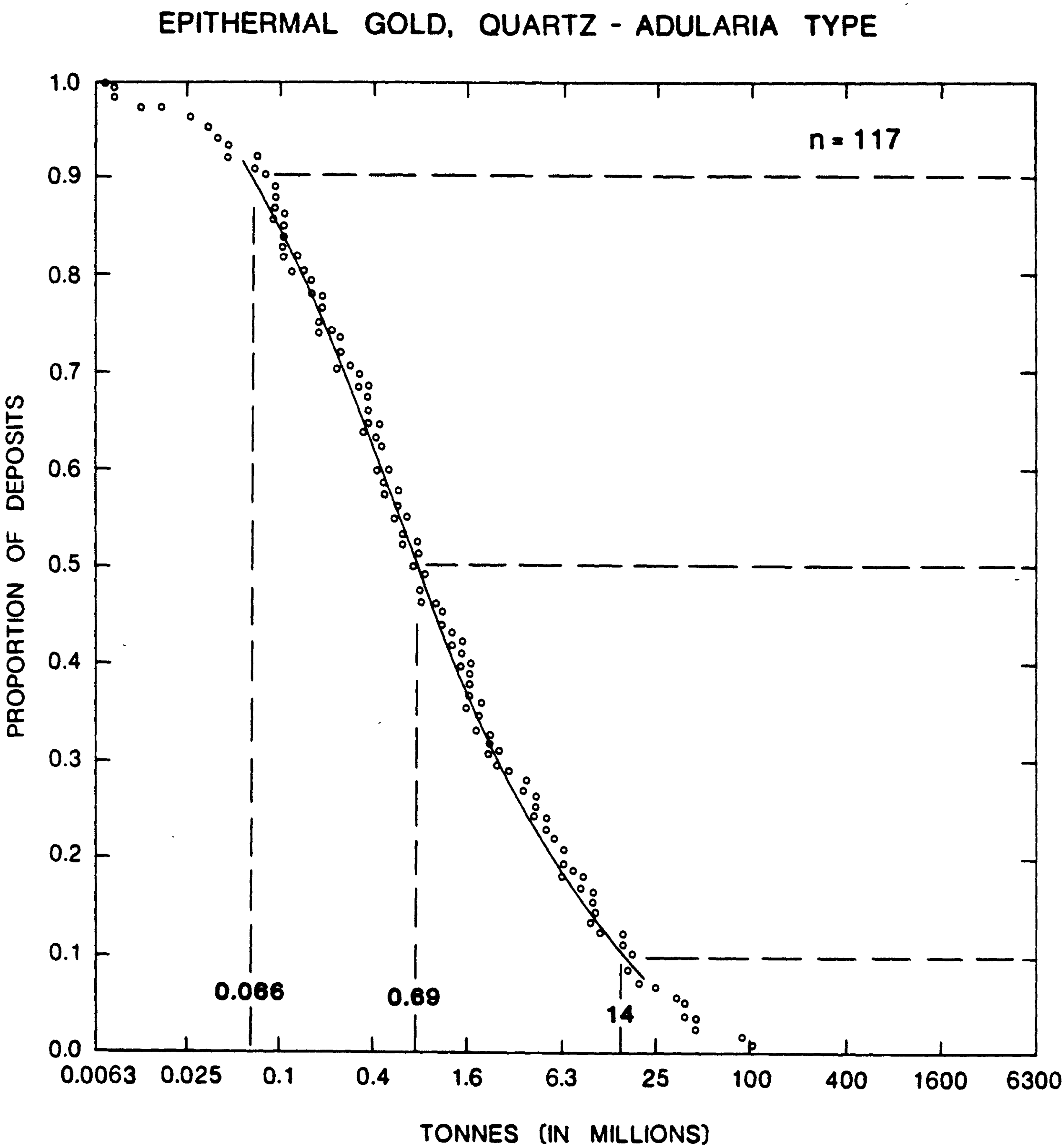
Name	Country	Name	Country
Angangueo	MXCO	Eagle Valley	USNV
Arakawa	JAPN	Eastgate	USNV
Arapdagi-Alurcakoy	TRKY	El Dorado	ELSA
Ashio	JAPN	El Rincon	MXCO
Aurora	USNV	El Tigre	MXCO
Avino	MXCO	Fairview	USNV
Bajo	JAPN	Flathead	USMT
Bellehelen	USNV	Funauchi	JAPN
Blue River	USOR	Gold Circle	USNV
Bodie	USCA	Gold Mountain	USUT
Bolanos	MXCO	Gold Spring	USUT
Bonanza	USCO	Guadalupe y Calvo	MXCO
Bovard	USNV	Guanacevi	MXCO
Bullfrog	USNV	Guanajuato	MXCO
Bruner	USNV	Hata	JAPN
Calistoga	USCA	Hosokura	JAPN
Casapalca	PERU	Hostotipaquilla	MXCO
Cerro de Pasco	PERU	Ikuno	JAPN
Chavin	PERU	Innai	JAPN
Chitose	JAPN	Jarbidge	USNV
Colqui	PERU	Julcani	PERU
Coco Mina	NCRG	Kata	JAPN
Como	USNV	Katherine	USAZ
Comstock	USNV	Kishu	JAPN
Cornucopia	USNV	Kofa	USAZ
Creede	USCO	Konomai	JAPN
Daira	JAPN	Kushikino	JAPN
Divide	USNV	La Libertad	MXCO
Dolores	MXCO	Los Mantiales	AGTN

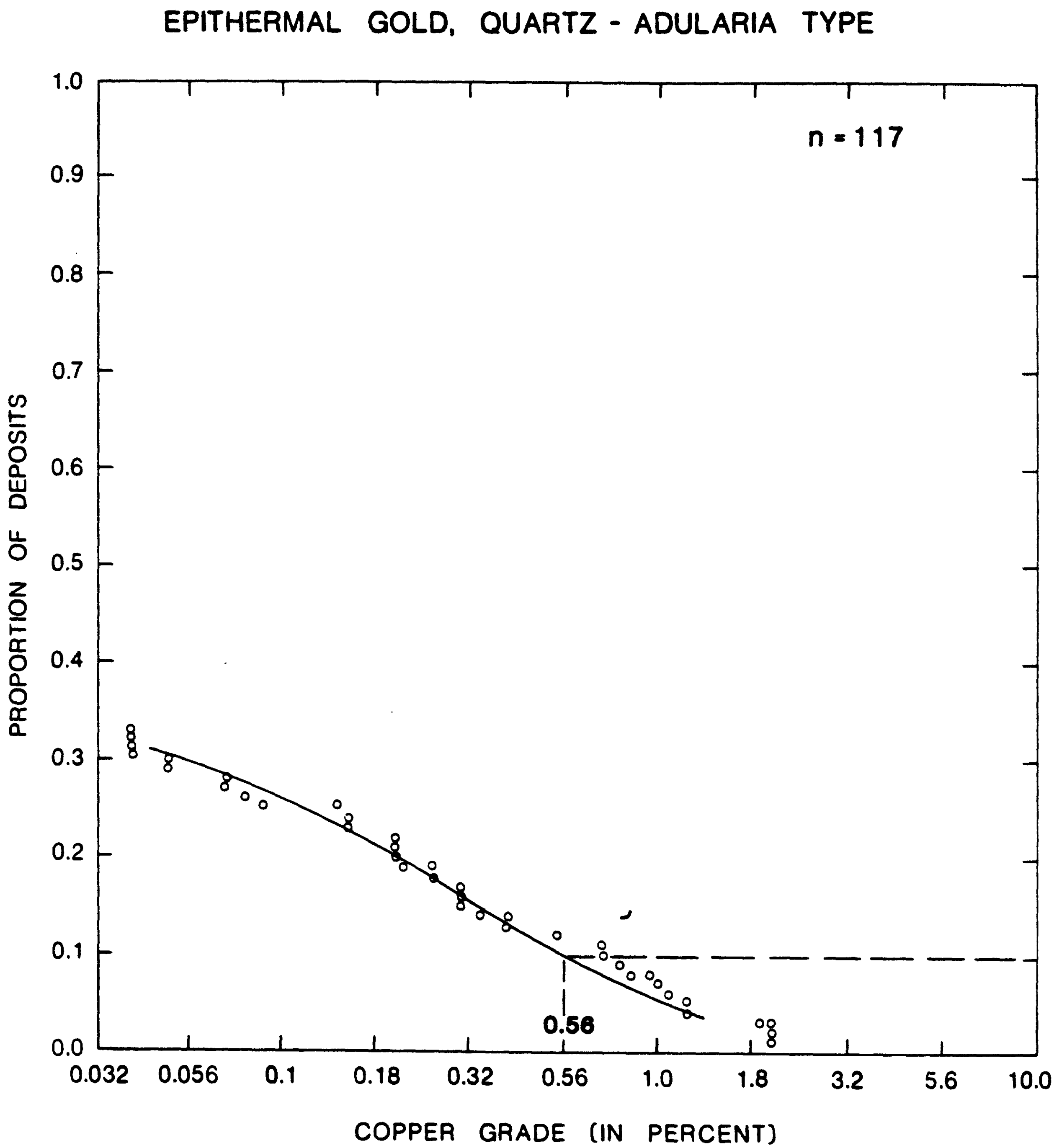
(continued on next page)

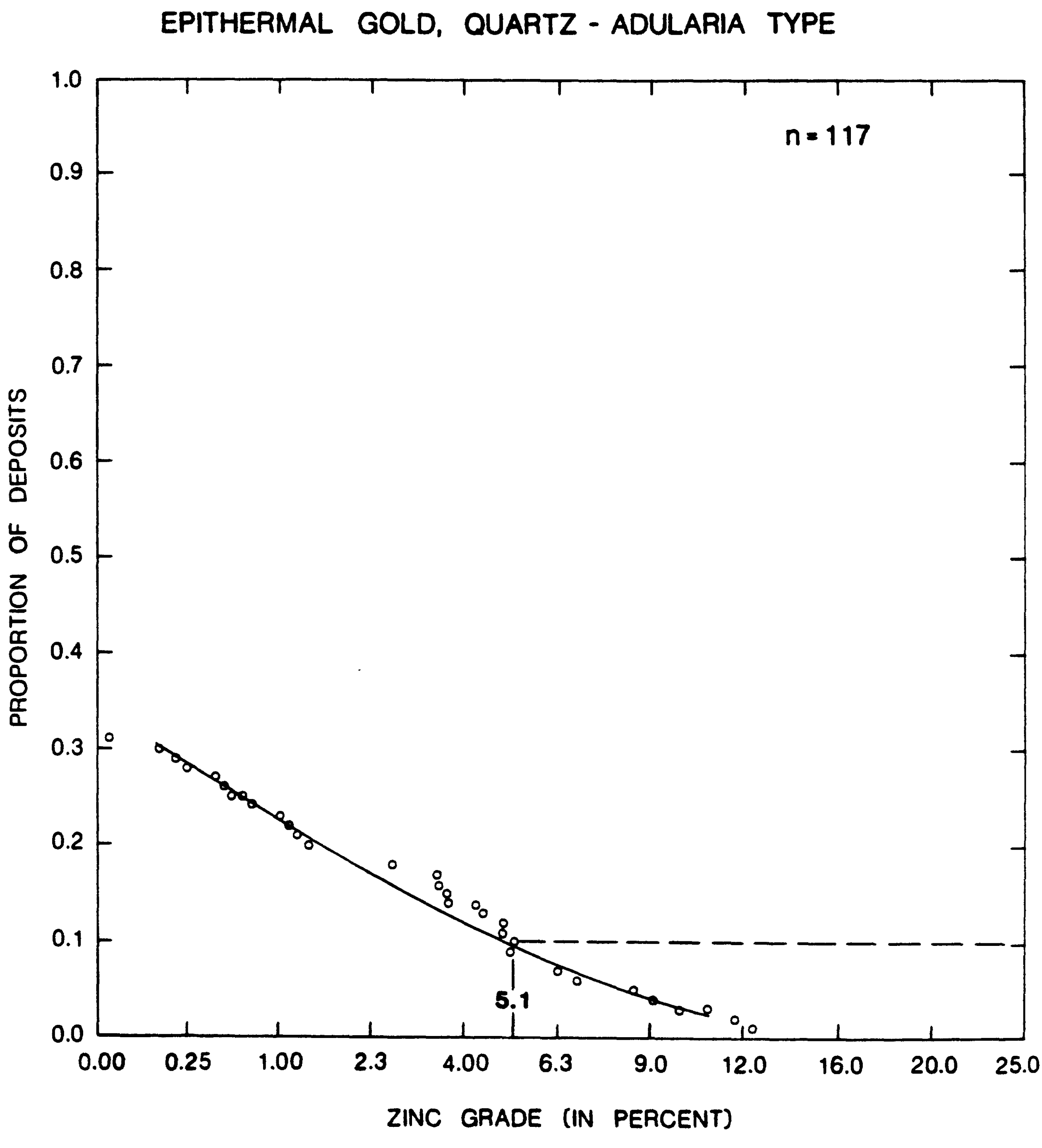
DEPOSIT TYPE Epithermal gold, quartz-adularia type MODEL NUMBER 5.4

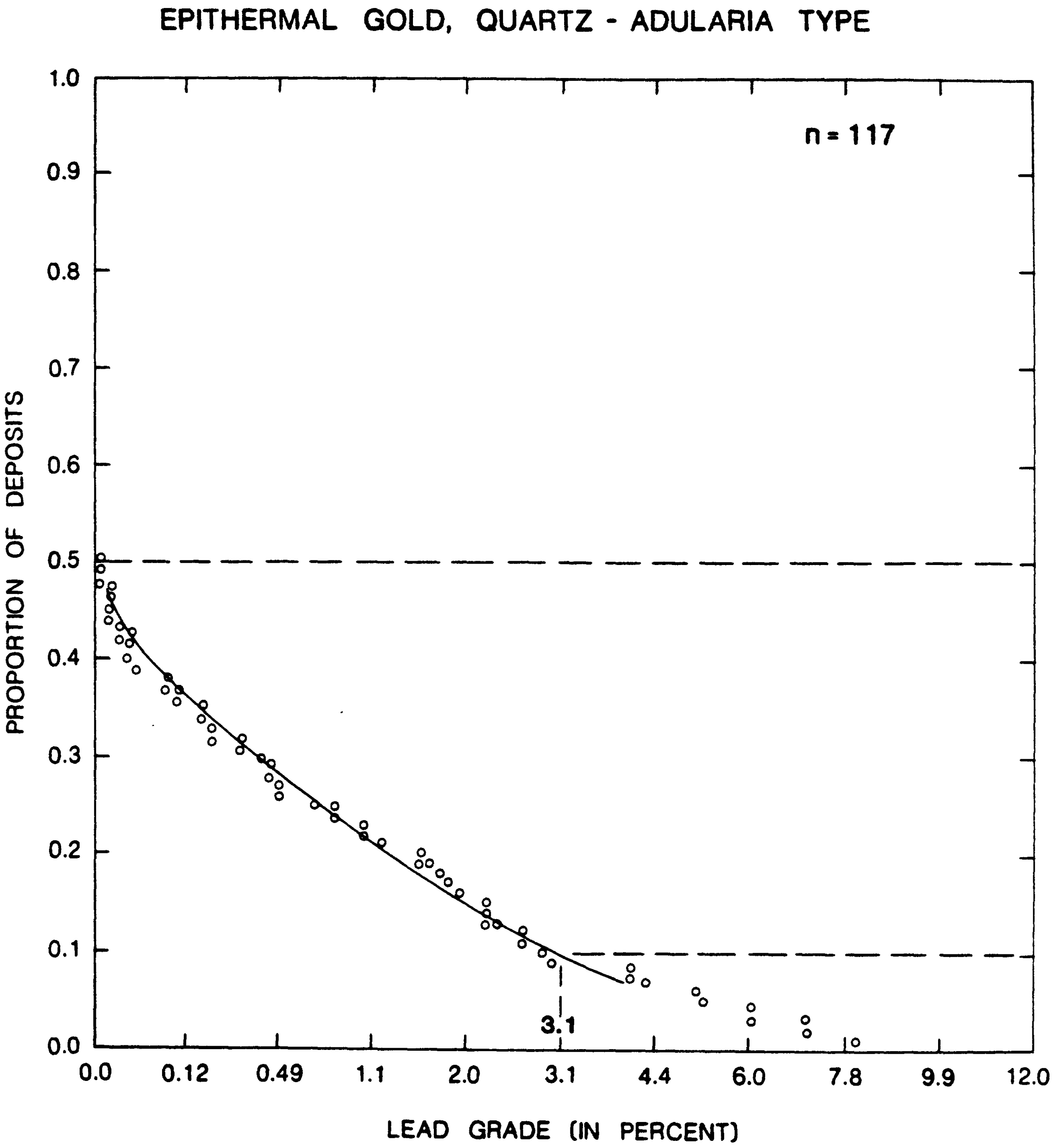
DEPOSITS (continued)

Name	Country	Name	Country
Madrigal	PERU	Sand Springs	USNV
Mikawa	JAPN	Searchlight	USNV
Minamizawa	JAPN	Seikoshi	JAPN
Mizobe	JAPN	Seven Troughs	USNV
Mochikoshi	JAPN	Sheep Tanks	USAZ
Mogollon	USNM	Shizukari	JAPN
Monitor	USCA	Silver City	USNV
Montana Mountain	CNYT	Stateline	USUT
Mount Nansen	CNYT	Steeple Rock	USNM
Nagamatsu	JAPN	Taio	JAPN
National	USNV	Taisei	JAPN
Nawaji	JAPN	Takatama	JAPN
Neves Corvo	PERU	Tambo Grande	PERU
Nogal	USNM	Tayolita	MXCO
Numanoue	JAPN	Telluride	USCO
Oatman	USNV	Todoroki	JAPN
Odomori	JAPN	Toi	JAPN
Ogane	JAPN	Tokusei	JAPN
Ohito	JAPN	Tonopah	USNV
Oizumi	JAPN	Topia	MXCO
Osarizawa	JAPN	Toyoha	JAPN
Otaez	MXCO	Tuscarora	USNV
Pacheco-Real del Monte	MXCO	Unga	USAK
Provenir	PERU	Urauchic	MXCO
Pueblo Viejo	DMRP	Waihi	NZLD
Rawhide	USNV	Wonder	USNV
Republic	USWA	Yoquivo	MXCO
Rio Pallanga	PERU	Yugashima	JAPN
Rosario	HNDR	Zeh Abad	IRAN
Sado	JAPN		


EPITHERMAL GOLD, QUARTZ - ADULARIA TYPE
n = 117
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.066
0.69
14
0.0063
0.025
0.1
0.4
1.6
6.3
25
100
400
1600
6300
TONNES (IN MILLIONS)

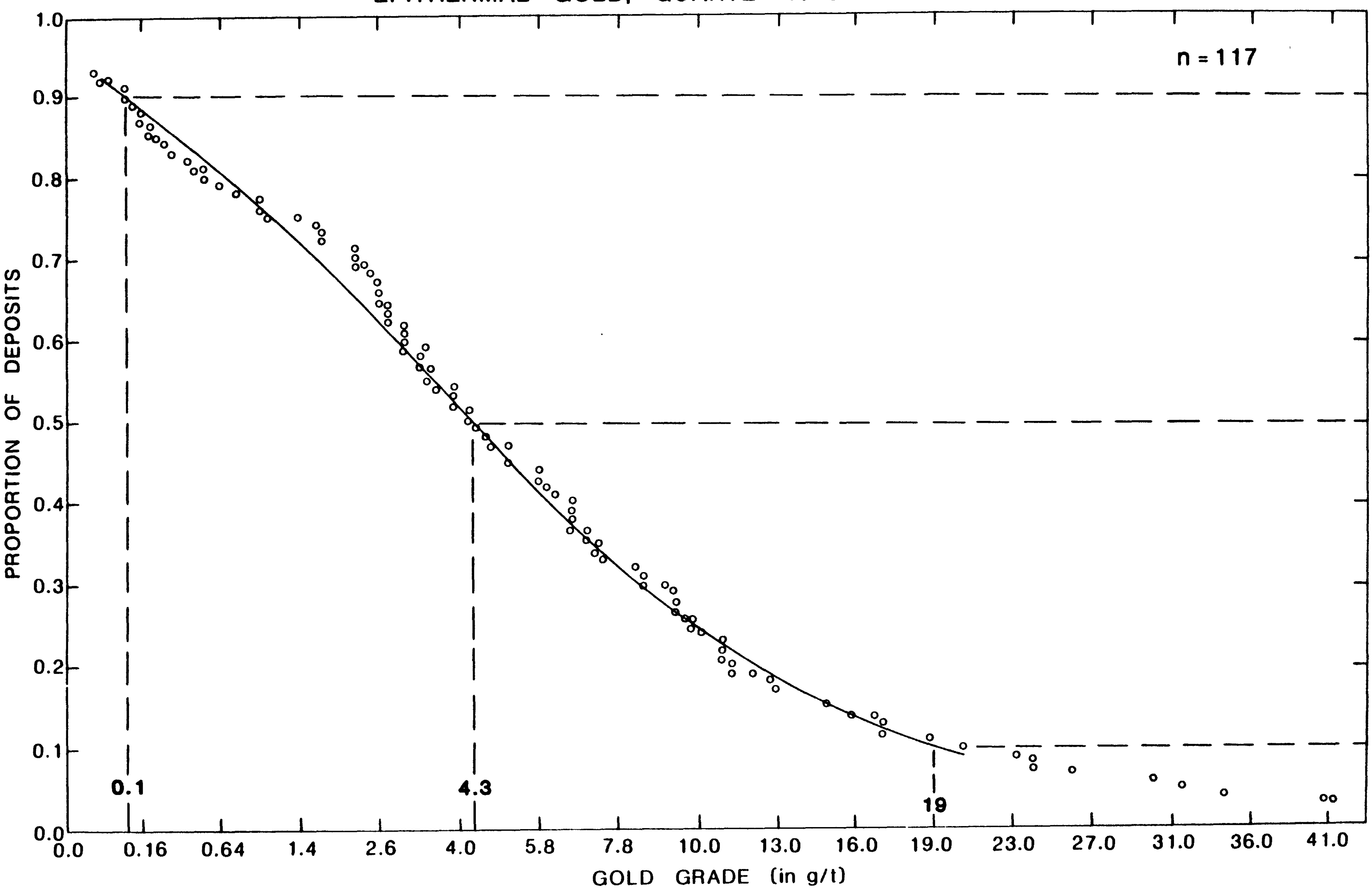

EPITHERMAL GOLD, QUARTZ - ADULARIA TYPE
n = 117
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.56
0.032
0.056
0.1
0.18
0.32
0.56
1.0
1.8
3.2
5.6
10.0
COPPER GRADE (IN PERCENT)

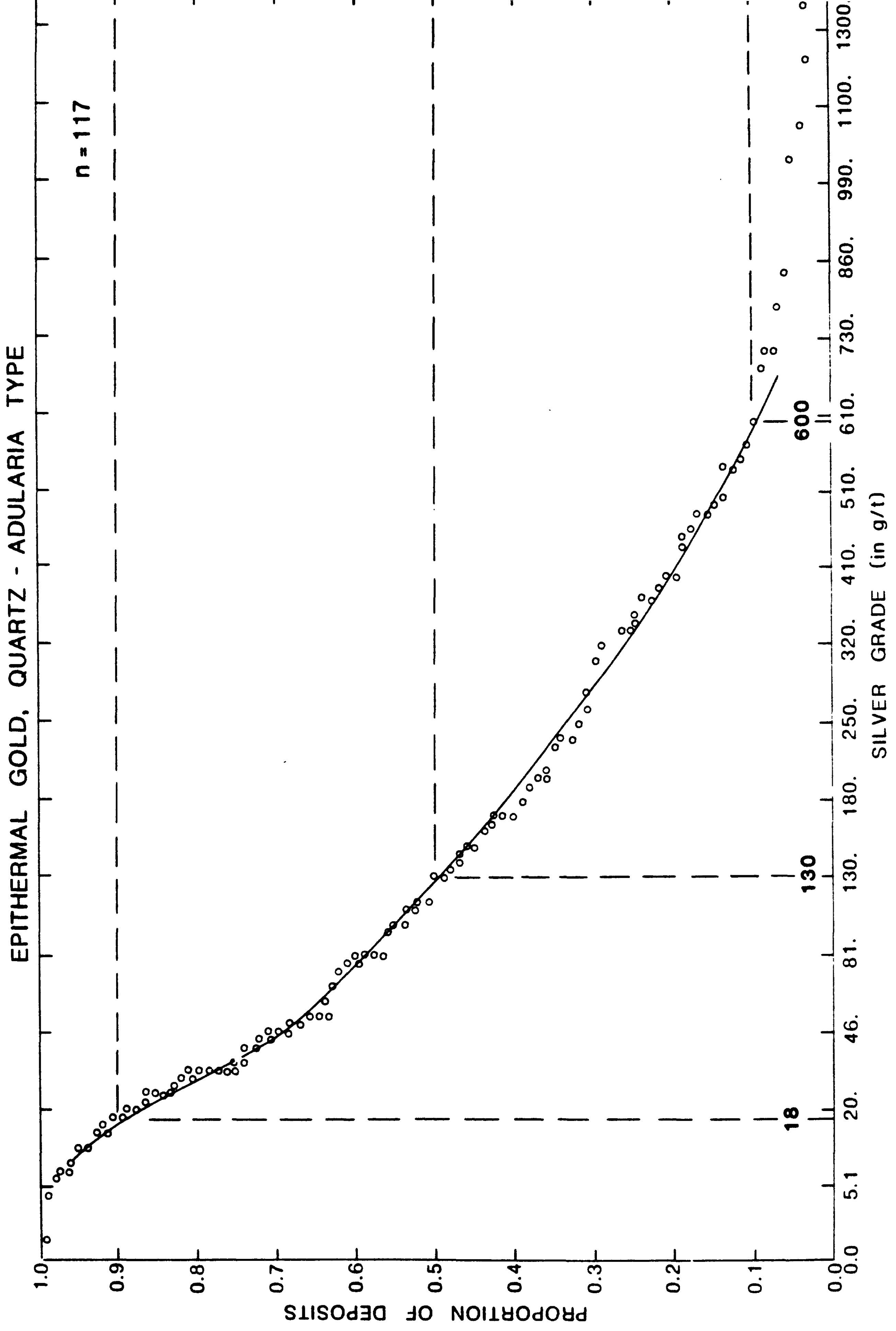

EPITHERMAL GOLD, QUARTZ - ADULARIA TYPE
n = 117
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PROPORTION OF DEPOSITS
5.1
0.00
0.25
1.00
2.3
4.00
6.3
9.0
12.0
16.0
20.0
25.0
ZINC GRADE (IN PERCENT)



EPITHERMAL GOLD, QUARTZ - ADULARIA TYPE
n = 117
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PROPORTION OF DEPOSITS
3.1
0.0
0.12
0.49
1.1
2.0
3.1
4.4
6.0
7.8
9.9
12.0
LEAD GRADE (IN PERCENT)

EPITHERMAL GOLD, QUARTZ - ADULARIA TYPE




EPITHERMAL GOLD, QUARTZ - ADULARIA TYPE
n = 117
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
SILVER GRADE (in g/t)
0.0
5.1
20.
46.
81.
130.
180.
250.
320.
410.
510.
610.
730.
860.
990.
1100.
1300.
18
130
600

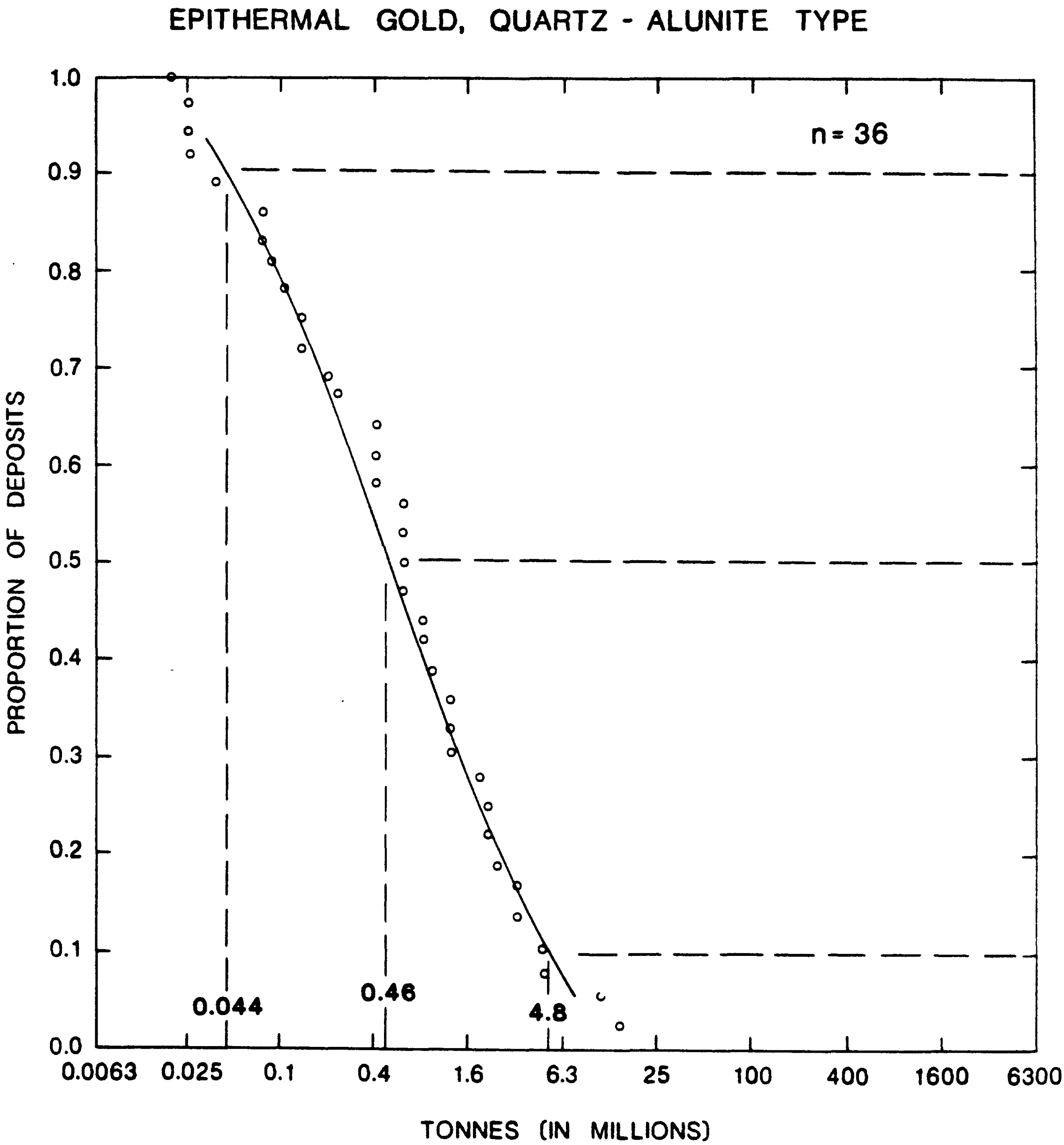
DEPOSIT TYPE Epithermal gold, quartz-alunite type MODEL NUMBER 5.5

AUTHOR D. L. Mosier and W. D. Menzie

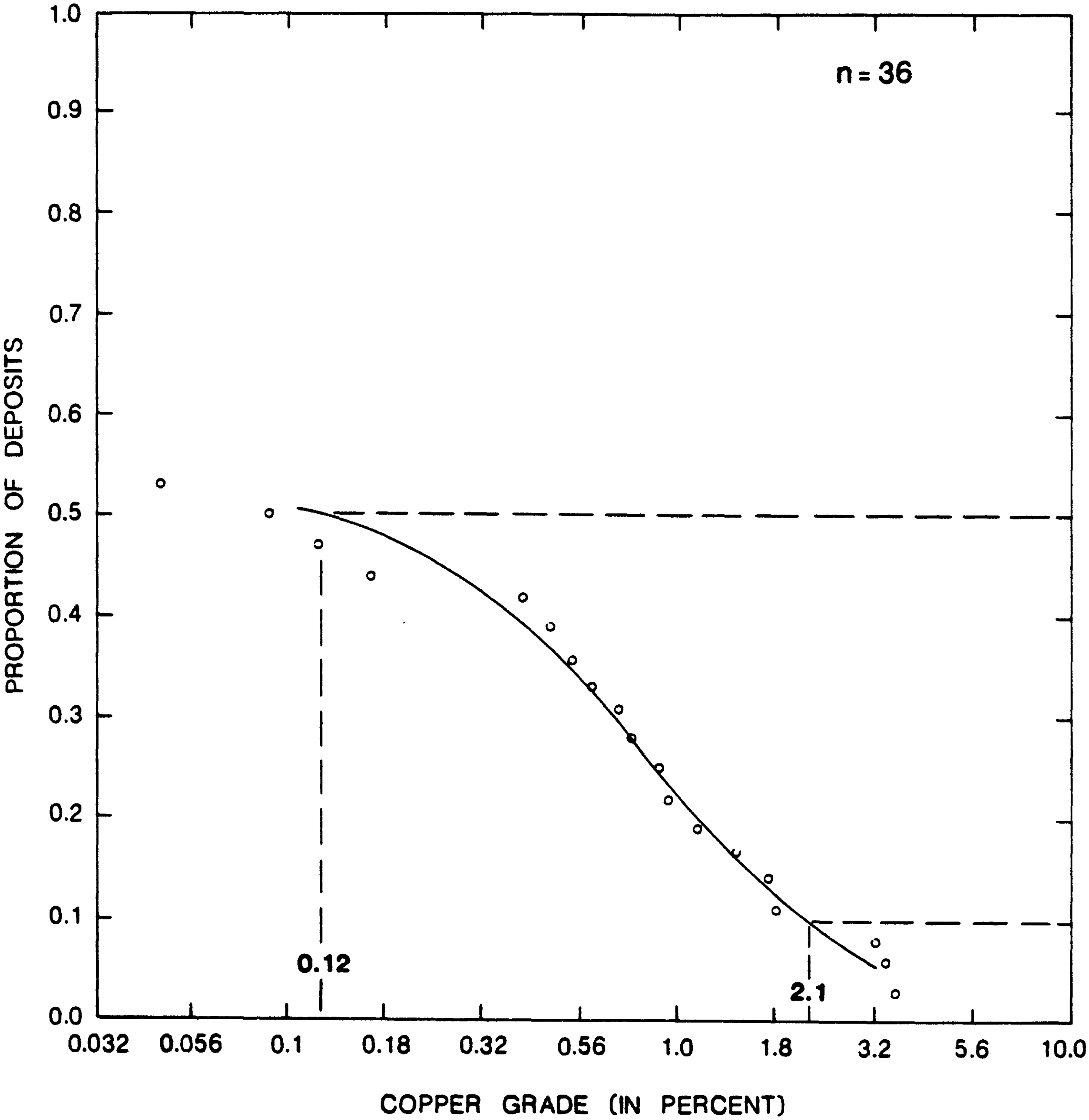
COMMENTS none

DEPOSITS

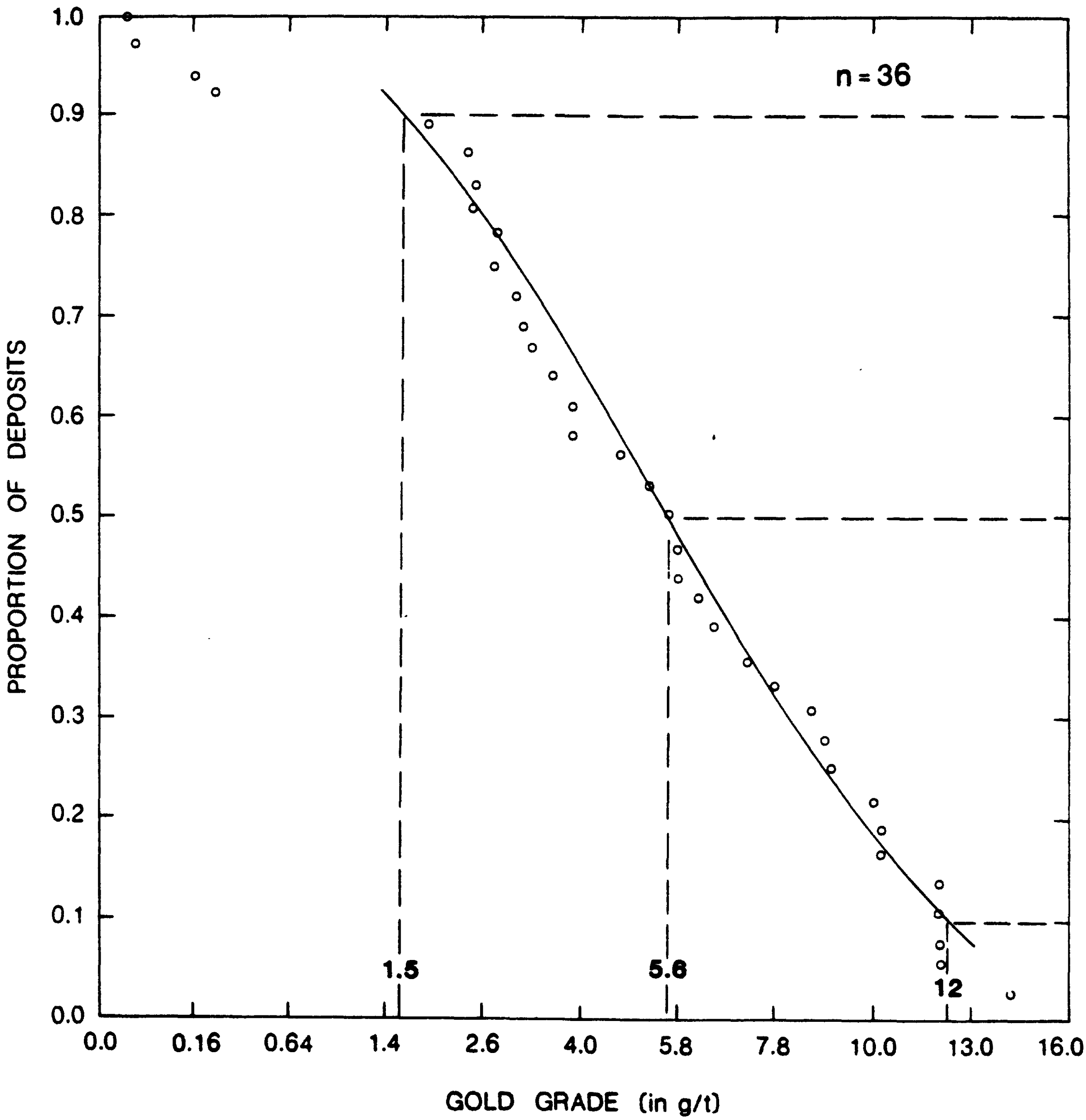
Name	Country
Akabane	JAPN
Akaishi	JAPN
Ani	JAPN
Benten	JAPN
Borealis	USNV
Chinkuashih	TIWN
El Indio	CILE
Eniwa	JAPN
Fuke	JAPN
Furokura	JAPN
Goldfield	USNV
Hiyama	JAPN
Hokuryu	JAPN
Iwato	JAPN
Kasuga	JAPN
Kawasaki	JAPN
Kitanoo	JAPN
Kushikino-Hajima	JAPN
Kushikino-Otani	JAPN
Mamuro	JAPN
Masbate	PLPN
Masonic	USCA
Mohave	USCA
Nikko	JAPN
Oguchi	JAPN
Okinoura	JAPN
Okuzu	JAPN
Orient	USWA
Sanei	JAPN
Sanru	JAPN
Stedman	USCA
Takahata	JAPN
Takeno	JAPN
Teine	JAPN
Tomisu	JAPN
Tozawa	JAPN

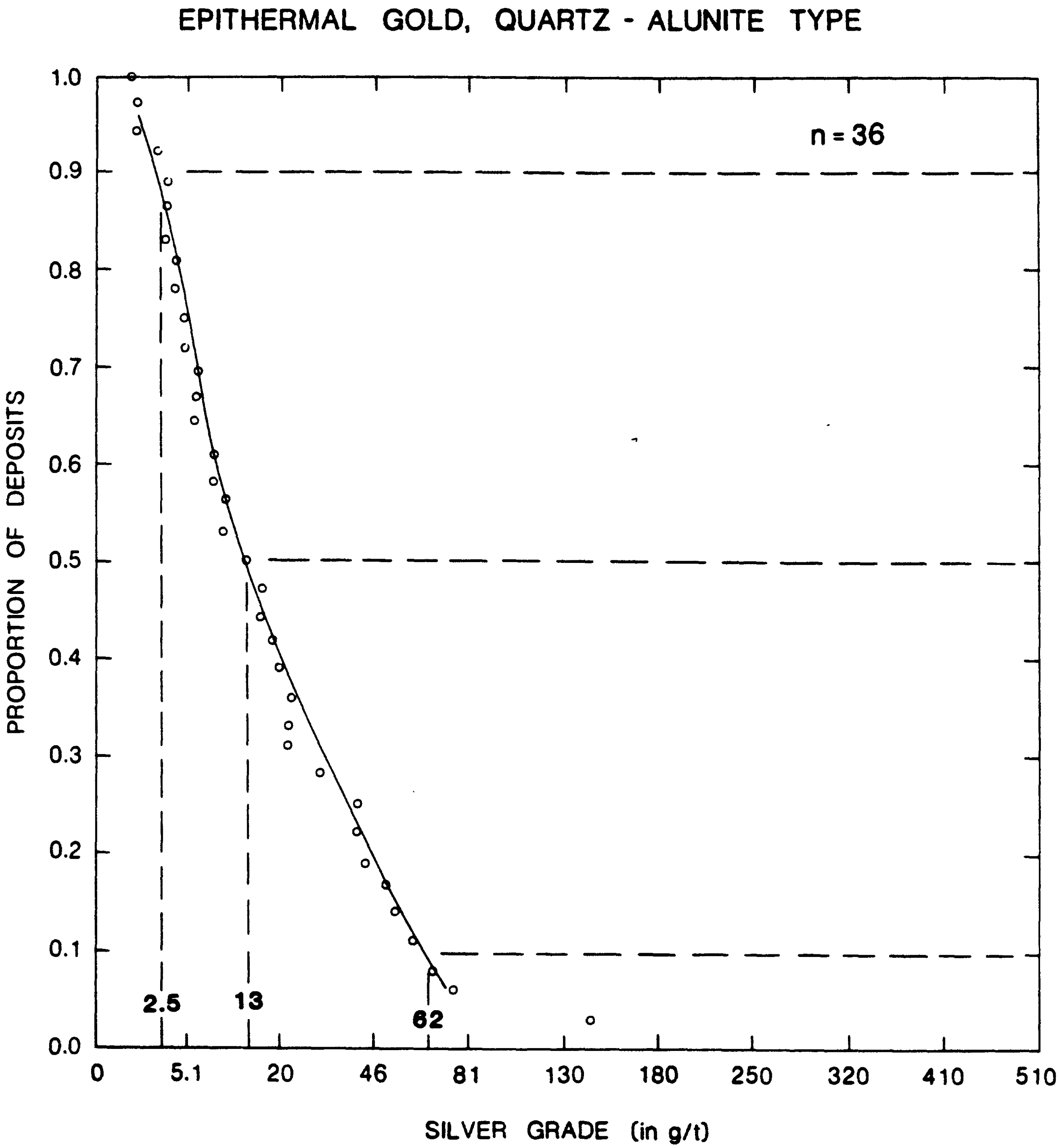

EPITHERMAL GOLD, QUARTZ - ALUNITE TYPE
n= 36
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.044
0.46
4.8
0.0063
0.025
0.1
0.4
1.6
6.3
25
100
400
1600
6300
TONNES (IN MILLIONS)

EPITHERMAL GOLD, QUARTZ - ALUNITE TYPE



EPITHERMAL GOLD, QUARTZ - ALUNITE TYPE




EPITHERMAL GOLD, QUARTZ - ALUNITE TYPE
n = 36
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2.5
13
62
0
5.1
20
46
81
130
180
250
320
410
510
SILVER GRADE (in g/t)

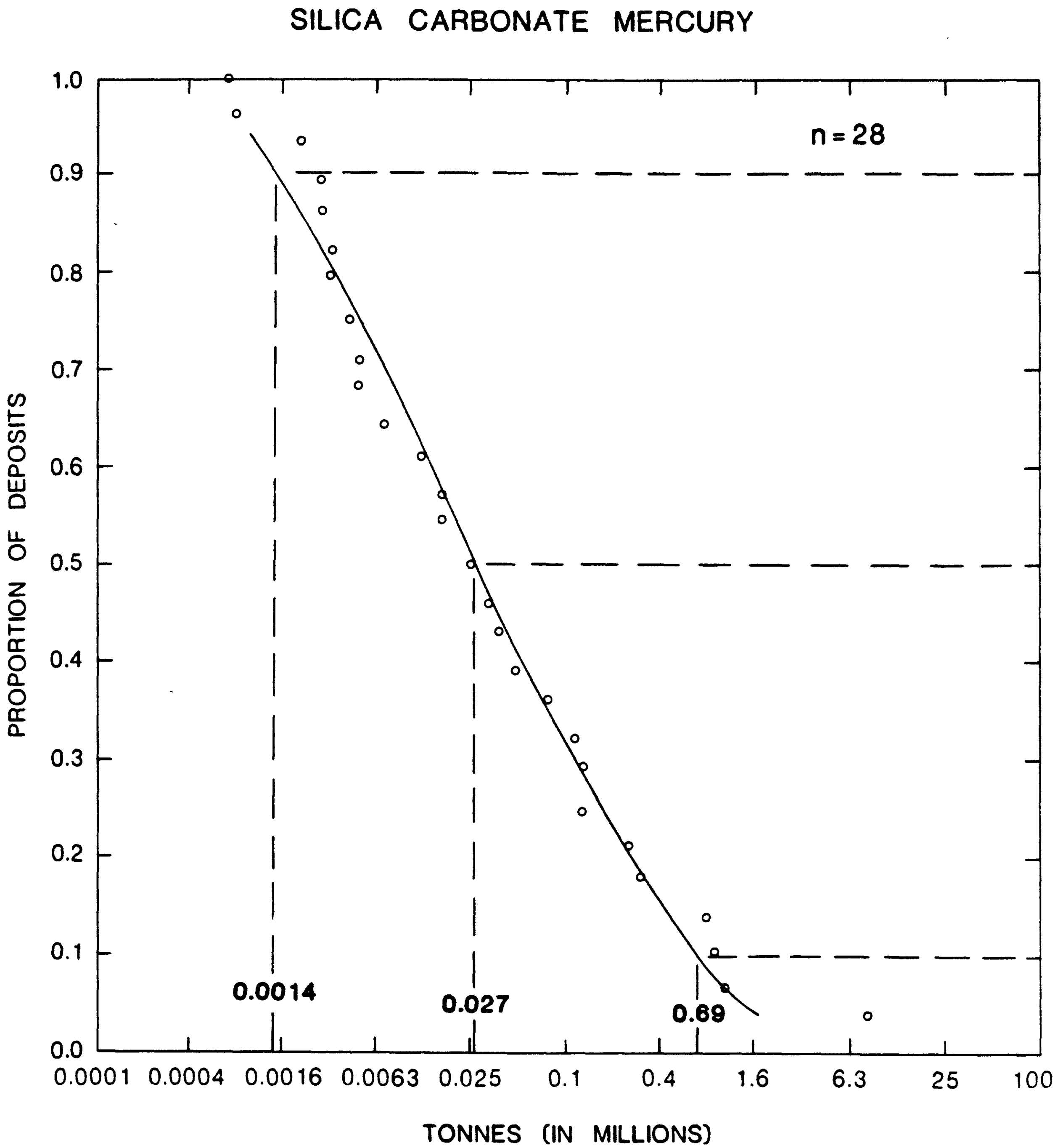
DEPOSIT TYPE Silica-carbonate mercury MODEL NUMBER 5.8

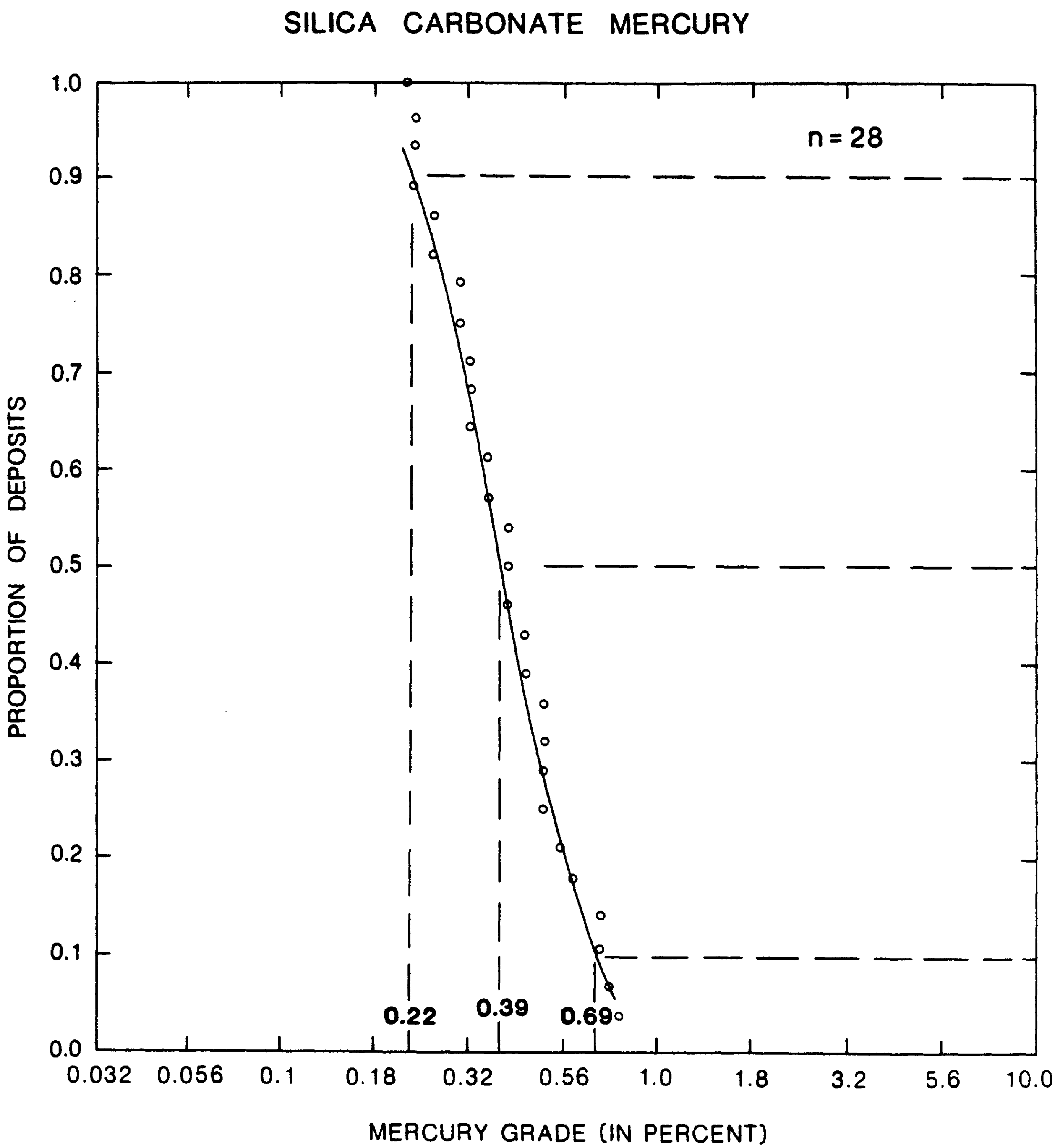
AUTHOR J.J. Rytuba and S. Cargill

COMMENTS

DEPOSITS

Name	Country
Abbott	USCA
Aetna	USCA
Bella Oak	USCA
Chicago	USCA
Contact	USCA
Corona	USCA
Culver Bear	USCA
Dewey's	USCA
Esperanza	USCA
Great Eastern-Mt. Jackson	USCA
Harrison	USCA
Helen	USCA
Keystone	USCA
Knoxville	USCA
La Joya	USCA
La Libertad	USCA
Lion Den	USCA
Mirabel	USCA
Mt. Diablo	USCA
New Almaden	USCA
Patriquin	USCA
Polar Star	USCA
Red Elephant	USCA
Red Rick	USCA
Reed	USCA
Socrates	USCA
Twin Peaks	USCA
Wall Street	USCA


SILICA CARBONATE MERCURY
n = 28
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0014
0.027
0.69
0.0001
0.0004
0.0016
0.0063
0.025
0.1
0.4
1.6
6.3
25
100
TONNES (IN MILLIONS)


SILICA CARBONATE MERCURY
n = 28
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.22
0.39
0.69
0.032
0.056
0.1
0.18
0.32
0.56
1.0
1.8
3.2
5.6
10.0
MERCURY GRADE (IN PERCENT)

DEPOSIT TYPE Hot springs mercury

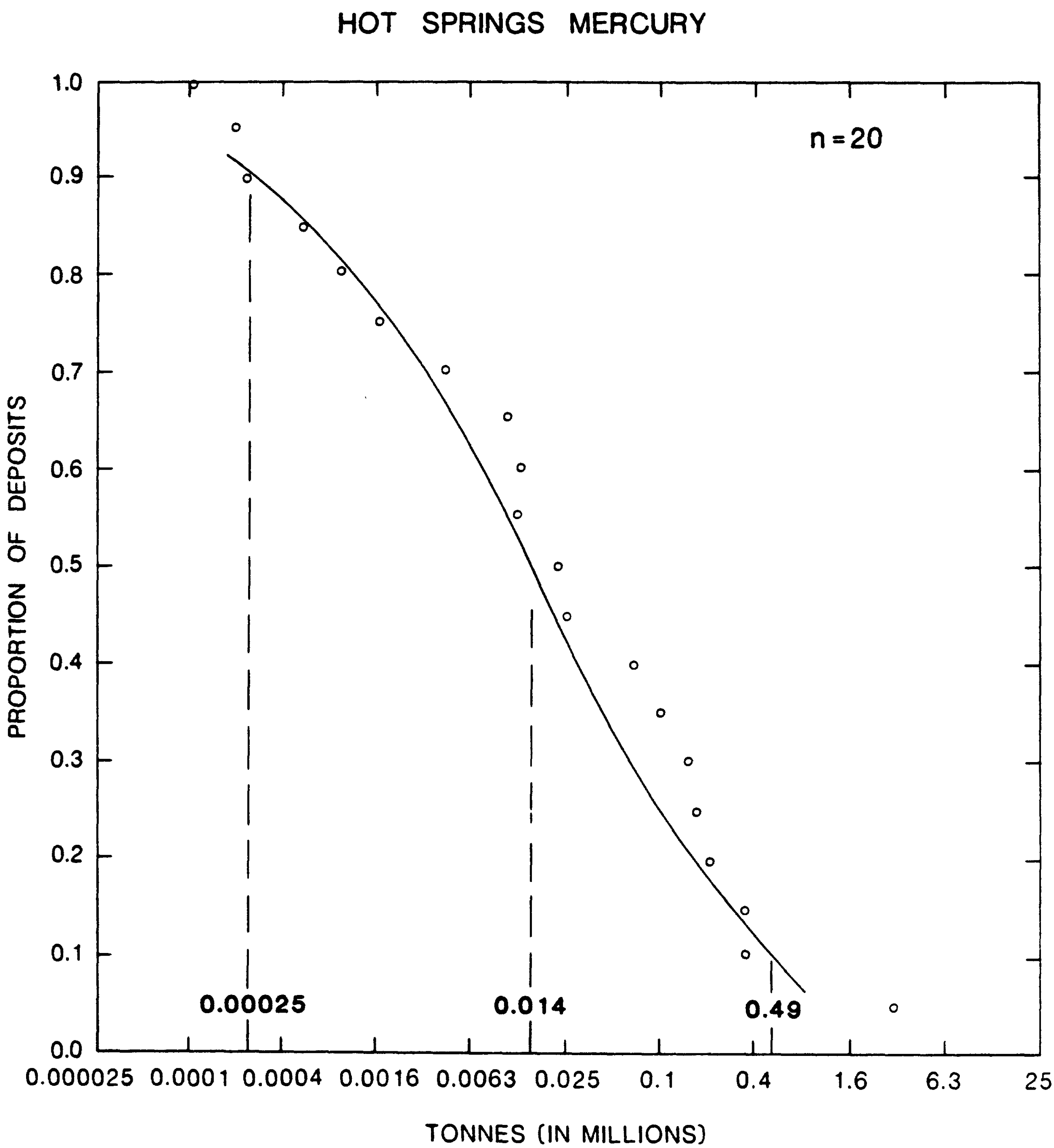
MODEL NUMBER 5.9

AUTHOR J. J. Rytuba

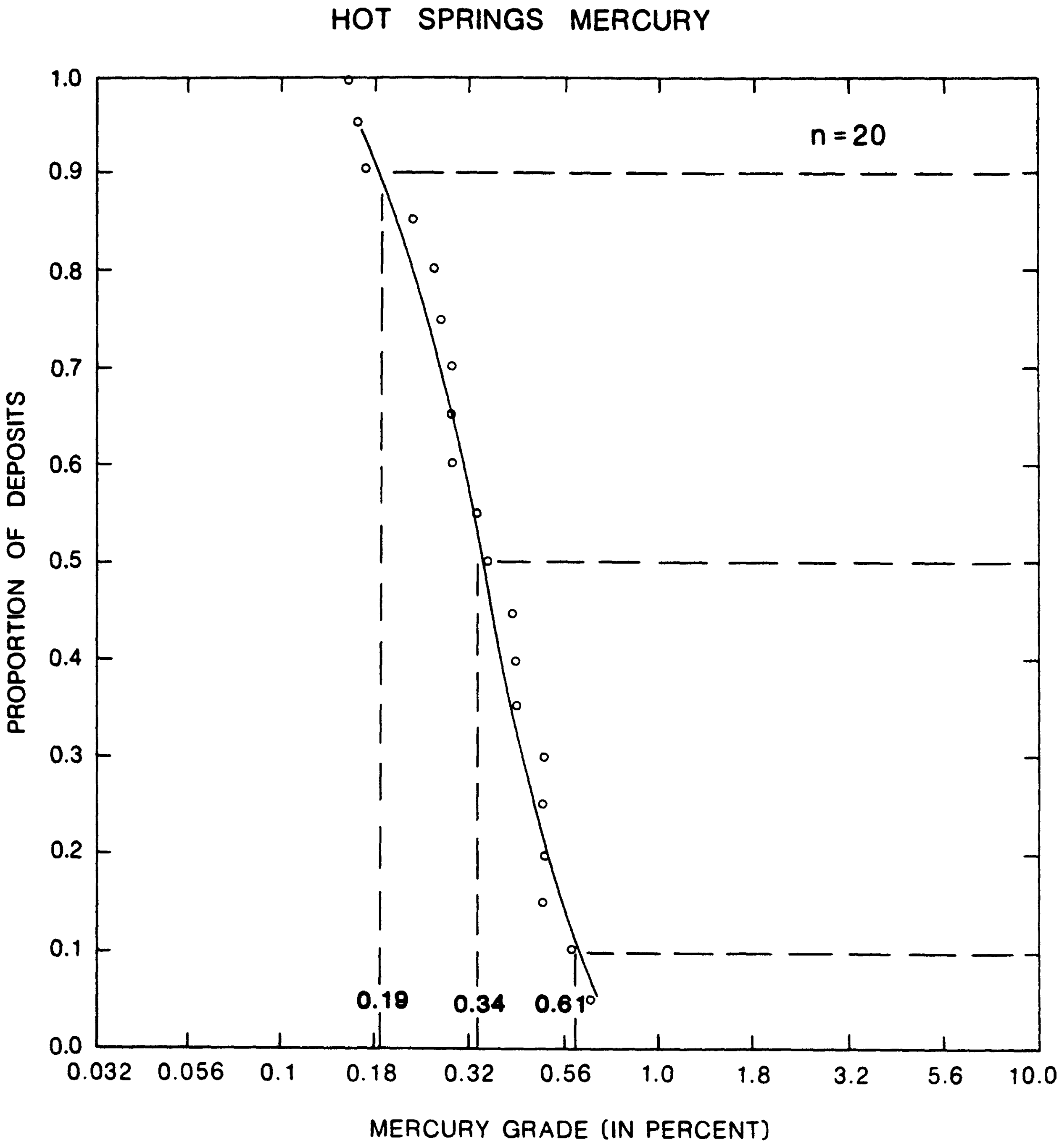
COMMENTS

DEPOSITS

Name	Country
Baldwin	USNV
B and B	USNV
Bretz	USOR
Butte	USNV
Coleman	USNV
Cordero	USNV
F and L Mine	USNV
Glass Butte	USOR
Goldbanks	USNV
Governor	USNV
Idaho Almaden	USID
Mahattan	USCA
McDermitt	USNV
Nevada Sulphur co.	USNV
Opalite	USOR
Rim Rock and Homestake	USNV
Silver Cloud	USNV
Steamboat Springs	USNV
Sulphur Bank	USCA
Walibu	USCA



HOT SPRINGS MERCURY
n = 20
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.00025
0.014
0.49
0.000025
0.0001
0.0004
0.0016
0.0063
0.025
0.1
0.4
1.6
6.3
25
TONNES (IN MILLIONS)


HOT SPRINGS MERCURY
n = 20
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PROPORTION OF DEPOSITS
0.19
0.34
0.61
0.032
0.056
0.1
0.18
0.32
0.56
1.0
1.8
3.2
5.6
10.0
MERCURY GRADE (IN PERCENT)

DEPOSIT TYPE Subaerial volcanogenic manganese   MODEL NUMBER 5.13

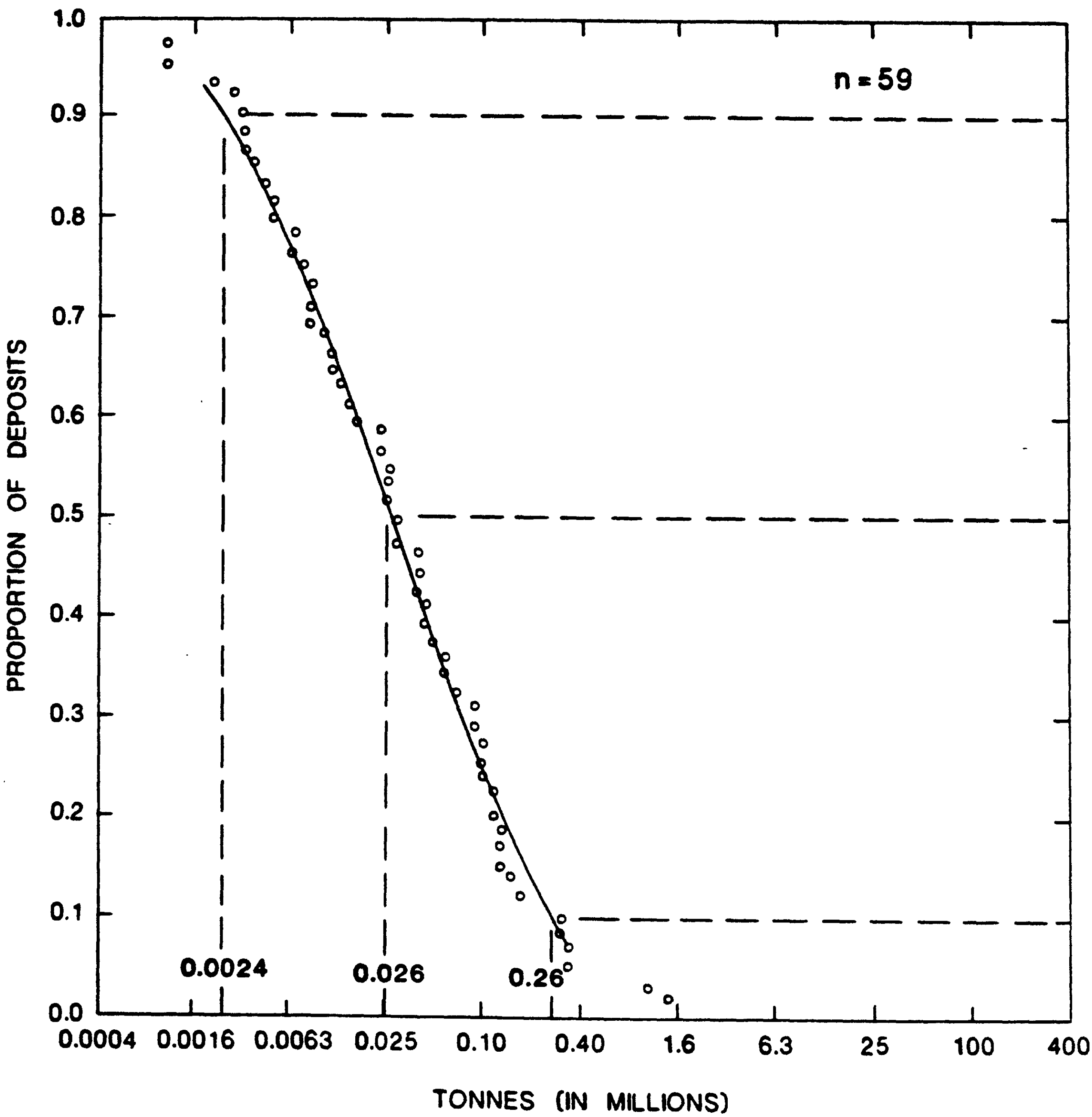
AUTHOR D. L. Mosier

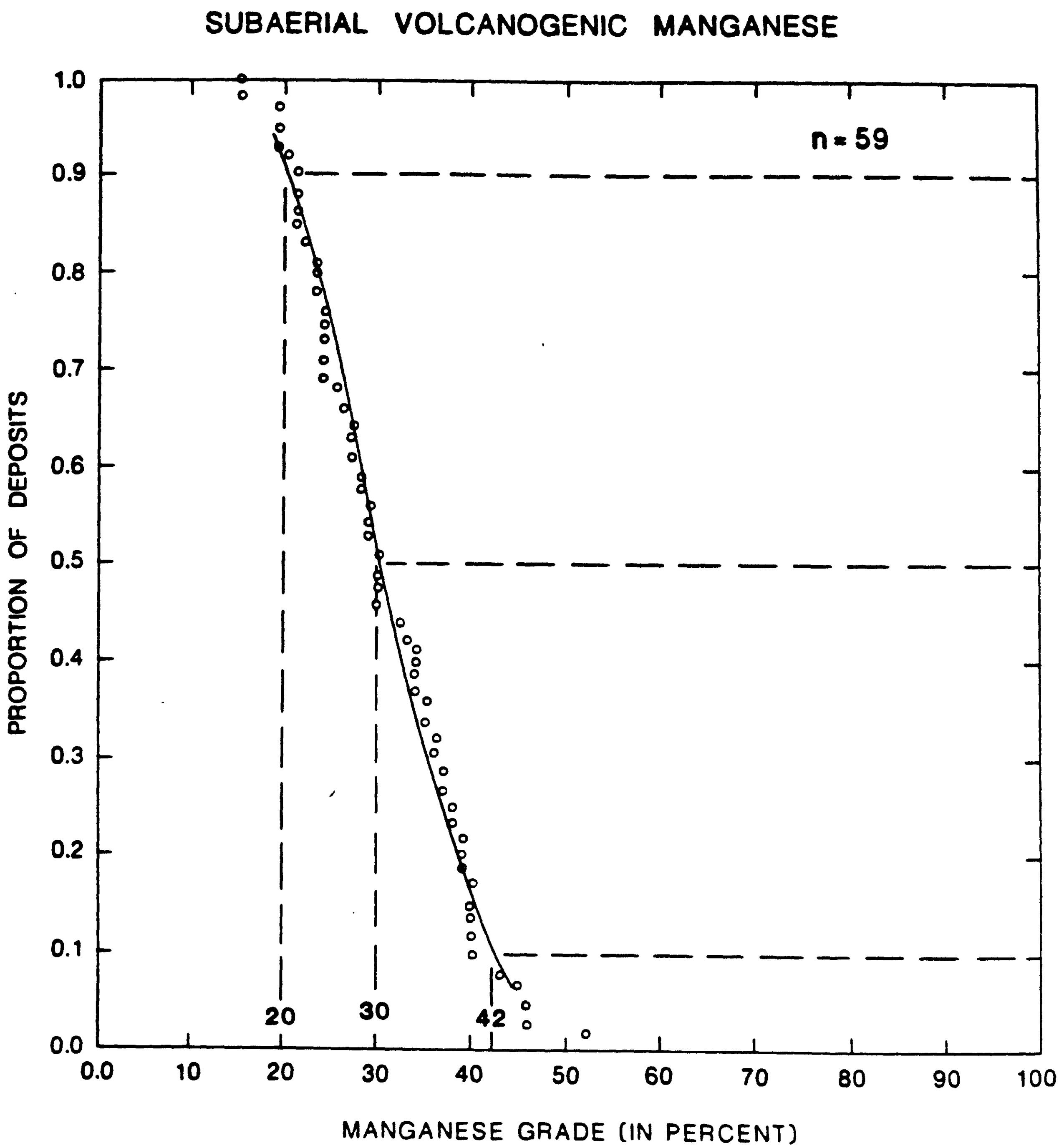
COMMENTS Manganese grade is correlated with tonnage at the 5% level (r=-0.28).

DEPOSITS

Name	Country	Name	Country
Abra Negra	MXCO	Murguia	MXCO
Armour Group	USAZ	Nacozari	MXCO
Atenguillo	MXCO	Niggerhead	USNM
Black Crow-San Juan	USNM	Oviachic 1&2	MXCO
California Group	USAZ	Phillips Lease	USNM
Casa de Janos	MXCO	Pito Real	MXCO
Casas Grandes	MXCO	Red Hill-Red Hill Ext.	USNM
Ciudad Obregon	MXCO	St. Pietro	ITLY
Cliff Roy	USNM	San Bernardo	MXCO
Estacion Llanos	MXCO	San Miguel El Alto	MXCO
Gloryana	USNM	Santa Ana	MXCO
Griffith	USNM	Sardegna	ITLY
Hatton	USAZ	Satevo	MXCO
J.M. Meadows Group	USAZ	Selimiye	TRKY
JVB Claim	USNM	Shag Rock	CNBC
Karangnunggal	INDS	Sierra de El Alto	MXCO
Karatas	TRKY	Sierra de Enmedio	MXCO
Kliripan	INDS	Sierra Los Organos	MXCO
Lajas	MXCO	Soto	MXCO
La Leona	MXCO	Talamantes	MXCO
La Noria	MXCO	Terrenates	MXCO
Las Varas-La Vaca	MXCO	Thurston & Hardy	USAZ
Los Borregos	MXCO	Topock	USAZ
Los Volcanes	MXCO	Turfullar	TRKY
M and M Group	USNM	U.S. Group	USAZ
Manganese Chief	USNM	Viterbo-Roma	ITLY
Manganese Development	USAZ	West Niggerhead	USNM
Matamoros	MXCO	Yahualica	MXCO
Mezcala	MXCO	Zacate-Cerro Chino	MXCO
Montosa	MXCO		

SUBAERIAL VOLCANOGENIC MANGANESE




SUBAERIAL VOLCANOGENIC MANGANESE
n = 59
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
20
30
42
0.0
10
20
30
40
50
60
70
80
90
100
MANGANESE GRADE (IN PERCENT)

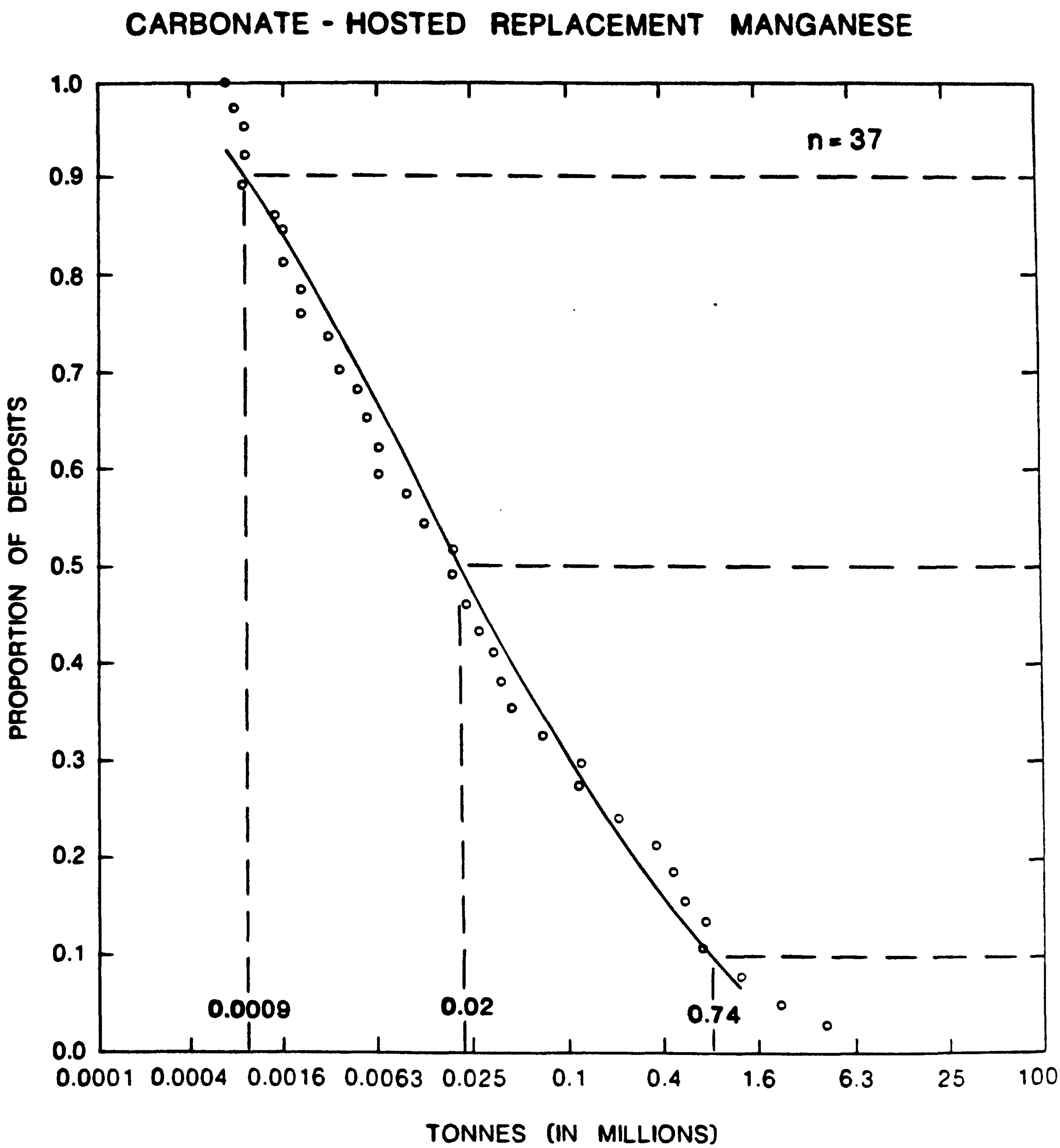
DEPOSIT TYPE Carbonate-hosted replacement manganese MODEL NUMBER 5.14

AUTHOR D. L. Mosier

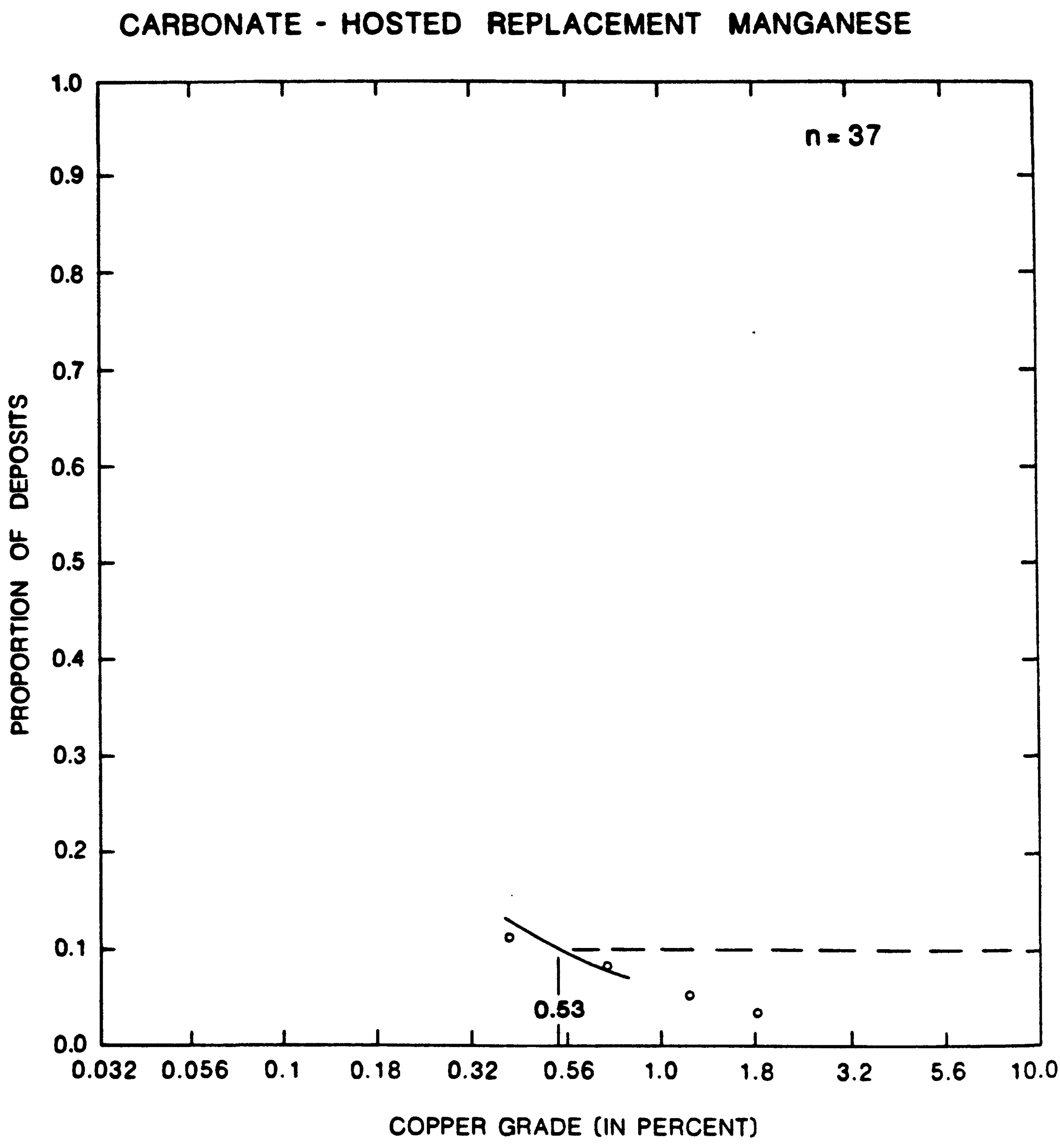
COMMENTS Copper grades are only available for some of the low tonnage deposits.

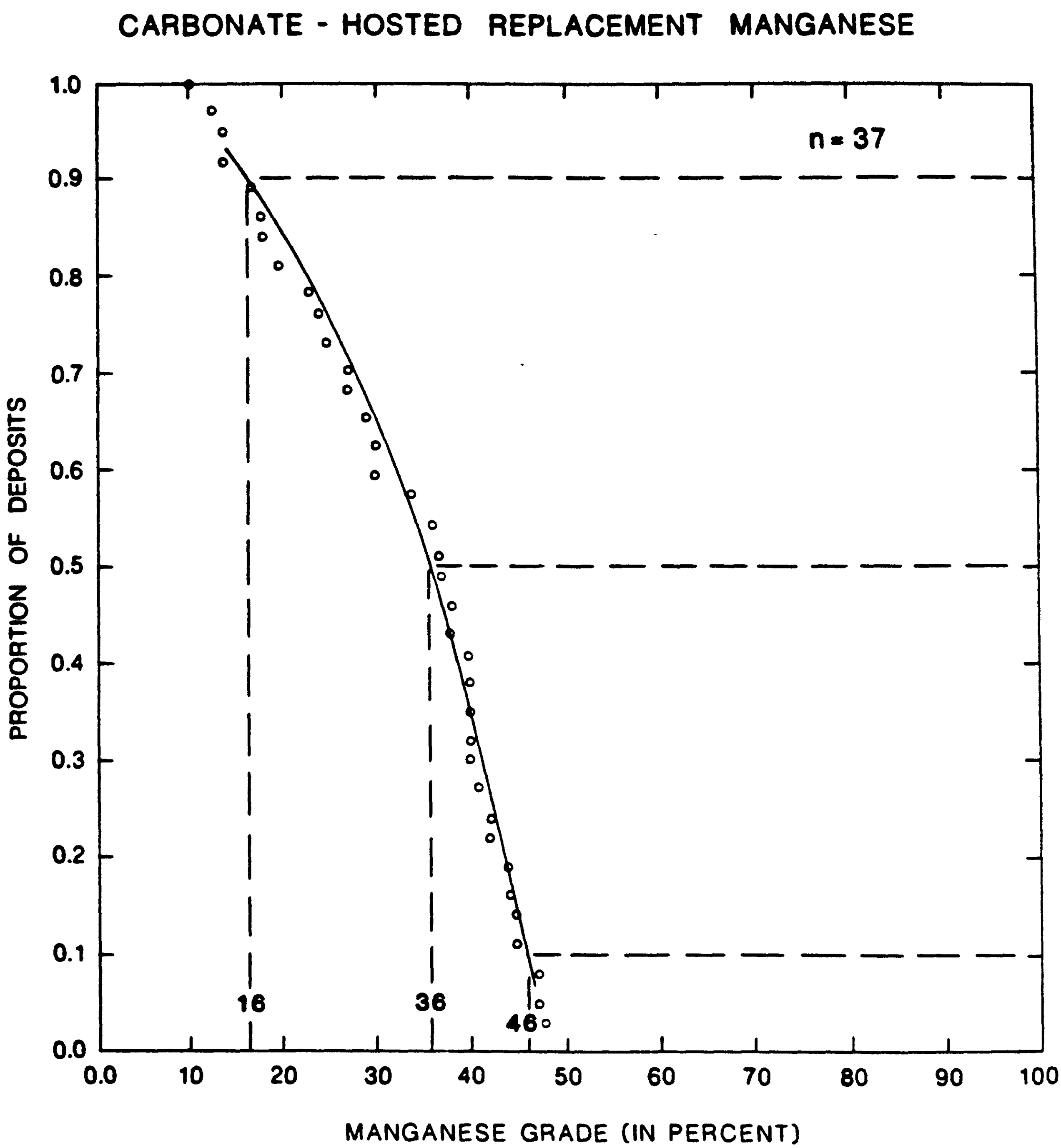
DEPOSITS

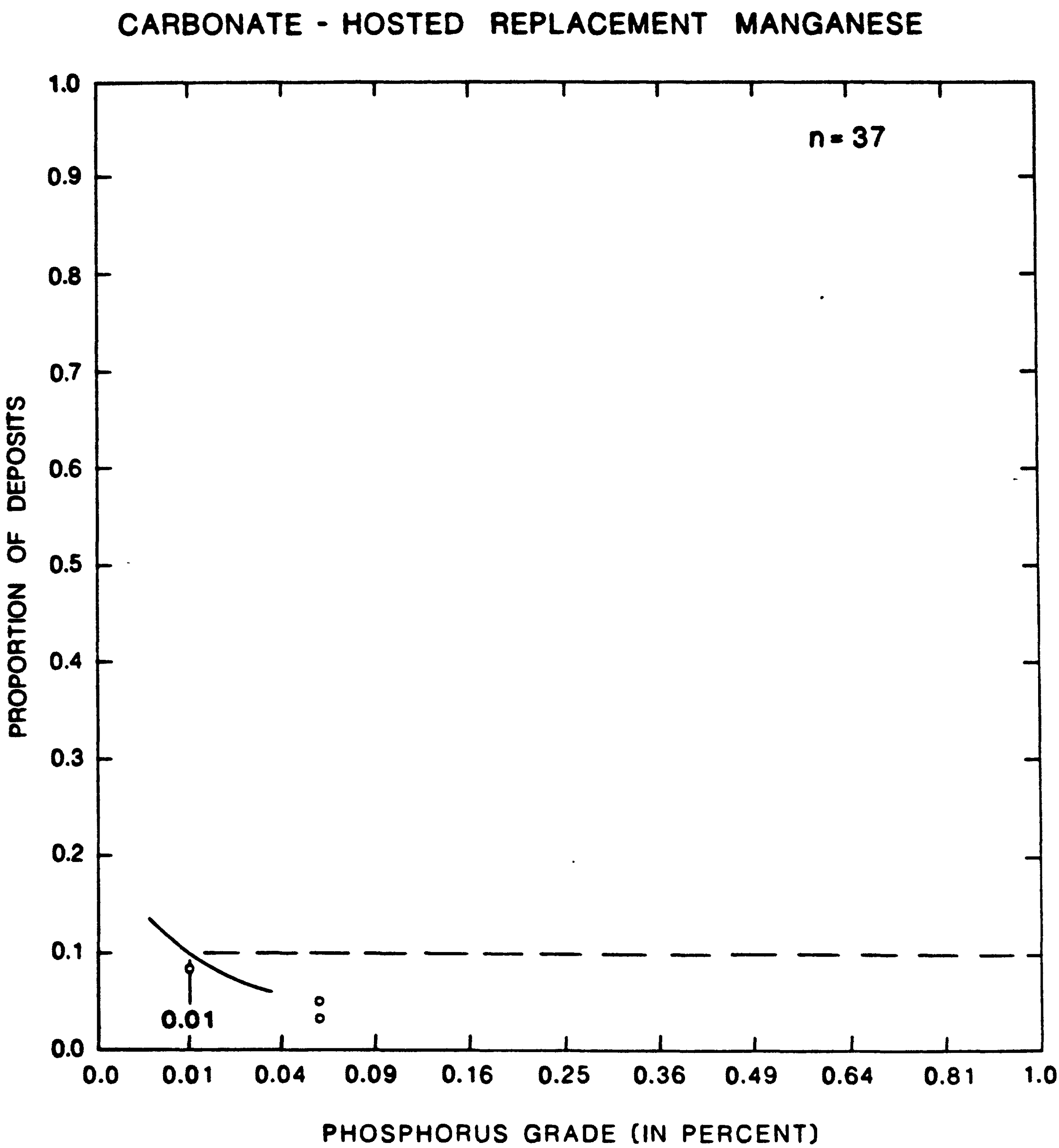
Name	Country
Atlas	USAZ
Bear Mountain	USNM
Birchfield	USNM
Blinman	AUSA
Brachy	FRNC
Chloride Flat	USNM
Crown King	USAZ
Cynthia	GREC
Danville-Hanchette	USAZ
Detroit	USUT
Dinamita	MXCO
Djebel El Aziza	TUNS
Essex and Steptoe	USNV
Golden Gate	USAZ
Hendricks-Twilight	USAZ
Kahal de Brezina	ALGR
Kingston	USNM
Lake Valley	USNM
Lammereck	ASTR
Las Ambollas	FRNC
Las Cabesses	FRNC
Lone Mountain	USNM
Los Volcanes	MXCO
Mammoth	USAZ
Mercedes	CUBA
No. 4-Summit	USAZ
Philipsburg	USMT
Poludnig-Hermagor	ASTR
Oregon	USAZ
Saligny	FRNC
San Carlos	MXCO
Sattelberges	ASTR
Thuburnic	TUNS
Ulukoy	TRKY
Veitsch	ASTR
Vorderen Strubberges	ASTR
Waterloo	USAZ



CARBONATE - HOSTED REPLACEMENT MANGANESE
n = 37
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0009
0.02
0.74
0.0001
0.0004
0.0016
0.0063
0.025
0.1
0.4
1.6
6.3
25
100
TONNES (IN MILLIONS)


CARBONATE - HOSTED REPLACEMENT MANGANESE
n = 37
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.53
0.032
0.056
0.1
0.18
0.32
0.56
1.0
1.8
3.2
5.6
10.0
COPPER GRADE (IN PERCENT)


CARBONATE - HOSTED REPLACEMENT MANGANESE
n = 37
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
16
36
46
0.0
10
20
30
40
50
60
70
80
90
100
MANGANESE GRADE (IN PERCENT)


CARBONATE - HOSTED REPLACEMENT MANGANESE
n = 37
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.01
0.0
0.01
0.04
0.09
0.16
0.25
0.36
0.49
0.64
0.81
1.0
PHOSPHORUS GRADE (IN PERCENT)

DEPOSIT TYPE Platinum--gold placers MODEL NUMBER 6.3

AUTHOR D. A. Singer and N. J Page

DATA REFERENCES Calkins and others, 1978.

COMMENTS All deposits used for the model are from the Urals of USSR. The platinum grade plot suggests these populations. Many of the deposits with grades less then 1,000 ppb Pt were probably mined by dredges, whereas the majority of deposits were mined by conventional placering methods. Some of the very high grades may represent reporting errors such as grades for a high grade portion of a deposit being reported as representative of the total deposit. Probably because of the effects of combining deposits mined by two technologies, tonnage is correlated with platinum grade (r=0.42) and with gold grade (r=-0.52, n=22). Platinum grade is correlated with gold grade (r=0.56, n=22), with osmium grade (r=0.89, n=21), with isidium grade (r=0.98, n=10), and with palladium grade (r=0.99, n=13). Gold grade is correlated with palladium grade (r=0.97, n=6). Osmium grade is correlated with iridium grade (r=0.97, n=9) and with palladium grade (r=0.89, n=12). Iridium grade is correlated with palladium grade (r=0.97, n=9). Other correlations were not significant with the available number of samples. All correlations were calculated with logarithmically transformed data.

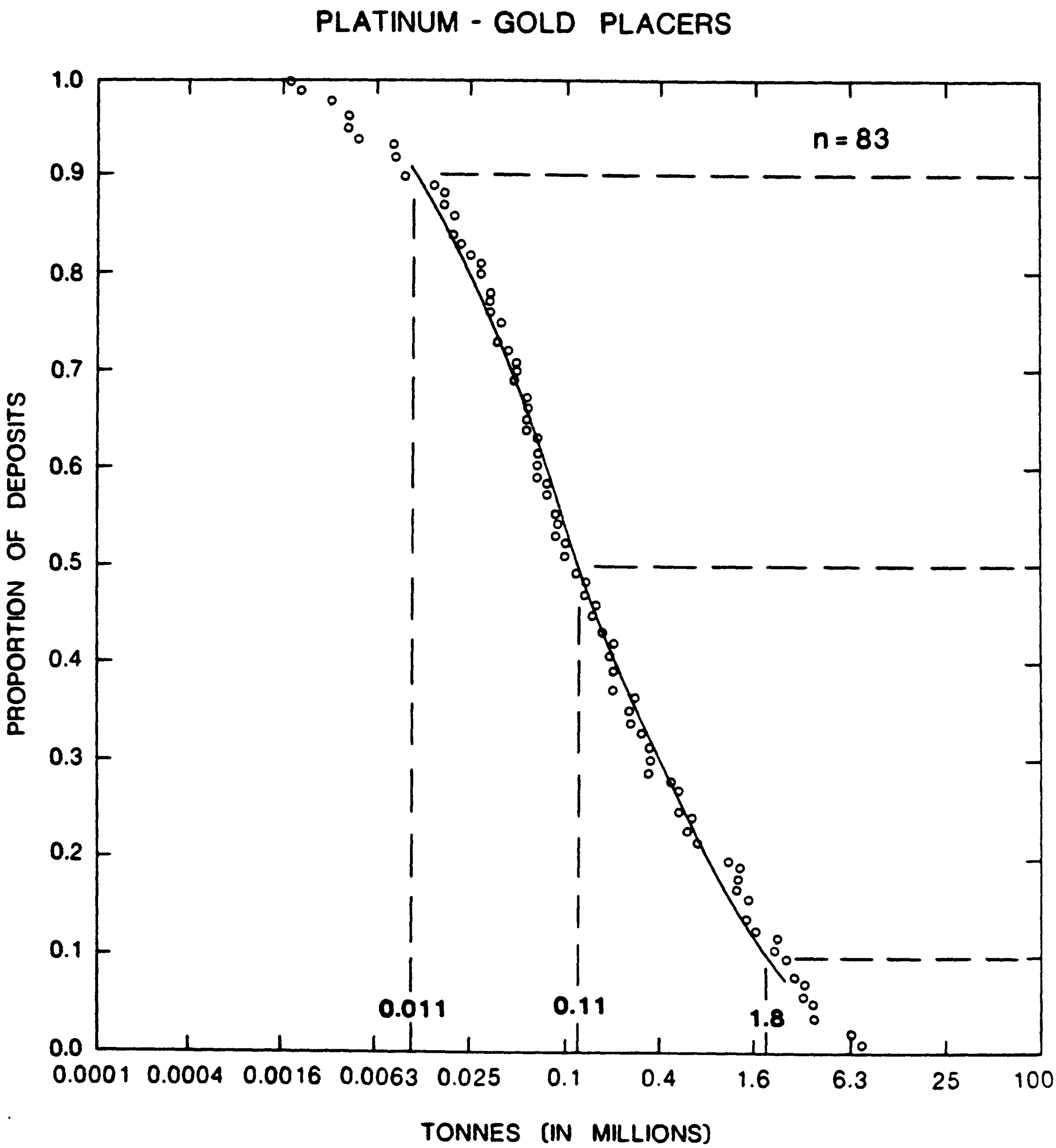
DEPOSITS

Name	Country	Name	Country
Aleksandrovskii Log	URRS	Kamenka	URRS
Alexii-Olginsky Log	URRS	Kamenka R.	URRS
Anianowsky Lojok	URRS	Kisslaia-Peruonatchainik	URRS
Arkhangelskii Log	URRS	Kitlim, Severniy R.	URRS
Besimianni Log	URRS	Korobowsky Lojok	URRS
Bielgorsky Log	URRS	Kossia R.	URRS
Bobrowka River	URRS	Kossoi-Log	URRS
Bolshaya Choumika R.	URRS	Kossorgskii Log	URRS
Bolshaya Kamenouchka	URRS	Krutoi Log	URRS
Bolshaya Ossokina R.	URRS	Lobwa R.	URRS
Bolshaya Prostokischenka	URRS	Log No. 1-Propretschnoi	URRS
Bolshaya Sosnovka	URRS	Log No. 2-Suftlii Bor	URRS
Bolshoi Pokap R.	URRS	Log No. 3-Suftlii Bor	URRS
Bolshoi Sakciam	URRS	Log No. 6-Suftlii Bor	URRS
Boyandinskaia	URRS	Log No. 7-Suftlii Bor	URRS
Ejowka	URRS	Logwinska	URRS
Gloubokia 1	URRS	Lojok at Bisserskaya	URRS
Gloubokia 2	URRS	Lojok No. 1&2 Omoutnaia	URRS
Illinsky Log	URRS	Main Valley of Kisslaia	URRS
Ivov R.	URRS	Malaia Koswa R.	URRS
Jerusalimsky-Priisk	URRS	Malaia Prostokischenka	URRS
Jourawlik R.	URRS	Malaia Sosnowka	URRS
Judinsky-Lojok	URRS	Malomalsky-Priisk	URRS
		Malot Pokap	URRS

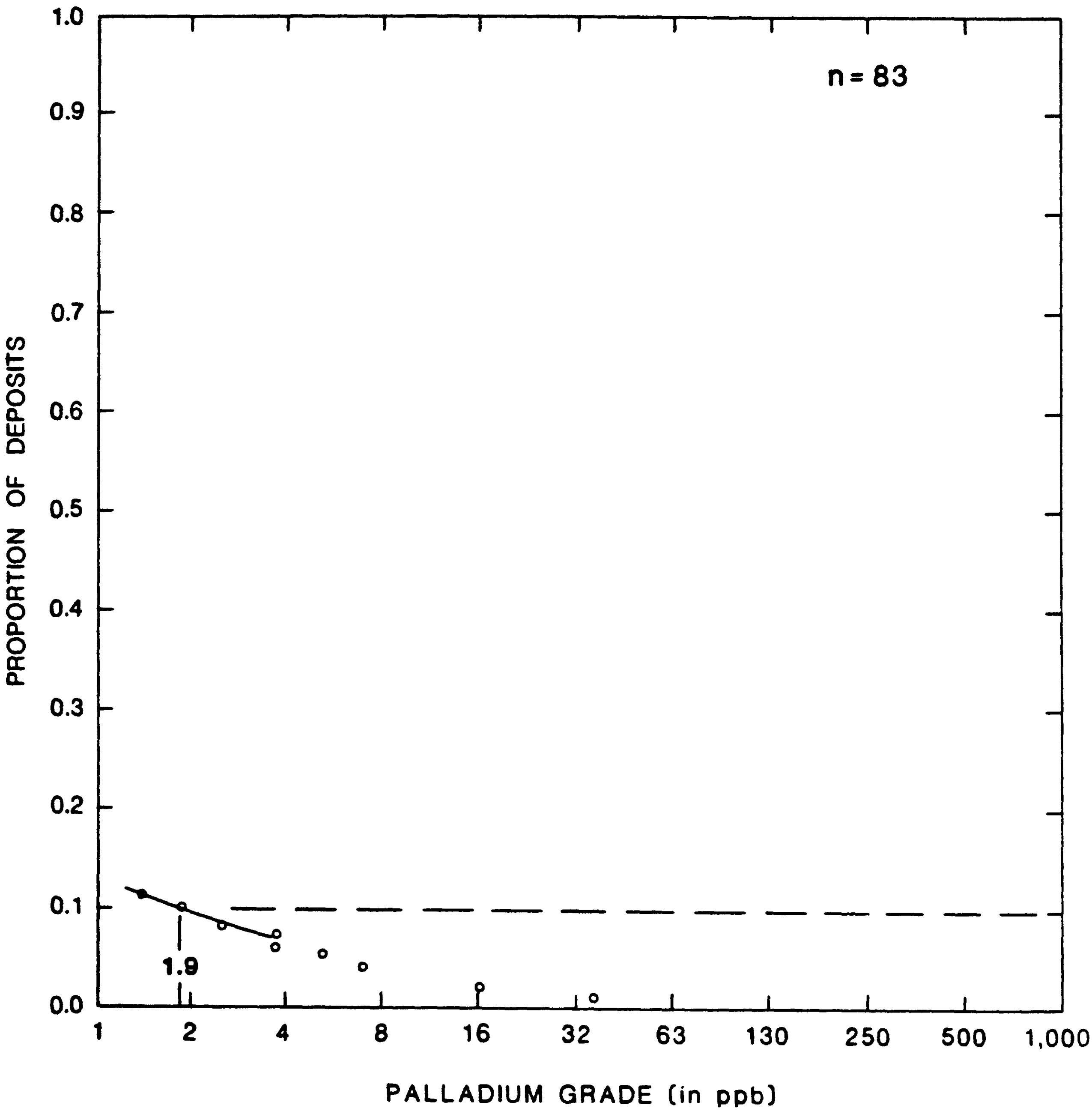
DEPOSIT TYPE Platinum--gold placers MODEL NUMBER 6.3

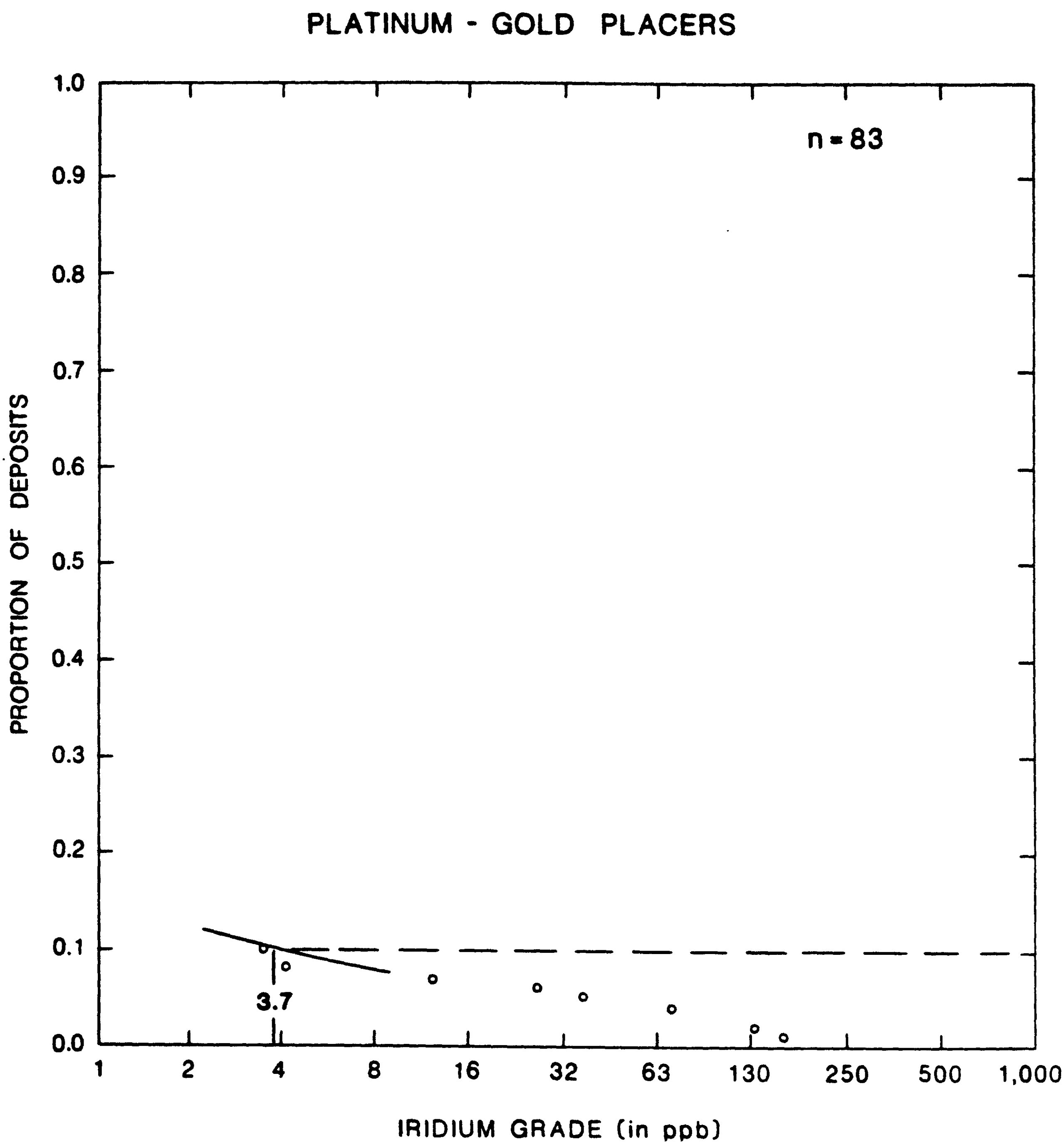
DEPOSITS (continued)

Name	Country	Name	Country
Martian R.	URRS	Small unnamed-Weressowy	URRS
Melnitschnaia	URRS	Solovyevskii Log	URRS
Molitchowka	URRS	Soukhoi Log	URRS
Morphine-Log	URRS	Srednia-Prostokischenka	URRS
Niasman R.	URRS	Stepanoff-Log	URRS
Nikolai-Tschoudotworsky	URRS	Syssim R.	URRS
Novoi-Log	URRS	Tilai R.	URRS
Obodranny-Lojok	URRS	Toura R.	URRS
Panowka	URRS	Trudny-Log	URRS
Patchek	URRS	Tsauch R.	URRS
Pestchanka R.	URRS	Tschachewitaia	URRS
Phedinan R.-Triok	URRS	Tschch R.	URRS
Podbornaia	URRS	Unnamed creek-B. Sosnowka	URRS
Podmoskowoi-Log	URRS	Verkho-Tourie	URRS
Popowsky-Lojok	URRS	Wyssim R.	URRS
Popretschne-Log	URRS	Yermakof-Log	URRS
Roublewik R.	URRS	Zaetzeff, R.	URRS
Sirkov Log	URRS	Zemlianoi-Mostik Log	URRS

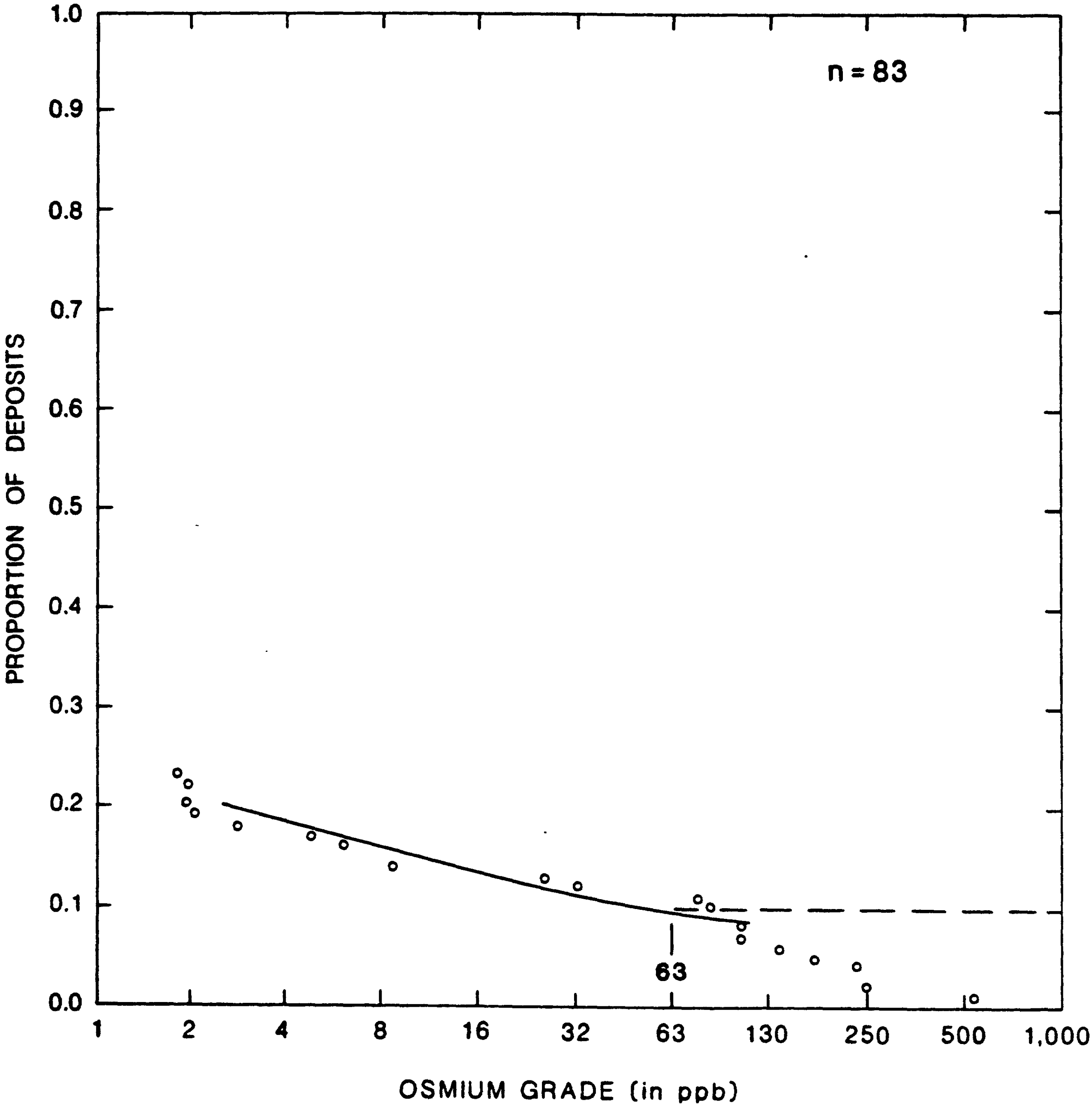

PLATINUM - GOLD PLACERS
n = 83
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.011
0.11
1.8
0.0001
0.0004
0.0016
0.0063
0.025
0.1
0.4
1.6
6.3
25
100
TONNES (IN MILLIONS)

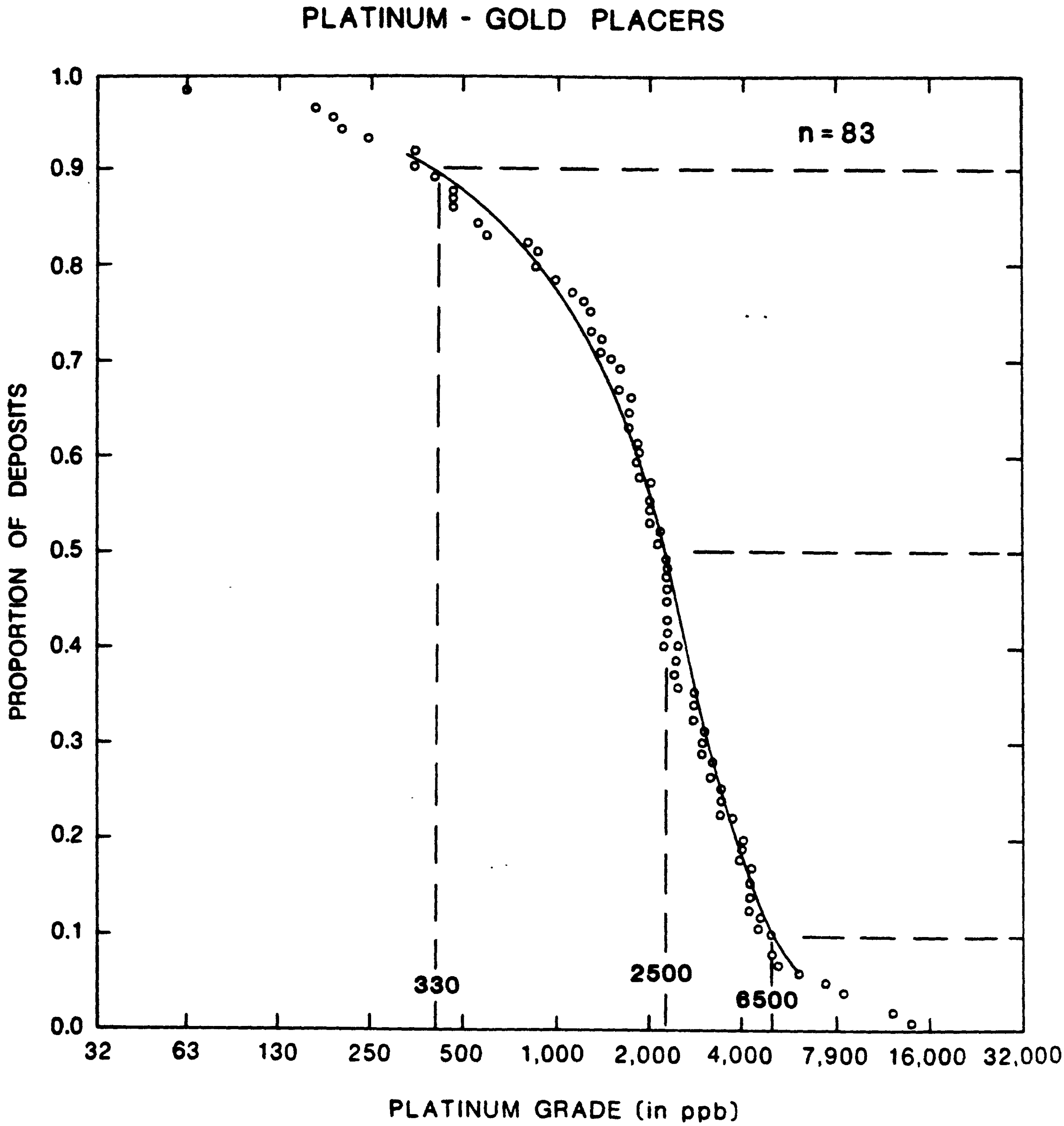
PLATINUM - GOLD PLACERS

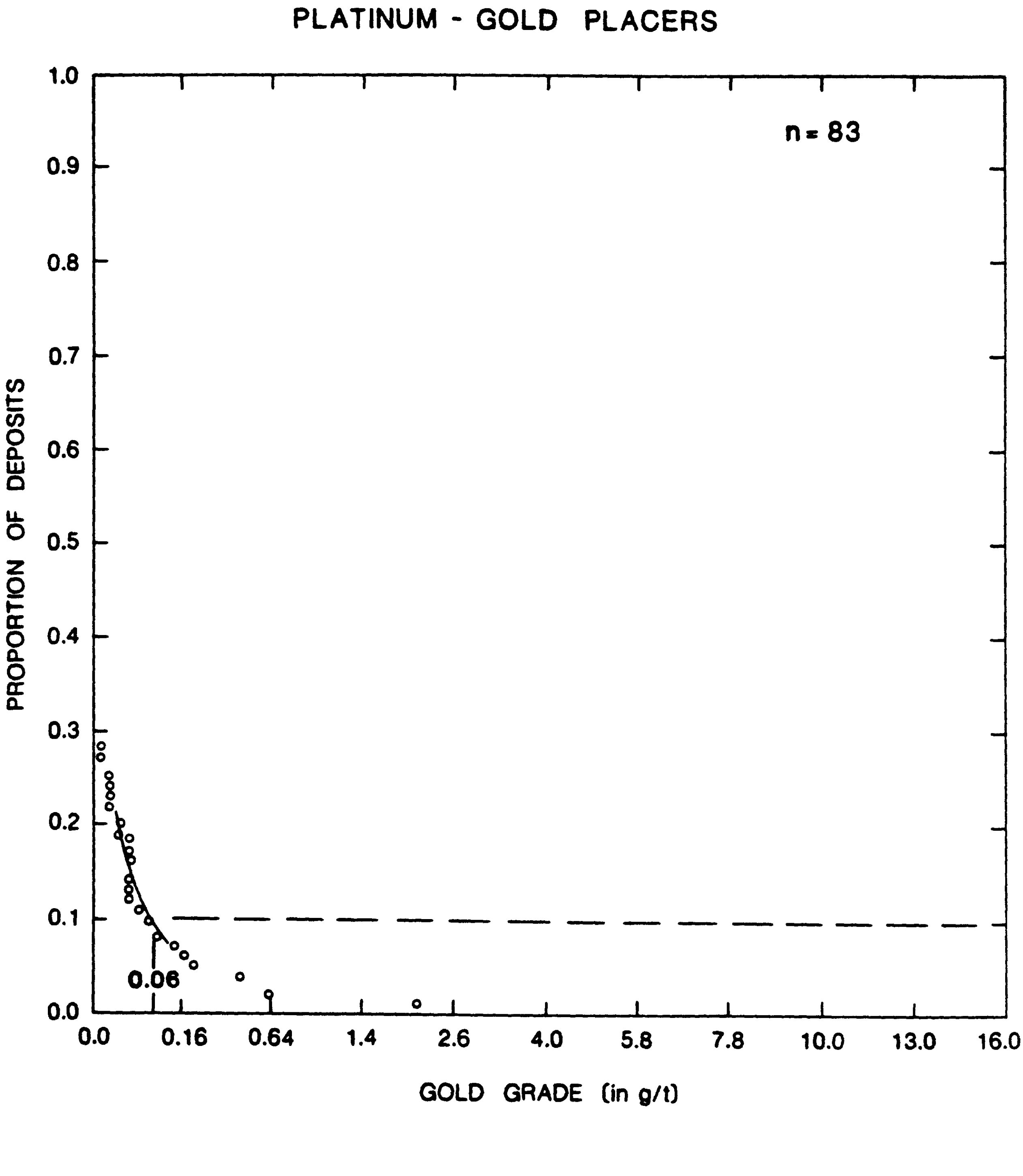



PLATINUM - GOLD PLACERS
n = 83
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PROPORTION OF DEPOSITS
3.7
1
2
4
8
16
32
63
130
250
500
1,000
IRIDIUM GRADE (in ppb)

PLATINUM - GOLD PLACERS




PLATINUM - GOLD PLACERS
n = 83
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
330
2500
6500
32
63
130
250
500
1,000
2,000
4,000
7,900
16,000
32,000
PLATINUM GRADE (in ppb)


PLATINUM - GOLD PLACERS
n = 83
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.06
0.0
0.16
0.64
1.4
2.6
4.0
5.8
7.8
10.0
13.0
16.0
GOLD GRADE (in g/t)

DEPOSIT TYPE Sedimentary manganese MODEL NUMBER 6.5

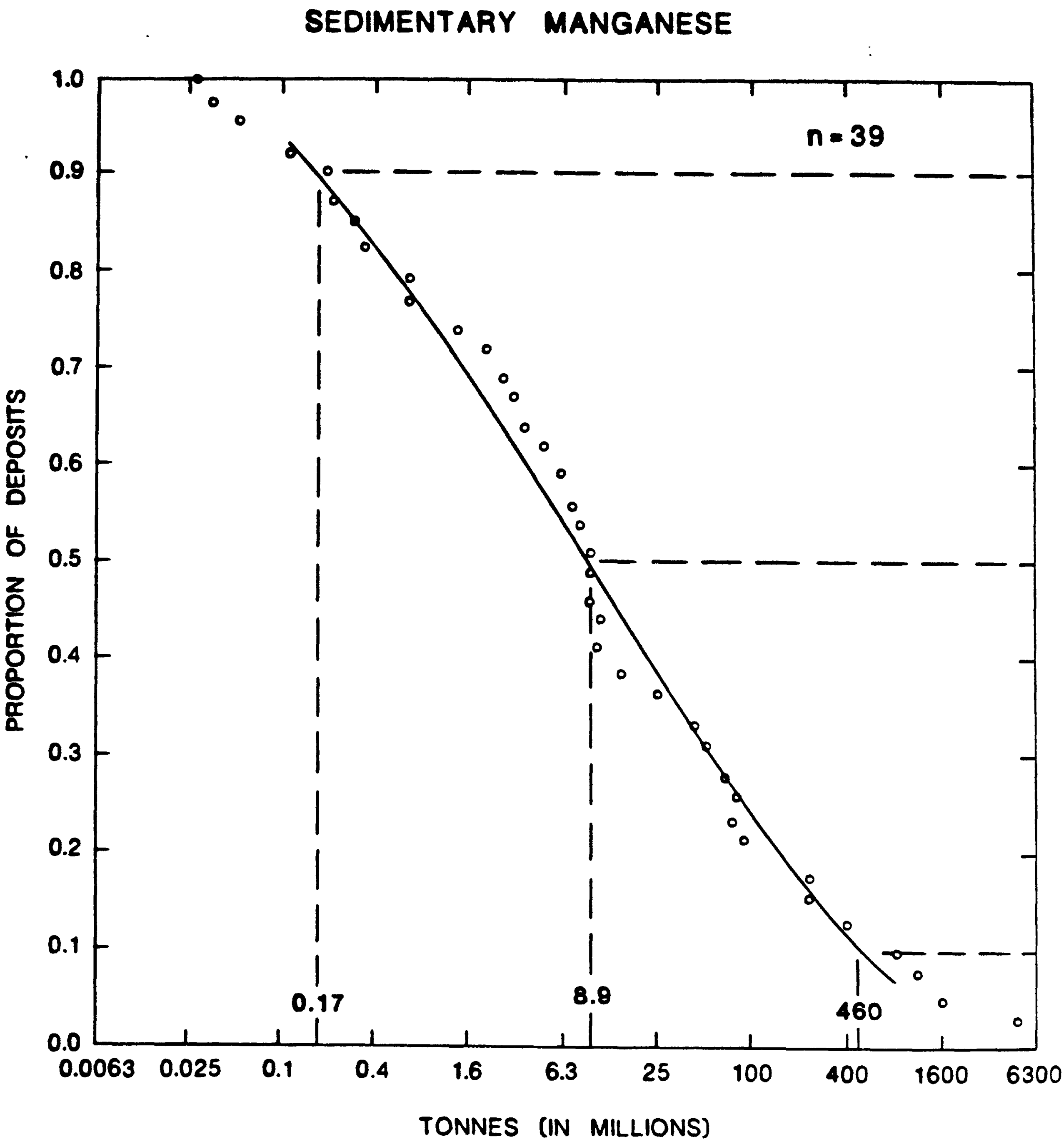
AUTHOR D. L. Mosier et al.

DATA REFERENCES Anon., 1983, and others

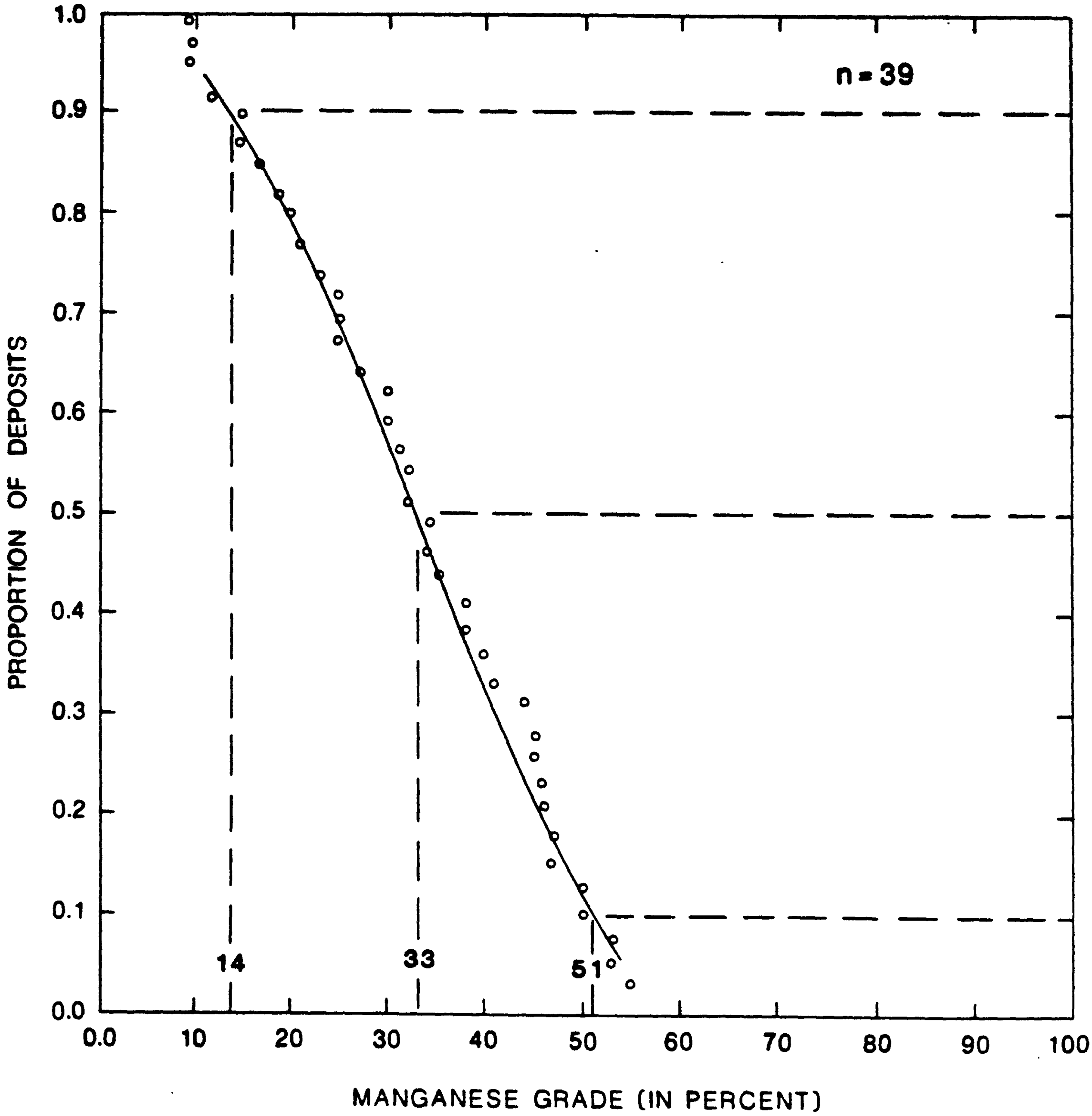
COMMENTS Because available grade and tonnage estimates represent mines from, in some cases, very extensive deposits and because the numbers are calculated at differing cutoff grades, the endowment of these deposits is undoubtedly much larger than indicated in these figures.

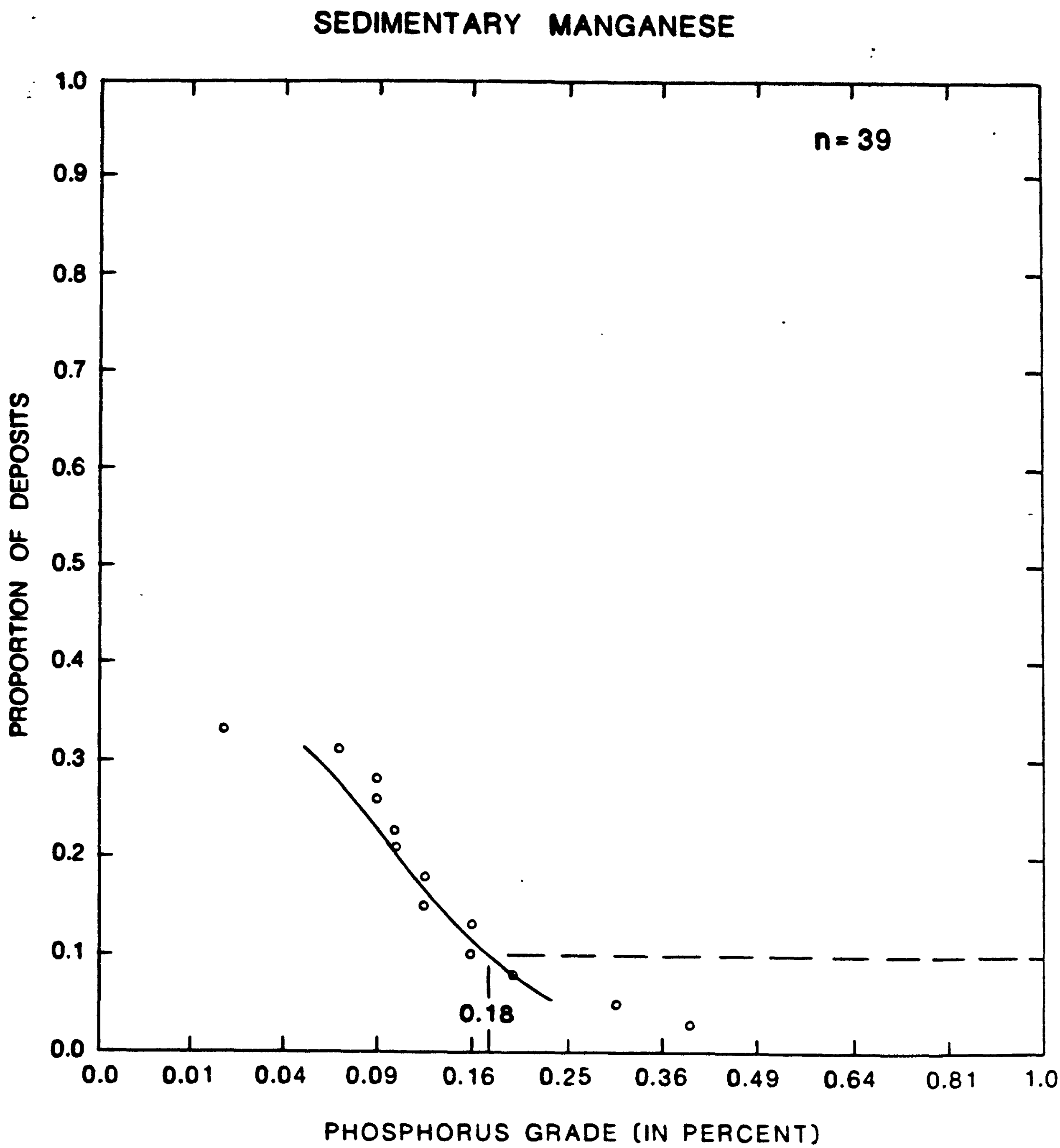
DEPOSITS

Name	Country	Name	
Akviran	TRKY	Manuel Killigrews	CNNF
Andhra Pradesh	INDA	Matese-Ciociaria	ITLY
Ansongo	MALI	Molango	MXCO
Azul-Carajas	BRZL	Morro da Mina	BRZL
Bolske-Tokmak	URRS	Naniango	UVOL
Chiatura	URRS	Nikolaevskoe	URRS
Chiwefwe	ZIMB	Nikopol	URRS
Groote Eylandt	AUNT	Nizne-Udinskaja	URRS
Gujarat	INDA	Otjosondu	SAFR
Horseshoe	AUWA	Ravensthorpe	AUWA
Hsiangtan	CINA	Seiba	URRS
Imini	MRCO	Shimoga (Karnatoka)	INDA
Istranca	TRKY	Timna	ISRL
Kalahari	SAFR	Uracum	BRZL
Kamenskoe	URRS	Urkut	HUNG
Kaochiao	CINA	Usinsk	URRS
Madhya Pradesh	INDA	Varna	BULG
		Wafangtzu	CINA


SEDIMENTARY MANGANESE
n = 39
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.17
8.9
460
0.0063
0.025
0.1
0.4
1.6
6.3
25
100
400
1600
6300
TONNES (IN MILLIONS)

SEDIMENTARY MANGANESE




SEDIMENTARY MANGANESE
n = 39
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.18
0.0
0.01
0.04
0.09
0.16
0.25
0.36
0.49
0.64
0.81
1.0
PHOSPHORUS GRADE (IN PERCENT)

DEPOSIT TYPE Marine phosphate-upwelling type MODEL NUMBER None

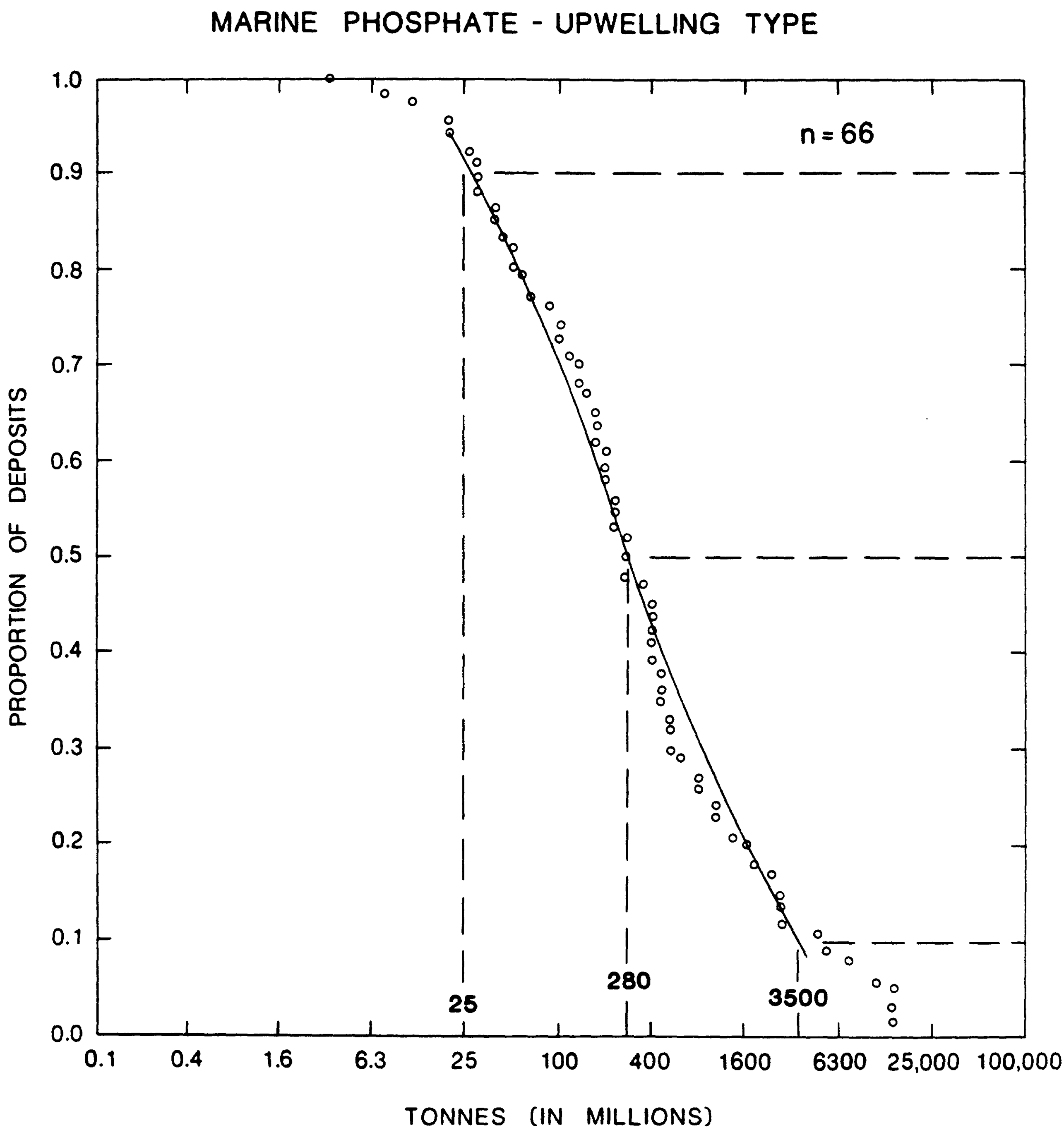
AUTHOR D. L. Mosier

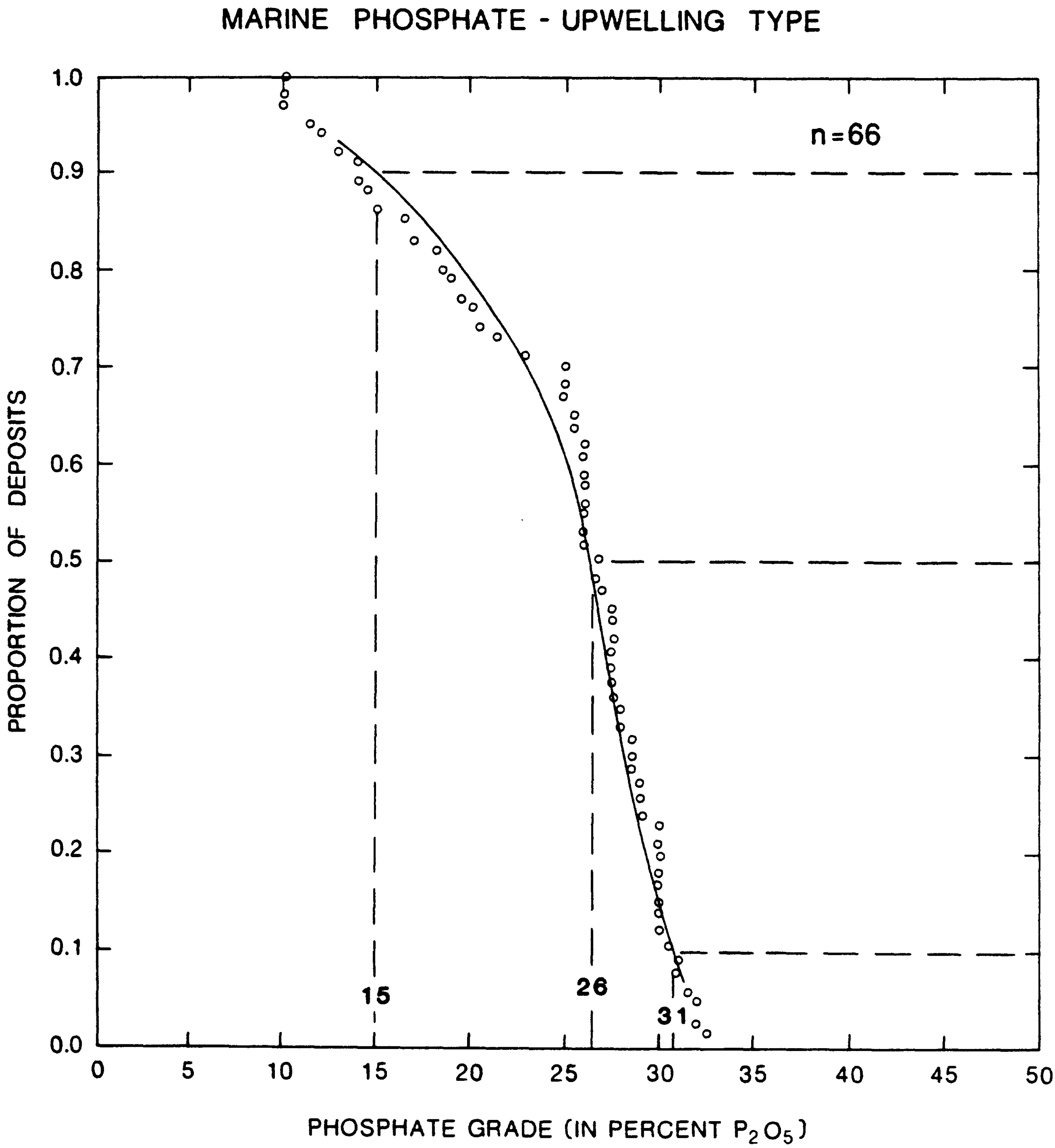
DATA REFERENCES Anon., 1983

COMMENTS

DEPOSITS

Name	Country	Name	Country
Abu Tartur	EGPT	Mazidagi	TRKY
Akashat	IRAQ	Mdilla	TUNS
Aktyubinsk	URRS	Meskala	MRCO
Al-Hasa/Oatrana	JRDN	Metlaoui	TUNS
Arad	ISRL	Montana	USMT
Beersheva	ISRL	Moulares	TUNS
Ben-Guerir	MRCO	Mrata	TUNS
Bou Craa	SPAN	Mzaita	ALGR
Brooks Range	USAK	Nahal-Zin	ISRL
Chilisai	URRS	New Cuyama	USCA
Conda	USID	Oron	ISRL
Dimitrovsk	URRS	Oulad-Abdoun	MRCO
Djebel Onk	ALGR	Patos de Minas	BRZL
D-Tree	AUQL	Qusseir	EGPT
Duchess	AUQL	Redeyef	TUNS
Eastern A&B	SYRA	Ruseifa	JRDN
El Hamrawein	EGPT	Safaga	EGPT
Ganntour	MRCO	San Juan de la Costa	MXCO
Hahotoe	TOGO	Sechura	PERU
Haikou	CINA	Sehib	TUNS
Henry	USID	S.E. Idaho	USID
Hubsugul	MNGL	Shediyah	JRDN
Idfu-Qena	EGPT	Sherrin Creek	AUQL
Kalaa Khasba	TUNS	Sidi Daoui	MRCO
Kara Tau	URRS	Stra Quertane	TUNS
Khneifiss	SYRA	Taiba	SNGL
Kondonakasi	ANGL	Thamar-Kotra	INDA
Kun Ming	CINA	Thies	SNGL
Lady Annie	AUQL	Uinta Mtns.	USUT
Lee Creek	USNC	Vernal	USUT
Le Kouif	ALGR	Warm Springs	USMT
Lily Creek	AUQL	Wooley Valley	USID
Makhtesh	ISRL	Wyoming	USWY
Maybe Canyon	USID	Youssoufra	MRCO


MARINE PHOSPHATE - UPWELLING TYPE
n = 66
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
25
280
3500
0.1
0.4
1.6
6.3
25
100
400
1600
6300
25,000
100,000
TONNES (IN MILLIONS)


MARINE PHOSPHATE - UPWELLING TYPE
n=66
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
15
26
31
0
5
10
15
20
25
30
35
40
45
50
PHOSPHATE GRADE (IN PERCENT P_2O_5)

DEPOSIT TYPE Marine phosphate-warm current type   MODEL NUMBER None

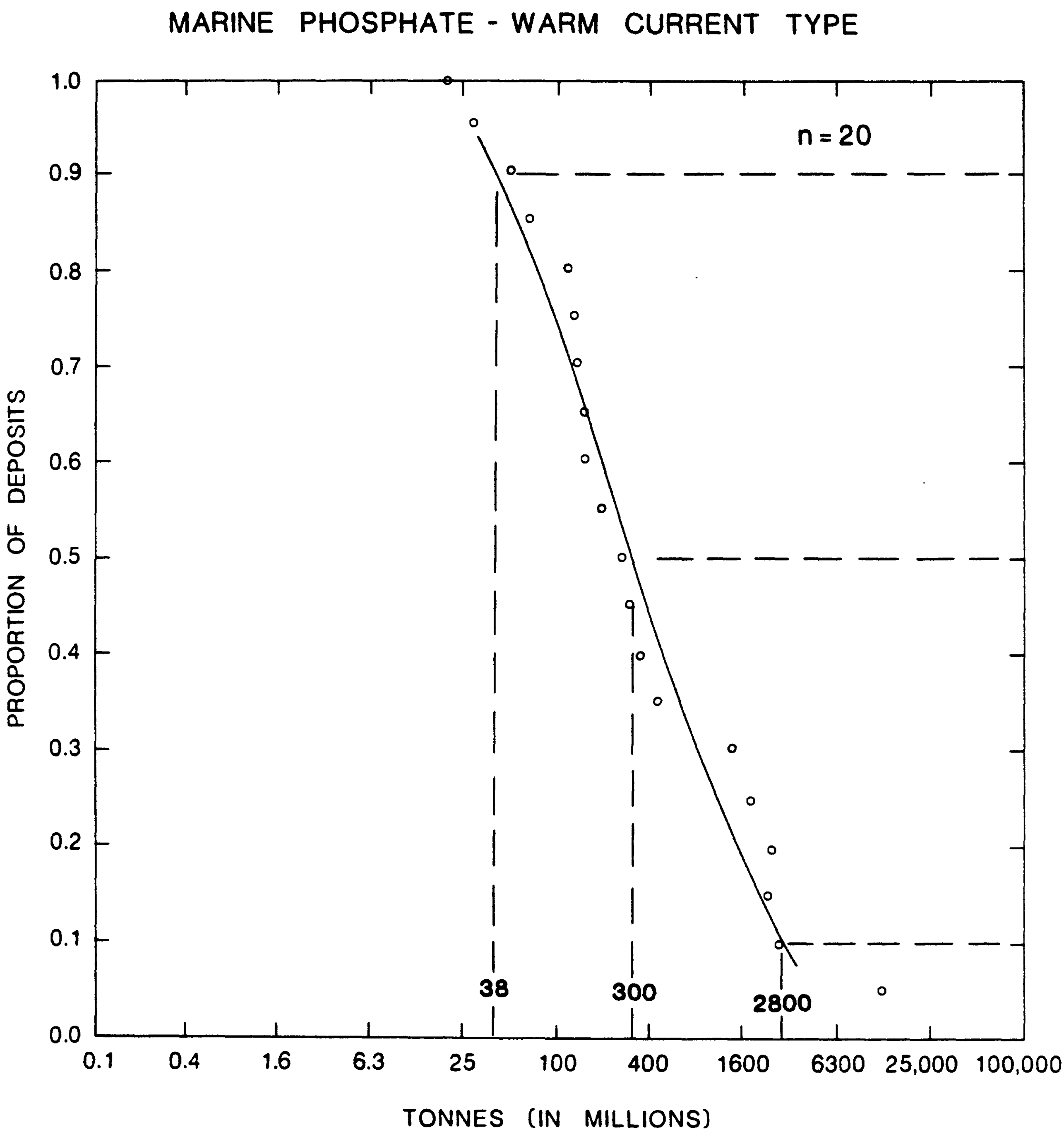
AUTHOR D. L. Mosier

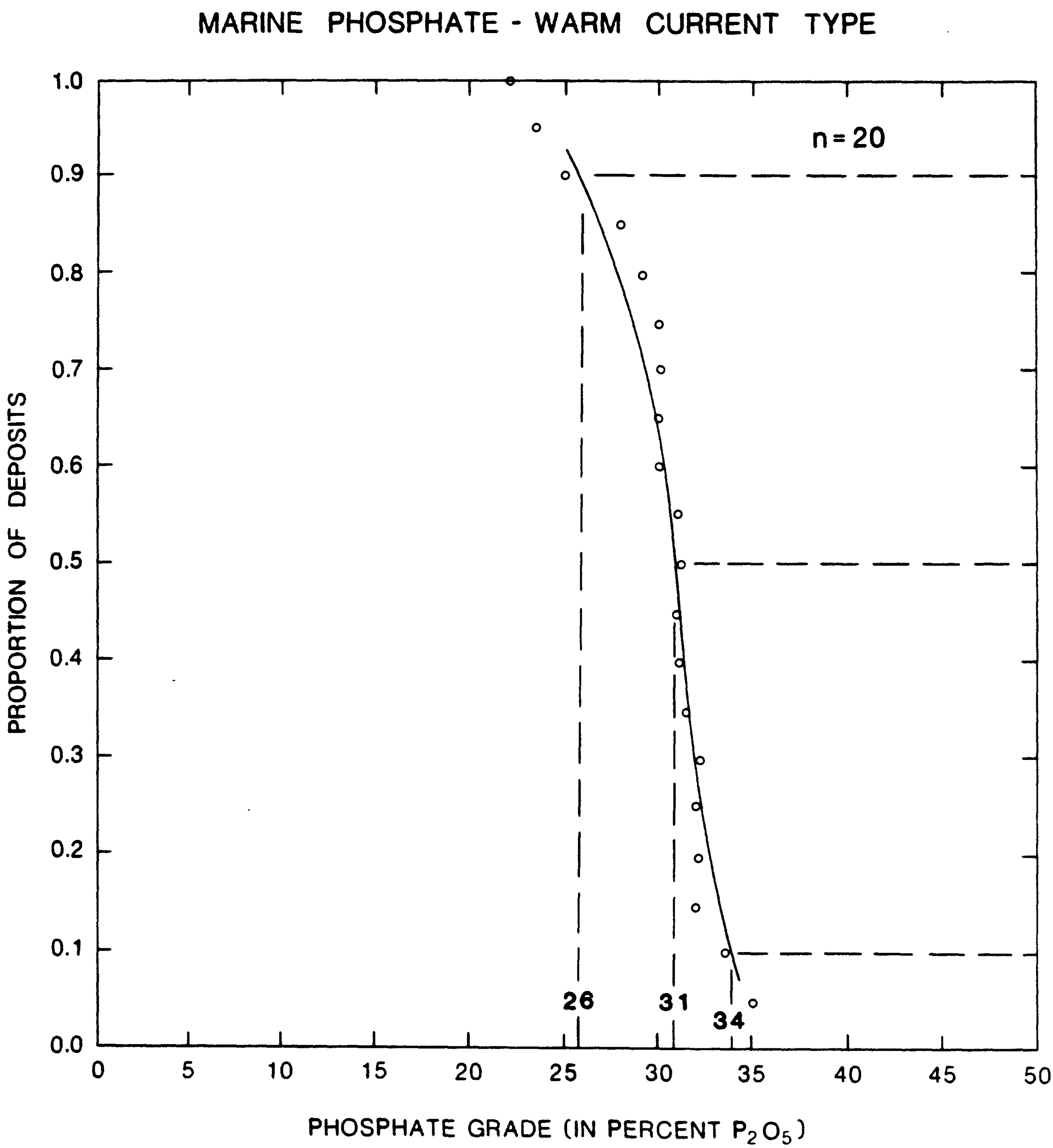
DATA REFERENCES Anon., 1983

COMMENTS Sometimes called the East Coast type.

DEPOSITS

Name	Country
Big Four	USFL
Bonny Lake	USFL
Clear Springs	USFL
East Florida	USFL
Fort Green	USFL
Hard Rock	USFL
Haynsworth	USFL
Kingsford	USFL
Land Pebble	USFL
Lonesome	USFL
Noralyn-Phosphoria	USFL
North Florida	USFL
North Carolina	USNC
Northeast Florida	USFL
Offshore Savannah	USGA
Paulista	BRZL
Payne Creek	USFL
Rockland	USFL
Saddle Creek	USFL
South Florida	USFL


MARINE PHOSPHATE - WARM CURRENT TYPE
n = 20
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
38
300
2800
0.1
0.4
1.6
6.3
25
100
400
1600
6300
25,000
100,000
TONNES (IN MILLIONS)


MARINE PHOSPHATE - WARM CURRENT TYPE
n = 20
PROPORTION OF DEPOSITS
PHOSPHATE GRADE (IN PERCENT P_2O_5)
26
31
34
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
5
10
15
20
25
30
35
40
45
50

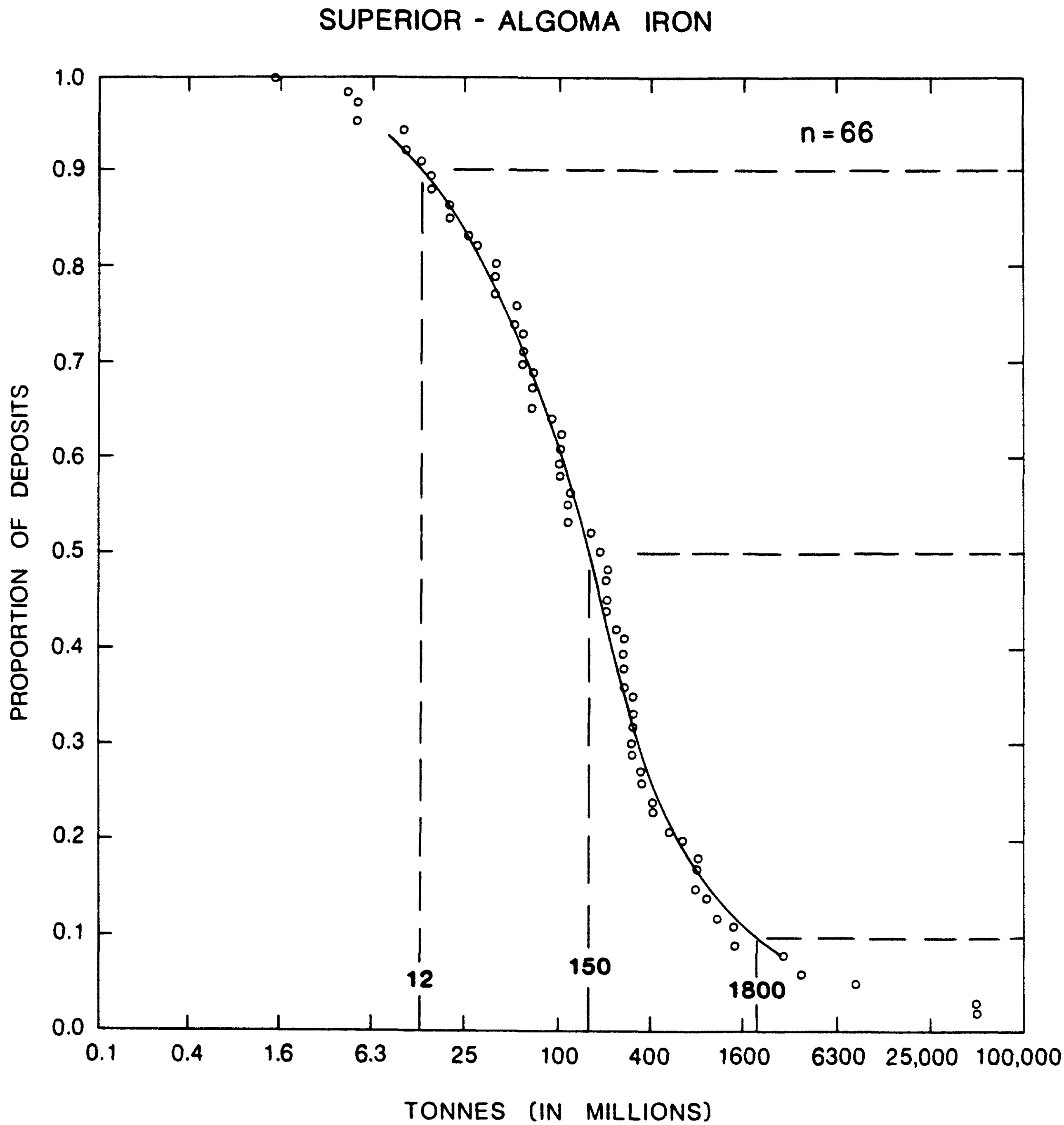
DEPOSIT TYPE Superior-Algoma iron MODEL NUMBER none

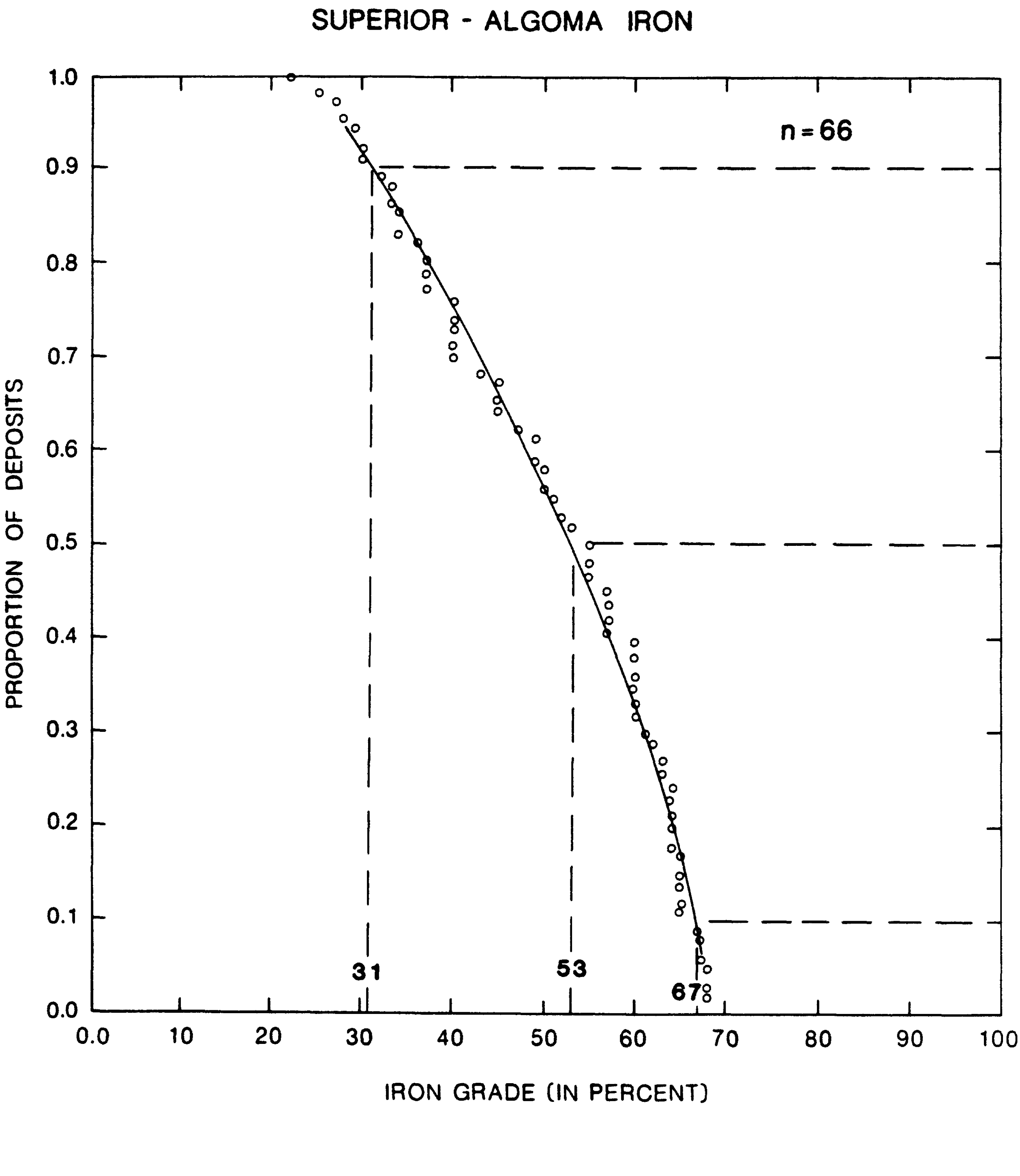
AUTHOR D. L. Mosier

COMMENTS Archean and Proterozoic banded iron formations are combined.

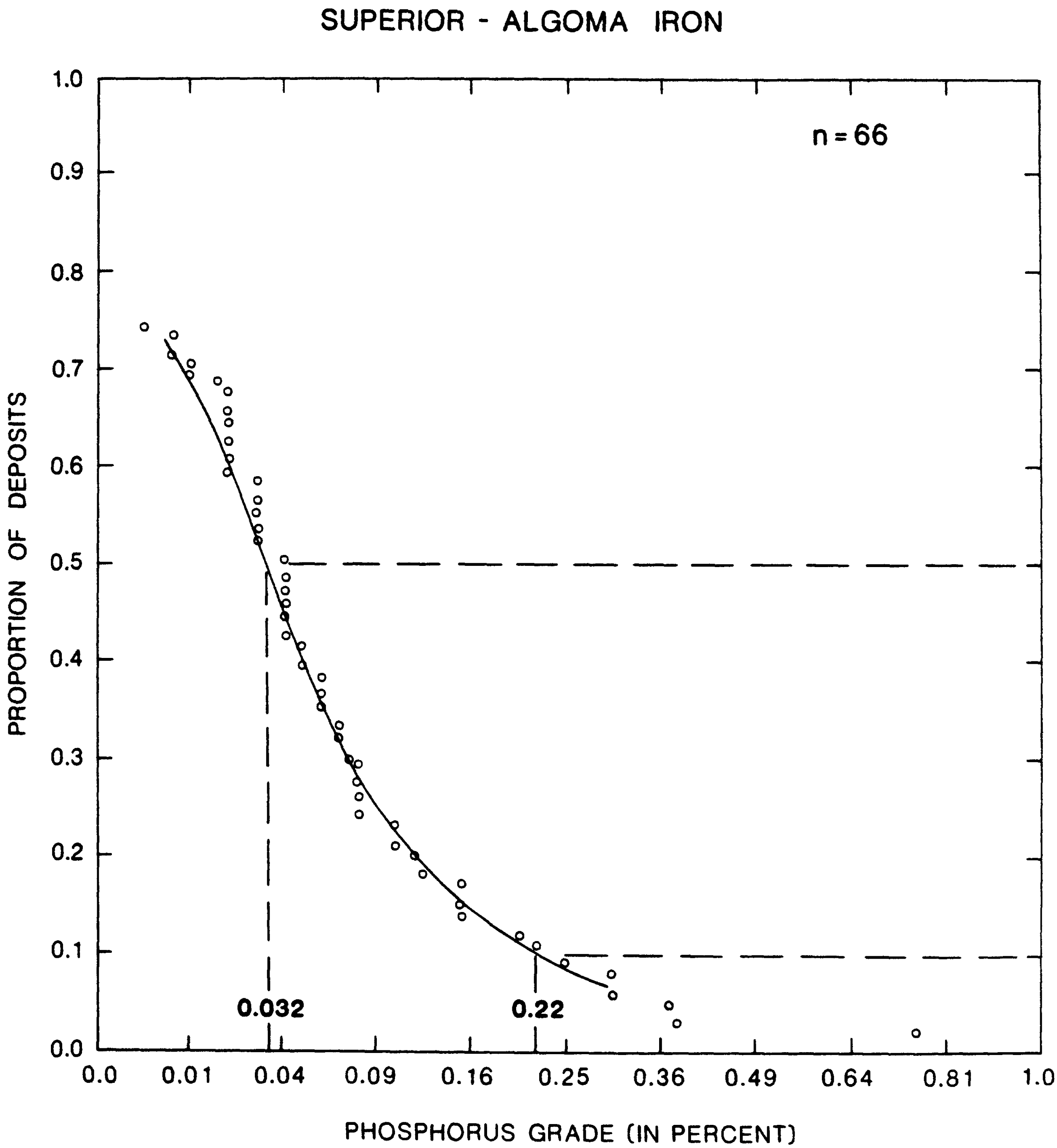
DEPOSITS

Name	Country	Name	Country
Altamira-Frontera	VNZL	Noamundi-Joda-Gua etc.	INDA
Amapa	BRZL	Norberg	SWDN
An-shan	CINA	Pa-pan-ling	CINA
Bahia	BRZL	Pen-chi-hu	CINA
Bailadila	INDA	Piacoa	VNZL
Bellary	INDA	Porkonen	FNLD
Bicholim	INDA	Relun	CILE
Burnt Hill-Knob Lake	CNQU	Rowghat	INDA
Cerro Bolivar	VNZL	Sangalwara	INDA
Chityal and others	INDA	Santa Barbaara	VNZL
Cuyuna	USMN	Sirigao	INDA
Dhalli-Rajhara	INDA	Ssu-chia-ying	CINA
El Pao	VNZL	Stripa-Striberg	SWDN
Fiskefjord	NRWY	Sydvananger	NRWY
Fort Apache	USAZ	Tallering Peak	AUWA
Fort Gourand	MAUR	Thabazimbi	SAFR
Gogebic	USMN	Tonkolili	SRLN
Gorumahisani and others	INDA	Vermilion	USMN
Goulais	CNON	Vestpolltind	NRWY
Guntur	INDA	Weld Range-Wilgie Mia	AUWA
Iron Monarch-Iron Knob	AUSA	Zalpa	AGTN
Jussaari	FNLD		
Kanjamalai and others	INDA		
Kemmangundi and others	INDA		
Koolyanobbing	AUWA		
Krivoi-Rog	URRS		
Kudremukh and others	INDA		
Kung-changling	CINA		
Kusalpur	INDA		
Labrador Quebec	CNQU		
Lohara and others	INDA		
Los Castillos	VNZL		
Maria Luisa	VNZL		
Marquette	USMN		
Mato Grosso	BRZL		
Menominee	USMN		
Mesabi	USMN		
Minas Gerais	BRZL		
Moose Mountain	CNON		
Mount Gibson	AUWA		
Mount Gould	AUWA		
Mount Hale	AUWA		
Mount Philp	AUQL		
Musan	NKOR		
Mutum	BLVA		


SUPERIOR - ALGOMA IRON
n = 66
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
PROPORTION OF DEPOSITS
12
150
1800
0.1
0.4
1.6
6.3
25
100
400
1600
6300
25,000
100,000
TONNES (IN MILLIONS)



SUPERIOR - ALGOMA IRON
n=66
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
31
53
67
0.0
10
20
30
40
50
60
70
80
90
100
IRON GRADE (IN PERCENT)



SUPERIOR - ALGOMA IRON
n = 66
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.032
0.22
0.0 0.01 0.04 0.09 0.16 0.25 0.36 0.49 0.64 0.81 1.0
PHOSPHORUS GRADE (IN PERCENT)

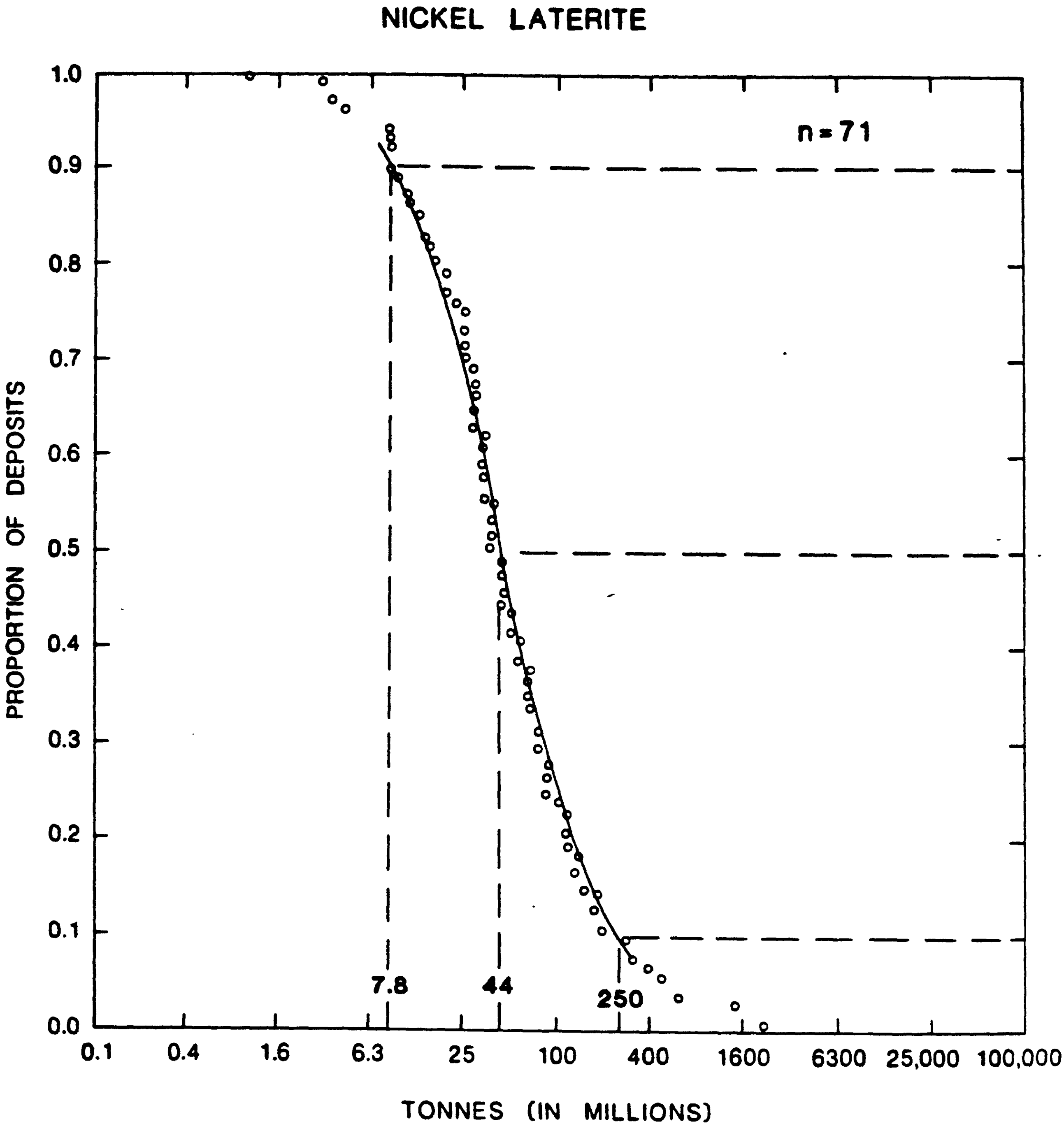
DEPOSIT TYPE Nickel laterite MODEL NUMBER 7.2

AUTHOR D. A. Singer

COMMENTS Higher grades are typically associated with the silicate type. Numerous low grade (less than 1 % Ni) and low tonnage deposits were not included in the data. Nickel grade is correlated with tonnage at the 1% level (r=-0.31).

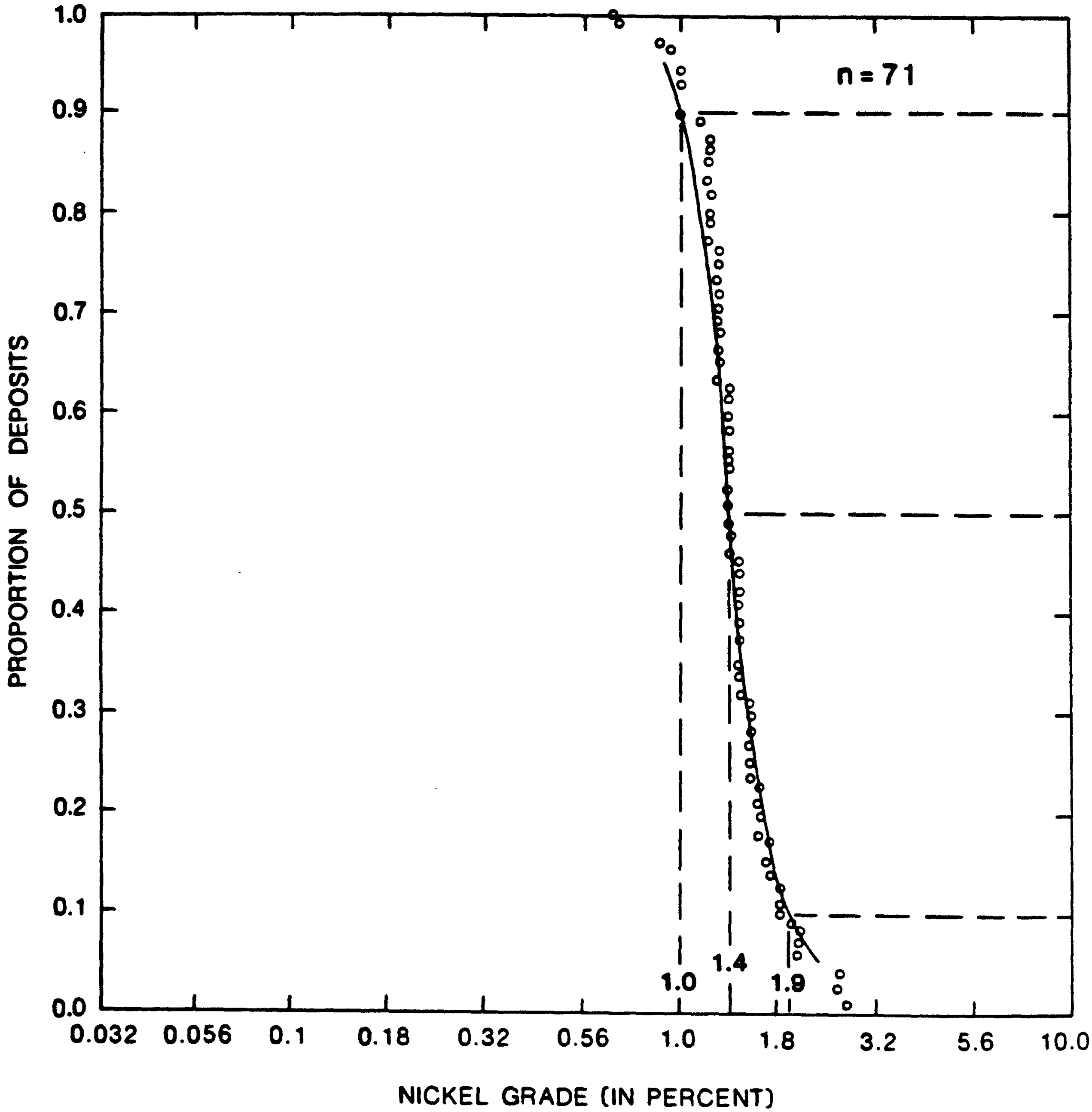
DEPOSITS

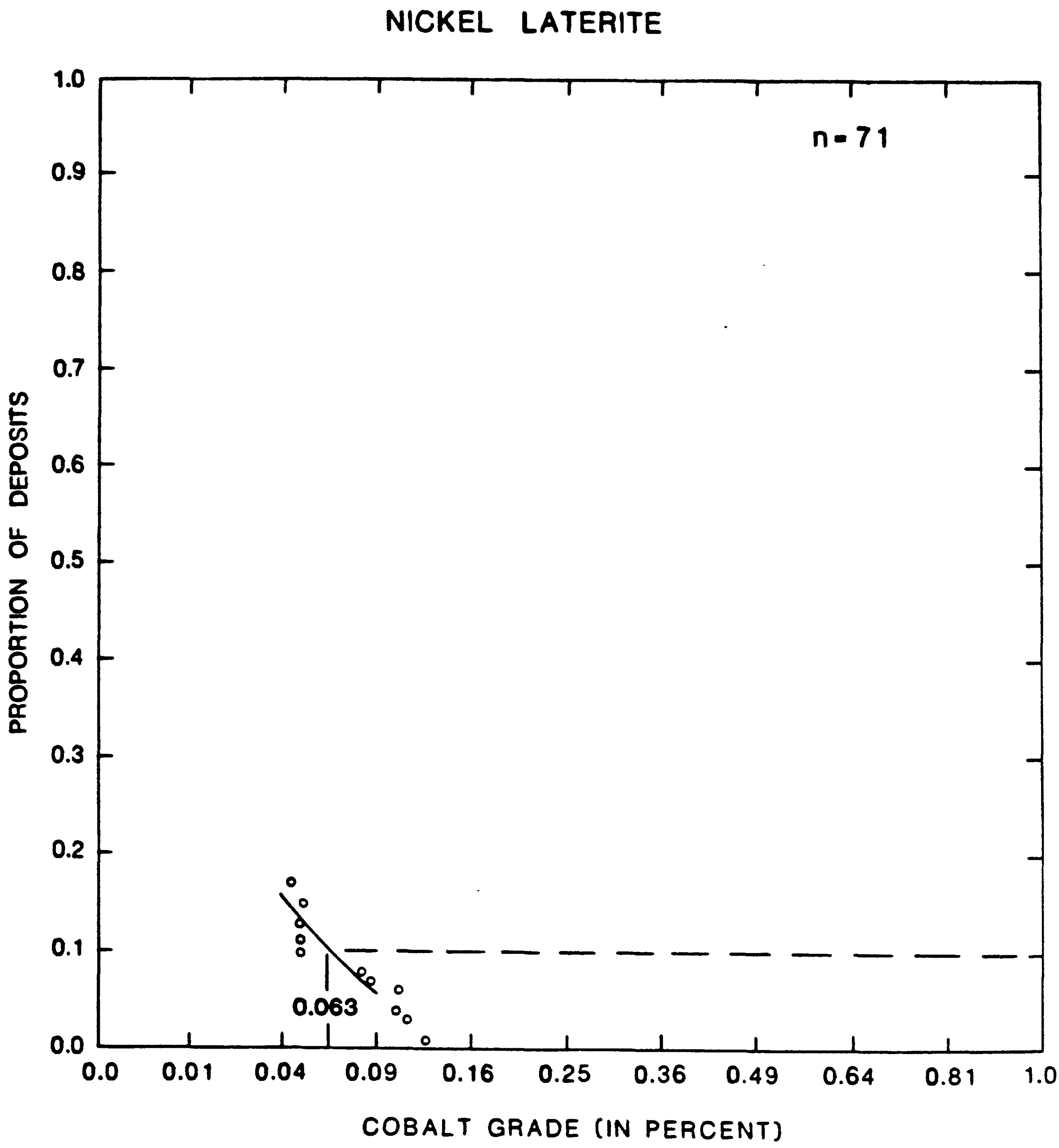
Name	Country	Name	Country
Ambatory	MDGS	Mon Bay	CUBA
Analumay	MDGS	Moorsom	PLPN
Barro Alto	BRZL	Moramanya	MDGS
Berong	PLPN	Morro de Engenho	BRZL
Bhimatangar	INDA	Mwaytung	BRMA
Br. Solomon Is.	SLMN	Nepoui	NCAL
Cabo Rojo	PTRC	New Frontier	PLPN
Cerro Matoso	CLBA	Niquelandia	BRZL
Claude Hills	AUSA	Nonoc	PLPN
Cyclops	INDS	Obi	INDS
Dinaget Is.	PLPN	Ora Banda	AUWA
Eubocu	GREC	Orsk	URRS
Eximbal	GUAT	Pojada Pen.	PLPN
Falconbridge	DMRP	Pomaloa	INDS
Gag Is.	INDS	Poro	NCAL
Golesh Mt.	YUGO	Poum	NCAL
Golos	YUGO	Pratapolis	BRZL
Goro	NCAL	Prony	NCAL
Greenvale	AUQL	Ramona-Loma	CUBA
Halmahera	INDS	Riddle	USOR
Ipaneme	BRZL	Rio Tuba	PLPN
Jacupuenga	BRZL	Sablayon	PLPN
Kaliapani	INDA	Sao Joando Piaui	BRZL
Kansa	INDA	Saruabi	INDA
Kauadarci	YUGO	S.E. Kalimantan	INDS
Laguney	PLPN	Sidamo	ETHP
Lake Joanina	GREC	Simlipal	INDA
Leviso R.	CUBA	Soroaka	INDS
Loma de Hierro	VNZL	Sukinda	INDA
Long Point	PLPN	Surigao	PLPN
Magios Ioannis	GREC	Taco Bay	CUBA
Marlborough	AUQL	Thio	NCAL
Masinloc	PLPN	Tiebaghi	NCAL
Mayari	CUBA	Wingelinna-Daisy	AUWA



NICKEL LATERITE
n=71
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
7.8
44
250
0.1
0.4
1.6
6.3
25
100
400
1600
6300
25,000
100,000
TONNES (IN MILLIONS)

NICKEL LATERITE




NICKEL LATERITE
n=71
PROPORTION OF DEPOSITS
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.063
0.0
0.01
0.04
0.09
0.16
0.25
0.36
0.49
0.64
0.81
1.0
COBALT GRADE (IN PERCENT)

COUNTRY NAMES

AGTN	Argentina
ALGR	Algeria
ANGL	Angola
AUNS	Australia, New South Wales
AUNT	Australia, N. Territory
AUQL	Australia, Queensland
AUSA	Australia, South Australia
AUTS	Australia, Tasmania
AUVT	Australia, Victoria
AUWA	Australia, Western Australia
ASTR	Austria
BULG	Bulgaria
BLVA	Bolivia
BRMA	Burma
BOTS	Botswana
BRZL	Brazil
CILE	Chile
CINA	China
CLBA	Colombia
CNBC	Canada, British Columbia
CNGO	Congo
CNMN	Canada, Manitoba
CNNB	Canada, New Brunswick
CNNF	Canada, Newfoundland
CNNS	Canada, Nova Scotia
CNNT	Canada, Northwest Territory
CNON	Canada, Ontario
CNQU	Canada, Quebec
CNSK	Canada, Saskatchewan
CNYT	Canada, Yukon Territory
CORI	Costa Rica
CUBA	Cuba
CYPS	Cyprus
CZCL	Czechoslovakia
DMRP	Dominican Republic
ECDR	Ecuador
EGPT	Egypt
ELSA	El Salvador
ETHP	Ethiopia
FIJI	Fiji
FNLD	Finland
FRNC	France
GHNA	Ghana
GRBR	Great Britain
GREC	Greece
GRLD	Greenland
GRMY	Germany
GUAT	Guatemala
HATI	Haiti
HONG	Hong Kong
HNDR	Honduras
HUNG	Hungary
INDA	India
INDS	Indonesia
IRAN	Iran
IRAQ	Iraq
IRLD	Ireland
ISRL	Israel
ITLY	Italy
IVCO	Ivory Coast
JAPN	Japan
JRDN	Jordan
KNYA	Kenya
MALI	Mali
MAUR	Mauritania
MDGS	Madagascar (Malgasy Rep.)
MLYS	Malaysia
MNGL	Mongolia
MRCO	Morocco
MXCO	Mexico
NCAL	New Caledonia
NCRG	Nicaragua
NKOR	North Korea
NRWY	Norway
NZLD	New Zealand
OMAN	Oman
PANA	Panama
PERU	Peru
PKTN	Pakistan
PLPN	Philippines
PORT	Portugal
PPNG	Papua New Guinea
PTRC	Puerto Rico
RMNA	Romania
SAAR	Saudi Arabia
SAFR	South Africa
SKOR	South Korea
SNGL	Senegal
SPAN	Spain
SRLN	Sierra Leon
SUDN	Sudan
SWDN	Sweden
SYRA	Syria
THLD	Thailand
TIWN	Taiwan
TNZN	Tanzania
TOGO	Togo
TRKY	Turkey
TUNS	Tunisia
UVOL	Upper Volta
URAM	USSR, Armenia
URKZ	USSR, Kazakhstan
URTD	USSR, Tadzhilistan
URUR	USSR, Russian Rep.
URUZ	USSR, Uzbekistan
USAK	US, Alaska

COUNTRY NAMES (Continued)

USAR	US, Arkansas
USAZ	US, Arizona
USCA	US, California
USCO	US, Colorado
USGA	US, Georgia
USID	US, Idaho
USME	US, Maine
USMN	US, Minnesota
USMS	US, Massechusetts
USMT	US, Montana
USNC	US, North Carolina
USNM	US, New Mexico
USNV	US, Nevada
USOR	US, Oregon
USPA	US, Pennsylvania
USUT	US, Utah
USVT	US, Vermont
USWA	US, Washington
USWI	US, Wisconsin
USWY	US, Wyoming
VNZL	Venezuela
VTNM	Vietnam
YUGO	Yugoslavia
ZIMB	Zimbabwe

REFERENCES

Anonymous, 1983, International Strategic Minerals Inventory: unpublished data, U. S. Geological Survey.

Calkins, J. L., Keefer, E. K., Ofsharick, R. A., Mason, G. T., Tracy, Patricia, and Alkins, Mary, 1978, Description of CRIB, the GIPSY retrieval mechanism and the interface to the General Electric Mark III Service: U. S. Geological Survey Circular 755-AK, 49 p.

Cox, D. P., ed., 1983a, U. S. Geological Survey-INGEOMINAS mineral resource assessment of Colombia: Ore deposit models; U. S. Geological Survey Open-file Report 83-423, 64 p.

Cox, D. P., ed., 1983b, U. S. Geological Survey-INGEOMINAS mineral resource assessment of Colombia: Ore deposit models-Part II; U. S. Geological Survey Open-file Report 83-___, ___ p.

Einaudi, M. T., 1981, Skarns associated with porphyry plutons. I. Description of deposits, southwestern North America, II. General features and origin, _in_ Titley, S. R., ed., Advances in geology of the porphyry copper deposits of southwestern North America: Tucson, Univ. Arizona Press, p. 139-183.

Einaudi, M. T., Meinert, L. D., and Newberry, R. S., 1981, Skarn deposits, Econ. Geol., 75th Anniversary Volume, p. 317-391.

Mosier, D. L., Singer, D. A., and Salem, B. B., 1983, Geologic and grade-tonnage information on volcanic-hosted copper-zinc-lead massive sulfide deposits: U. S. Geological Survey Open-file Report 83-89, 78 p.

Sinclair, A. J., Drummond, A. D., Carter, N. C., and Dawson, K. M., 1982, A preliminary analysis of gold and silver grades of porphyry-type deposits in western Canada, _in_ Levinson, A. A., ed., Precious metals in the northern Cordillera: The Association of Exploration Geochemists, p. 157-172.

Singer, D. A., and Mosier, D. L., eds., 1983a, Mineral deposit grade-tonnage models: U. S. Geological Survey Open-file Report 83-623, 100 p.

Singer, D. A., and Mosier, D. L., eds., 1983b, Mineral deposit grade-tonnage models II: U. S. Geological Survey Open-file Report 83-___, 101 p.

Singer, D. A., Menzie, W. D., DeYoung, J. H., Jr., Sander, M., and Lott, A., 1980, Grade and tonnage data used to construct models for the regional Alaskan Mineral Resource Assessment Program: U. S. Geological Survey Open-file Report 80-799, 58 p.

Theodore, T. G., and Menzie, W. D., 1983, Fluorine-deficient porphyry molybdenum deposits in the western North American Cordillera: IAGOD, Tbikis, USSR, Sept. 1982.