PORPHYRY COPPER DEPOSITS OF THE WORLD: DATABASE, MAPS, AND PRELIMINARY ANALYSIS

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INTRODUCTION

Mineral deposit models are important in exploration planning and quantitative resource assessments for two reasons: (1) grades and tonnages among deposit types are significantly different, and (2) many types occur in different geologic settings that can be identified from geologic maps. Mineral deposit models are the keystone in combining the diverse geoscience information on geology, mineral occurrences, geophysics, and geochemistry used in resource assessments and mineral exploration. Far too few thoroughly explored mineral deposits are available in most local areas for reliable identification of the important geoscience variables or for robust estimation of undiscovered deposits-thus we need mineral-deposit models. Globally based deposit models, such as those presented here, allow recognition of important features because the global models demonstrate how common different features are. Well-designed and -constructed deposit models allow geologists to know from observed geologic environments the possible mineral deposit types that might exist, and allow economists to determine the possible economic viability of these resources in the region. Thus, mineral deposit models play the central role in transforming geoscience information to a form useful to policy makers. The foundation of mineral deposit models is information about known deposits-the purpose of this publication is to make this kind of information available in digital form for a group of porphyry copper deposits.

This publication contains a computer file of information on porphyry copper deposits around the world. It also presents new grade and tonnage models for three subtypes of porphyry copper deposits, maps showing locations and general ages of these deposits, and a preliminary analysis with a number of figures summarizing many of the properties of these porphyry-style deposits. These summaries can be considered a new, quantified, form of most parts of descriptive models such as those in Cox and Singer (1986). The value of this information and analyses depends critically on the consistent manner of data gathering. For this reason, we first discuss the rules used in this compilation. Next the fields of the data file are considered. Finally, we discuss some of the things that can be done with the data.

RULES USED

A mineral deposit is a mineral occurrence of sufficient size and grade that might, under the most favorable circumstances, be considered to have economic potential (Cox, and others, 1986). Deposits sharing a relatively wide variety and large number of attributes are characterized as a "type," and a model representing that type can be developed. Porphyry copper deposits consist of stockwork, disseminated, and breccia-hosted copper mineralization that is generally restricted to plutons and their immediate wall rocks. They may have parts containing skarn. Deposits that may be derived from, or affected by, hypogene and supergene processes are included in the models. Deposits that are primarily breccia pipes or skarns were excluded from this database. An important consideration at the data gathering stage is the question of what the sampling unit should be. Grade and tonnage data are available to varying degrees for districts, deposits, mines, and shafts. For the deposits in this file, the following rule was used to determine which ore bodies were combined. All mineralization or alteration within two (2) kilometers was combined into one deposit. Some examples illustrate the effects of the application of this rule. In many other lists of mineral deposits, Chuqui Norte, Exotica, Radomiro Tomic (Pampa Norte), and Chuquicamata in Chile are reported as separate deposits, whereas, here they are reported as one because of the two kilometer rule. El Pachon in Argentina and Los Pelambres in Chile are two parts of the same deposit, frequently reported as separate deposits. Here they are reported as one record (deposit) but with El Pachon in Argentina acting as a place holder pointing to Los Pelambres in Chile which contains the information on both.

DATA FIELDS

The information on the porphyry copper deposits is contained in the files PorCu.FP5 and PorCu.txt which are FileMaker Pro 5 and tab-delineated text files respectively. The fields in both files are described below.

Deposit Name

The most recent deposit name is used. There is another field, "OtherNames," which contains alternative names that have been used for the deposit. A third field, "Includes," provides the names of deposits that have been combined with the primary deposit as a result of the two-kilometer minimum separation rule.

Locations

A number of fields are provided to show the deposit's location. "Country" and "StateProvince" are used for general locations. "CountryCode" is an abbreviated version of the country information **(Table 1)**. Degrees, minutes, and, in some cases seconds, of longitude and latitude are provided in the separate fields. Decimal degrees of latitude ("LatitudeDecimal") and longitude ("LongitudeDecimal") are calculated from the degrees, minutes and seconds fields. Southern latitudes and eastern longitudes are negative values. The field "Map number" is used to identify the location of the deposit on maps supplied in this publication.

Activity

Where the discovery date is know it is recorded ("DiscoveryDate"). If a deposit is known to be a prospect at the time of this publication it is recorded as a "yes" in the "Prospect?" field. If mining is known to have started, the date is listed in the "StartUp" field.

Grades and tonnages

Data gathered for each deposit include average grade of each metal or mineral commodity of possible economic interest and the associated tonnage based on the total production, reserves, and resources at the lowest possible cutoff grade. All further references to tonnage follow this definition. All tonnages reported here ("Tonnage") are in millions of metric tons. Copper ("Copper grade") and molybdenum ("Molybdenum grade") grades are reported as percent of the metals. Gold ("Gold grade") and silver ("Silver grade") grades are reported as grams/metric ton of the metal. Grades not available (always for by-products) are treated as zero. The "Comments" field contains supplementary information about some grades such as Pt and Pd when available. Two significant digits are presented for gold, silver, and molybdenum grades, but three significant digits are used for tonnage and copper grades.

Age

In the field "DepositAge", ages are in standard divisions of geologic time or in millions of years when available. Ages are reported in millions of years before the present ("AgeMY" field) based on reported absolute (typically thermal dates) ages or midpoints of geologic time scale units (Remane, 1998).

Mineralogy

Information on the mineralogy of the deposits varies widely in quantity and quality. Depending on the purpose of a study and the researcher's interest, a report on a mineral deposit might contain a detailed list of alteration minerals and a mention of unnamed sulfide and sulfosalt minerals, a detailed list of ore minerals and mention of alteration in broad terms, a complete list of all minerals, or a sparse list of minerals. In some studies, the author attempted to list the relative or absolute amounts of each mineral. Unfortunately, these attempts are not common and frequently not comparable with many other reports because of different standards. Thus, it was decided to use only the presence or absence of minerals ("Minerals") in this file. Most rock forming minerals such as plagioclase, quartz, and pyroxenes, are not included.

Subtypes of porphyry copper deposits

Each deposit type is coded ("Type") as appropriate deposit type number as listed in USGS Bulletins 1693 (Cox and Singer, 1986). Subtypes of porphyry copper deposits are defined in Cox and Singer (1992) as: porphyry Cu-Au (type 20c) if Au/Mo greater than or equal to 30, porphyry Cu-Mo (type 21a) if Au/Mo less than or equal to 3, and porphyry Cu (type 17) otherwise, where gold is in parts per million and molybdenum is in percent. Skarn-related porphyry copper deposits (type 18a) were not addressed as a separate category because of the difficulty of making an operational definition.

Size and shape of alteration, sulfide, and ore bodies

To consistently capture information about the size and shape of alteration, sulfide (pyrite) and ore bodies as represented in two-dimensional projection to the surface, we use the rigorous procedures used for mineral grain images (Griffiths, 1967). The shortest dimension (b axis) is measured as the distance between parallel rules that just touch the object. After the short dimension is determined, the long axis is measured perpendicular to the b axis using the same criteria. Many of the alteration, ore, and sulfide zones can be well represented by an ellipse. Where published estimates of the projected area of the body are not available we estimated the area using the standard formula for area of an ellipse (area = 3.14159 a b / 4). In some cases however, the body has significant concave parts and use of an ellipse to estimate area of the body would result in an over estimate of the area. An example of these effects is seen in the Malanjkhand ore-body in India that has a markedly concave shape and a measured area that is about half of that calculated assuming an ellipse shape-we used the measured area. The field "SulfideArea" represents the area of sulfides in square kilometers; the sulfide minor axis in kilometers is in the field "SulfideBAxis", and the major axis is in the field "SulfideAAxis". Area of alteration, alteration major axis, and minor axis are represented by the fields "AlterArea", "AlterAAxis", "AlterBAxis" respectively. The area of ore in square kilometers is in the field "OreArea", the major axis of ore is in "OreAAxis", and the minor axis in "OreBAxis".

Spatially associated rocks

Rocks in and around the porphyry copper deposit are recorded here in the same terms used in the published maps and reports. Reports of rocks from different sources were treated equally. We have used three fields in an attempt to provide some spatial information. The field "RocksInDeposit" is used for rocks that are only represented in the deposit itself and not observable on a regional map. Rocks that are recorded both in the deposit and on a regional map are placed in the field "RocksOnMapInDeposit". Rocks on a regional map, but not in the deposit are in the field "RocksOnMap".

Emplacement Depth

The depth of emplacement of the porphyry copper deposits in kilometers is recorded ("EmplacementDepthkm") when it was estimated in the literature.

Spatially related deposits

Here we record other deposits by type that are within 5 ("Assoc Deposits less 5km") and within 10 ("Assoc Deposits less 10km") km of a porphyry copper deposit. In many situations, these other deposits are merely occurrences and not economic mineral deposits. Nevertheless, many of these occurrences can be typed and their types might provide important information about possible porphyry copper deposits. Each deposit type is coded as the deposit type number and deposit type as listed in USGS Bulletins 1693 (Cox and Singer, 1986) and 2004 (Bliss, 1992). In most cases the age of spatially associated deposits is not know. No attempt is made here to record the age in the rare case where it is known.

Sources

An attempt was made to refer to the papers/web sites that were used for each deposit ("References"). In a few cases unpublished sources were used.

PRELIMINARY ANALYSIS

Grade and tonnage models

Grade and tonnage models of mineral deposits are useful in quantitative resource assessments and exploration planning. Having some idea of the possible values of alternative kinds of deposits that might be sought is critical to good exploration planning. In quantitative resource assessments these models play two roles: first, grade and tonnage models can help classify into types the known deposits in a region and therefore aid in delineation of areas permissive for types; second, the models provide information about the potential value of undiscovered deposits in the assessment area and are key to economic analyses of these resources.

Construction of grade and tonnage models involves multiple steps; the first is the identification of a group of well-explored deposits that are believed to belong to the mineral deposit type being modeled. Well-explored here means completely drilled in three dimensions. After deposits are identified, data from each are compiled. These data consist of average grades of each metal or mineral commodity of possible economic interest and tonnages based on the total production, reserves, and resources at the lowest available cutoff grade. Here we use the deposits that have tonnages recorded in the "Tonnage" field and exclude deposits with grades and tonnages only in the "Comments" field because we believe more exploration is needed for these deposits.

Relationships among variables are important for simulations of resources, for their affect our understanding of how deposits form, and for their affect our assumptions about resource availability. A plot of average copper grade versus tonnage of all porphyry coppers **(Fig. 1)** shows a slight positive correlation that is not significant at the one percent level. The independence of grade and tonnage is expected when the relationship between copper content and tonnage of ore is examined **(Fig. 2)**-the two are highly correlated and grade is a ratio of the two. Ratios of highly correlated variables tend to be independent of either. Tonnage is correlated with gold grade **(Fig. 3)** and gold is correlated with molybdenum **(Fig.** 4) and with silver **(Fig. 5)**.

If there were no differences in grades or tonnages among deposit types, we could use one model for all types. For this reason, it is desirable to perform some tests to determine if the types are significantly different with respect to grade or tonnages. Analysis of variance tests of differences in mean (in logarithms) tonnage, copper, molybdenum, gold, and silver grades by type of porphyry copper deposit reveal significant differences in gold **(Fig. 6)** and molybdenum **(Fig. 7)** grade as expected because of how subtypes were defined. Silver grades are significantly higher in gold-rich porphyry copper deposits than in the other subtypes based on those deposits with reported grades **(Fig. 8)**. In addition, tonnages of the molybdenum-rich subtype are significantly larger than the porphyry copper and the porphyry copper-gold subtypes **(Fig. 9)**.

The analysis of variance tests demonstrate an important reason for separating the porphyry coppers into subtypes where possible-they have different grade and tonnage models and probably different economic values. Within the types, other statistical tests were performed to determine if a lognormal model adequately describes the frequencies of tonnages and grades and to determine if there are significant correlations among the variables.

Based on the Lillifors test (SYSTAT, 1992), the only variable that can be rejected (at 1 percent level) as having come from a lognormal distribution is the gold grade of porphyry Cu deposits. Gold grades of this type are correlated with molybdenum grades ($r = 0.63$, $n = 54$). Silver grades are correlated with tonnage ($r = -0.37$, $n = 49$) in the porphyry Cu-Au group. In the porphyry Cu-Mo group, tonnage is correlated with copper grade ($r = 0.41$, $n = 49$) and with molybdenum grade ($r = -0.45$, $n = 48$), and molybdenum grade is correlated with silver grade ($r = 0.50$, $n = 35$).

Grade and tonnage models are presented in a graphical format to make it easy to compare deposit types and to display the data. The grade and tonnage plots show the cumulative proportion of deposits versus the tonnage or grade of the deposits. Individual symbols represent the deposits and intercepts for the 90th, 50th, and 10th percentiles are plotted. The 90th and 10th percentiles are 1.282 standard deviations (in logarithms) from the mean. For each deposit type these models help define a deposit, as opposed to a mineral occurrence or a weak manifestation of an ore-forming process.

Frequency distributions of tonnage, copper grade, molybdenum grade, silver grade, and gold grade for the porphyry Cu-Au type are presented in figures **10**, **11**, **12**, **13**, and **14**, respectively. Porphyry Cu frequency distributions are in figures **15**, **16**, **17**, **18**, and **19** and those for porphyry Cu-Mo deposits are in figures **20**, **21**, **22**, **23**, and **24**. Files containing the data used in these plots are provided separately (files PorCu.G-T.xls, PorCu-Au.G-T.xls, PorCu-Mo.G-T.xls).

Deposits through time

For both economic and scientific reasons, there are questions about the distribution of the metals in porphyry copper deposits over geologic time. Are there preferential times in the earth's history of formation of these deposits and is the observed pattern a result of biased sampling because of erosion? Using the UNESCO International stratigraphic chart (Remane, 1998), we assigned the dated deposits and their contained metals to one of 13 eons or epochs.

Most copper from porphyry copper deposits is in deposits formed during the Cenozoic with noticeably lesser amounts in pre-Cenozoic deposits **(Fig. 25)**. A plot of the amount of copper per year from porphyry copper deposits also shows the Cenozoic predominating **(Fig. 26)**. If this pattern was due to erosion we would expect to see the average size of deposits decrease as we move backward through time because older deposits would have been more exposed to erosion. A plot of average copper content per deposit over geologic time shows no such trend **(Fig. 27)**. There are fluctuations in the average, but the number of deposits used to calculate them varies as shown on the figure. In an analysis of variance that properly accounts for the various number of deposits and the skewed nature of tonnages, the logarithms of tonnage are not significantly different and could vary this much by chance alone about 5 percent of the time. Another way to examine possible erosion effects is to plot the percent of all porphyry copper deposits that belong to the gold-rich class because these tend to form in shallower environments than the other porphyry copper deposits. In **figure 28**, we can see no trend of gold-rich porphyry copper deposits becoming less common through time.

Plots of the gold content through time of the gold-bearing porphyry copper deposits display a pattern similar to that shown above for copper (Figs. **29**, **30**, and **31**). The Cenozoic predominates as the most productive age. The average content per deposit is highest during the Permian, although this average is based on only seven deposits. An analysis of variance shows that this result could happen 55 percent of the time by chance suggesting that not much should be made of it.

The Cenozoic is observed as the predominate age of copper and gold production in porphyry copper deposits. If erosion is the reason for this pattern, then it would have needed to destroy complete deposits and both shallow and deeper-seated deposits equally.

Mineralogy

The presence or absence of each mineral listed in the file is recorded by deposit in the tab-delineated files "PorCu-Au.Mins", "PorCu.Mins", and "PorCu-Mo.Mins" for the named types of porphyry copper deposit. A few rare minerals are excluded from these files. The minerals are ordered from most to least common by the percent of deposits in the grade and tonnage models with the minerals reported. These summaries can be considered a new, quantified, form of the mineralogy part of descriptive models in Cox and Singer (1986). Some of the more commonly reported minerals in these files such as epidote, covellite, and alunite, are not mentioned in the original descriptive models, demonstrating one of the values of quantifying the models.

Figures showing some of the frequencies of reported minerals are in figures **32**, **33**, **34**, and **35**. Two things should be remembered when viewing these figures, the number of deposits in the porphyry Cu-Mo grade and tonnage model is relatively small, and the porphyry Cu model contains deposits which, in some cases, have too little information to classify into one of the other groups. A fairly consistent pattern in these figures is the decreasing frequency of the presence of certain minerals in gold-rich porphyry copper deposits compared to molybdenum-rich porphyry copper deposits with intermediate porphyries having intermediate frequencies. Other minerals show the opposite trend. Both the increasing and decreasing patterns are consistent with the emplacement depths of these types of deposits. Files containing the data used in these plots are provided separately (files PorCu.Mins.xls, PorCu-Au.Mins.xls, PorCu-Mo.Mins.xls).

Associated rocks

The database contains three fields of associated rocks. In order to simplify things, here we combine two fields and exclude rocks reported as occurring only in the deposit. Additionally, we combine the rocks into groups based on the British Geological Survey standard for igneous rocks (Gillespie, and Styles, 1999). Tab-delineated files recording the presence or absence of each of the grouped rocks are provided (PorCu-Au.Rocks, PorCu.Rocks, PorCu-Mo.Rocks) for the named types of porphyry copper deposit.

No clear differences in the percent of rock types associated with types of porphyry copper deposits are seen for many sedimentary and some volcanic rocks **(Fig. 36)**. The commonness of some rock types such as conglomerate which is reported to occur near 30 percent or more of porphyry copper deposits might not be expected by some. Some igneous rocks such as granite, syenite, and rhyolite occur more frequently near molybdenum-rich porphyry copper deposits than near gold-rich porphyries **(Fig. 37)**. Other types, such as diorite, show no such preference and some rocks such as shoshonite are only reported to be associated with 5 of the porphyry copper deposits. Files containing the data used in these plots are provided separately (files PorCu.Rocks.xls, PorCu-Au.Rocks.xls, PorCu-Mo.Rocks.xls).

Spatially related deposit types

Associated deposits are listed in the descriptive models of USGS Bulletin 1693 as deposit types whose presence might indicate suitable conditions for deposits of the type (**Table 2**) portrayed by the model. Here we have specific information both about types of associated deposits and about their spatial relations to known deposits.

It is probably no surprise that similar deposits are found near each other; gold-rich porphyry copper deposits occur more commonly near gold-rich porphyry copper deposits than near the other porphyry copper types and the same pattern is seen for molybdenum-rich porphyry copper deposits **(Fig. 38)**. These porphyry deposits seem to occur more frequently in the 5-10 kilometer distance than they do in the 0-5 kilometer distance from know deposits. Copper and zinc-lead skarn, polymetallic replacement and polymetallic vein deposits on the other hand, are more likely to be within 5 kilometers of the porphyry copper deposit **(Fig. 39)**. The incidence of polymetallic vein deposits seems to be higher at the 5-10 kilometer distance near the molybdenum-rich porphyries than for the gold-rich porphyries. Epithermal gold-bearing deposits and placer gold deposits tend to occur more often within the 5 kilometer distance and they are much more common near gold-rich porphyry copper deposits than the deeper-formed molybdenum-rich deposits **(Fig. 40)**.

Sulfide areas

Because there is a strong positive relation between area of sulfides (disseminated pyrite) and the deposits' contained copper, one might only examine large sulfide systems if looking for large porphyry copper deposits (Singer and Mosier, 1981). Reexamination of the relation between area of sulfide minerals and deposits' contained Cu shows the strength of the relationship is stronger in the deeper-formed porphyry Cu-Mo deposits **(Fig. 41)**. Some of the differences among deposit types could be due to incomplete exploration of some of the larger systems such as Pebble Copper in Alaska.

Location Maps

A map showing the locations of the deposits is provided in **Map 1**. The numbers on the map match the numbers in the MapNumber field of the data file. A similar map showing generalized deposit ages is **Map 2**. Because of the large number of deposits in some localities, we have included more detailed maps for central Europe **(Map 3)**, the Philippines **(Map 4)**, North America **(Map 5)**, and South America **(Map 6)**. These maps have both the general age categories and the location numbers.

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SYSTEM REQUIREMENTS

The data and text require either a Macintosh or compatible computer or an IBM or compatible personal computer. The Macintosh should have a 68020 or higher processor (PowerPC recommended), 8 megabytes RAM (16 MB recommended), Apple System Software version 7.0 or later (7.1.2 or later recommended), and a 13- inch color monitor that can display thousands of colors. The PC should have a 386 or higher processor (Pentium recommended), Microsoft Windows 3.1 or higher (Windows 95, 98, or NT recommended), 8 megabytes RAM (16 MB recommended), and a VGA color monitor that can display 256 colors. Both platforms require Adobe Acrobat Reader 4.0 or higher or other software that can translate PDF files. If you are using Acrobat Reader 4 or lower, you will need to upgrade.

This was produced in accordance with the ISO 9660 and Macintosh HFS standards. All ASCII and TXT files can be accessed from DOS, Macintosh, and Unix platforms, the display software packages provided are designed for use under a DOS- based, Windows-based, or Macintosh system, as appropriate.

FILES

OF 02-268.TXT (ASCII text file describing all contents.)

COUNTRY CODES.XLS (A text file relating country codes to country names.)

PorCu.FP5.XLS. (A FileMaker Pro5 file containing the porphyry copper database.)

PorCu.XLS (A tab-delineated text file containing the porphyry copper database.)

PorCu.G-T.XLS (A tab-delineated text file containing the tonnages, and copper, molybdenum, silver, and gold grades used in the grade and tonnage model for porphyry Cu deposits.)

PorCu-Au.G-T.XLS (A tab-delineated text file containing the tonnages, and copper, molybdenum, silver, and gold grades used in the grade and tonnage model for porphyry Cu-Au deposits.)

PorCu-Mo.G-T.XLS (A tab-delineated text file containing the tonnages, and copper, molybdenum, silver, and gold grades used in the grade and tonnage model for porphyry Cu-Mo deposits.)

Types.XLS (A tab-delineated text file containing deposit type numbers and their names.)

PorCu.Mins.XLS (A tab-delineated text file noting the presence (1) or absence (0) of reported minerals in deposits used in the porphyry Cu grade and tonnage model.)

PorCu-Au.Mins.XLS (A tab-delineated text file noting the presence (1) or absence (0) of reported minerals in deposits used in the porphyry Cu-Au grade and tonnage model.)

PorCu-Mo.Mins.XLS (A tab-delineated text file noting the presence (1) or absence (0) of reported minerals in deposits used in the porphyry Cu-Mo grade and tonnage model.)

PorCu.Rocks.XLS (A tab-delineated text file noting the presence (1) or absence (0) of reported rocks in deposits used in the porphyry Cu grade and tonnage model. Rocks are grouped according to Gillespie and Styles, 1999.)

PorCu-Au.Rocks.XLS (A tab-delineated text file noting the presence (1) or absence (0) of reported rocks in deposits used in the porphyry Cu-Au grade and tonnage model. Rocks are grouped according to Gillespie and Styles, 1999.)

PorCu-Mo.Rocks.XLS (A tab-delineated text file noting the presence (1) or absence (0) of reported rocks in deposits used in the porphyry Cu-Mo grade and tonnage model. Rocks are grouped according to Gillespie and Styles, 1999.)

Map 1.PDF. Locations of all porphyry copper deposits in the PorCu.FM5 file plotted on a world map.

Map 2.PDF. Generalized ages of all porphyry copper deposits in the PorCu.FM5 file plotted on a world map.

Map 3.PDF. Locations and generalized ages of all porphyry copper deposits located in Europe in the PorCu.FM5 file plotted on a regional map.

Map 4.PDF. Locations and generalized ages of all porphyry copper deposits located in and just south of the Philippines in the PorCu.FM5 file plotted on a regional map.

Map 5.PDF. Locations and generalized ages of all porphyry copper deposits located in Northwestern North America (excluding Alaska) in the PorCu.FM5 file plotted on a regional map.

Map 6.PDF. Locations and generalized ages of all porphyry copper deposits located in Central and South America in the PorCu.FM5 file plotted on a regional map.

Table 1. Country Code definitions

COUNTRY CODE	COUNTRY NAME
AFGH	AFGHANISTAN
AGTN	ARGENTINA
ALBN	ALBANIA
ALGR	ALGERIA
AMSM	AMERICAN SAMOA
ANDR	ANDORRA
ANGL	ANGOLA
ANGU	ANGUILLA
ANTG	ANTIGUA
ASTR	AUSTRIA
AUNS	AUSTRALIA, NEW SOUTH WALES
AUNT	AUSTRALIA, NORTHERN TERRITORY
AUQL	AUSTRALIA, QUEENSLAND
AUSA	AUSTRALIA, SOUTH AUSTRALIA
AUTS	AUSTRALIA, TASMANIA
AUVT	AUSTRALIA, VICTORIA
AUWA	AUSTRALIA, WESTERN AUSTRALIA
BANG	BANGLADESH
BARB	BARBADOS
BELZ	BELIZE
BENN	BENIN
BHMS	BAHAMAS
BHRN	BAHRAIN
BHTN	BHUTAN
BLGM	BELGIUM
BLVA	BOLIVIA
BOTS	BOTSWANA
BRMA	BURMA
BRMD	BERMUDA
BRND	BURUNDI
BRNI	BRUNEI
BRZL	BRAZIL
BULG	BULGARIA
CAFR	CENTRAL AFRICAN REPUBLIC
CARL	CAROLINE ISLANDS
CHAD	CHAD
CILE	CHILE
CINA	CHINA
CLBA	COLOMBIA
CMRN	CAMEROON
CMRS	COMOROS
CNAL	CANADA, ALBERTA
CNBC	CANADA, BRITISH COLUMBIA
CNGO	CONGO
CNMN	CANADA, MANITOBA
CNNB	CANADA, NEW BRUNSWICK
CNNF	CANADA, NEWFOUNDLAND
CNNS	CANADA, NOVA SCOTIA
CNNT	CANADA, NORTHWEST TERRITORIES

Table 1. (continued) Country Code definitions

COUNTRY CODE	COUNTRY NAME
CNON	CANADA, ONTARIO
CNQU	CANADA, QUEBEC
CNSK	CANADA, SASKATCHEWAN
CNYT	CANADA, YUKON TERRITORY
COOK	COOK ISLAND
CORI	COSTA RICA
CPVD	CAPE VERDE
CUBA	CUBA
CYMN	CAYMAN ISLAND
CYPS	CYPRUS
CZCL	CZECHOSLOVAKIA
DHMY	DAHOMEY
DJBT	DJIBOUTI
DMNC	DOMINICA
DMRP	DOMINCAN REPUBLIC
DNMK	DENMARK
ECDR	ECUADOR
EGPT	EGYPT
ELSA	EL SALVADOR
EQGU	EQUATORIAL GUINEA
ETHP	ETHIOPIA
FAER	FAEROE ISLAND
FALK	FALKLAND ISLAND
FIJI	FIJI
FNLD	FINLAND
FRNC	FRANCE
FRPL	FRENCH POLYNESIA
GABN	GABON
GAMB	GAMBIA
GAZA	GAZA STRIP
GBLT	GIBRALTAR
GHNA	GHANA
GNBS	GUINEA-BISSAU
GNEA	GUINEA
GRBR	GREAT BRITAIN
GREC	GREECE
GRLD	GREENLAND
GRME	GERMANY, EAST
GRMW	GERMANY, WEST
GRMY	GERMANY
GRND	GRENADA
GRSY	GUERNSEY
GUAD	GUADELOUPE
GUAM	GUAM
GUAT	GUATEMALA
GUYN	GUYANA
HATI	HAITI
HNDR	HONDURAS
HONG	HONG KONG

Table 1. (continued) Country Code definitions

COUNTRY CODE	COUNTRY NAME
HUNG	HUNGARY
ICLD	ICELAND
INDA	INDIA
INDS	INDONESIA
IRAN	IRAN
IRAQ	IRAQ
IRLD	IRELAND
ISMN	ISLE OF MAN
ISRL	ISRAEL
ITLY	ITALY
IVCO	IVORY COAST
JAPN	JAPAN
JMCA	JAMAICA
JRDN	JORDAN
JRSY	JERSEY ISLAND
KAMP	KAMPUCHEA
KNYA	KENYA
KUWT	KUWAIT
LAOS	LAOS
LCSN	LIECHTENSTEIN
LEBN	LEBANON
LIBR	LIBERIA
LIBY	LIBYA
LSTH	LESOTHO
LXBG	LUXEMBOURG
MACU	MACAU
MALI	MALI
MAUR	MAURITANIA
MDGS	MADAGASCAR
MLDV	MALDIVES
MLTA	MALTA
MLWI	MALAWI
MLYA	MALAYSIA
MNCO	MONACO
MNGL	MONGOLIA
MRCO	MOROCCO
MRTQ	MARTINIQUE
MRTS	MAURITIUS
MTSR	MONTSERRAT
MXCO	MEXICO
MZMB	MOZAMBIQUE
NCAL	NEW CALEDONIA
NCRG	NICARAGUA
NEPL	NEPAL
NGRA	NIGERIA
NIGR	NIGER
NKOR	KOREA NORTH
NAMB	NAMIBIA
NRAN	NETHERLANDS ANTILLES

Table 1. (continued) Country Code definitions

COUNTRY CODE	COUNTRY NAME
NRLD	NETHERLANDS
NRWY	NORWAY
NZLD	NEW ZEALAND
OMAN	OMAN
PANA	PANAMA
PDRY	PEOPLE'S DEMOCRATIC REPUBLIC OF YEMEN
PERU	PERU
PKTN	PAKISTAN
PLND	POLAND
PLPN	PHILIPPINES
PORT	PORTUGAL
PPNG	PAPUA NEW GUINEA
PRGY	PARAGUAY
PTRC	PUERTO RICO
QATR	QATAR
REUN	REUNION
RMNA	ROMANIA
RWND	RWANDA
SAAR	SAUDI ARABIA
SAFR	SOUTH AFRICA
SING	SINGAPORE
SKOR	KOREA SOUTH
SLMN	SOLOMAN ISLAND
SLNK	SRI LANKA
SMLA	SOMALIA
SNAF	SPANISH NORTH AFRICA
SNGL	SENEGAL
SNMR	SAN MARINO
SPAN	SPAIN
SRLN	SIERRA LEONE
SRNM	SURINAM
STHL	ST. HELENA
STKN	ST. KITTS-NEVIS
STLC	ST. LUCIA
STPM	ST. PIERRE AND MIQUELON
STPR	SAO TOME AND PRINCIPE
STVN	ST. VINCENT
SUDN	SUDAN
SWAZ	SWAZILAND
SWDN	SWEDEN
SWTZ	SWITZERLAND
SYCL	SEYCHELLES
SYRA	SYRIA
THLD	THAILAND
TIWN	TAIWAN
TKCS	TURKS AND CAICOS ISLAND
TNGA	TONGA
TNZN	TANZANIA
TOGO	TOGO

Table 1. (continued) Country Code definitions

COUNTRY CODE	COUNTRY NAME
TRKY	TURKEY
TRTO	TRINIDAD AND TOBAGO
TUNS	TUNISIA
UAEM	UNITED ARAB EMIRATES
UGND	UGANDA
UKEN	UNITED KINGDOM, ENGLAND
UKSC	UNITED KINGDOM, SCOTLAND
URAM	ARMENIA
URAZ	AZERBAJDZANSKAJA
URBE	BELORUSSKAJA
URES	ESTONIA
URGR	GRUZINSKAJA
URGY	URUGUAY
URKG	KIRGIZSKAJA
URKZ	KAZAKHSTAN
URLA	LATVIA
URLI	LITHUANIA
URMD	MOLDAVIAN
URRO	ROSSIJSKAJA
URRS	RUSSIA
URTD	TADZHIKISTAN
URTK	TURKESTAN
URUK	UKRAINIA
URUZ	UZBEKISTAN
USAK	UNITED STATES, ALASKA
USAL	UNITED STATES, ALABAMA
USAR	UNITED STATES, ARKANSAS
USAZ	UNITED STATES, ARIZONA
USCA	UNITED STATES, CALIFORNIA
USCO	UNITED STATES, COLORADO
USCT	UNITED STATES, CONNECTICUT
USDE	UNITED STATES, DELAWARE
USFL	UNITED STATES, FLORIDA
USGA	UNITED STATES, GEORGIA
USHI	UNITED STATES, HAWAII
USIA	UNITED STATES, IOWA
USID	UNITED STATES, IDAHO
USIL	UNITED STATES, ILLINOIS
USIN	UNITED STATES, INDIANA
USKS	UNITED STATES, KANSAS
USKY	UNITED STATES, KENTUCKY
USLA	UNITED STATES, LOUISIANA
USMA	UNITED STATES, MASSACHUSETTS
USMD	UNITED STATES, MARYLAND
USME	UNITED STATES, MAINE
USMI	UNITED STATES, MICHIGAN
USMN	UNITED STATES, MINNESOTA
USMO	UNITED STATES, MISSOURI
USMS	UNITED STATES, MISSISSIPPI

Table 1. (continued) Country Code definitions

COUNTRY CODE	COUNTRY NAME
USMT	UNITED STATES, MONTANA
USNC	UNITED STATES, NORTH CAROLINA
USNE	UNITED STATES, NEBRASKA
USNH	UNITED STATES, NEW HAMPSHIRE
USNJ	UNITED STATES, NEW JERSEY
USNM	UNITED STATES, NEW MEXICO
USNV	UNITED STATES, NEVADA
USNY	UNITED STATES, NEW YORK
USOH	UNITED STATES, OHIO
USOK	UNITED STATES, OKLAHOMA
USOR	UNITED STATES, OREGON
USPA	UNITED STATES, PENNSYLVANIA
USRI	UNITED STATES, RHODE ISLAND
USSC	UNITED STATES, SOUTH CAROLINA
USSD	UNITED STATES, SOUTH DAKOTA
USTN	UNITED STATES, TENNESSEE
USTX	UNITED STATES, TEXAS
USUT	UNITED STATES, UTAH
USVA	UNITED STATES, VIRGINIA
USVI	VIRGIN ISLAND (U.S.)
USVT	UNITED STATES, VERMONT
USWA	UNITED STATES, WASHINGTON
USWI	UNITED STATES, WISCONSIN
USWV	UNITED STATES, WEST VIRGINIA
USWY	UNITED STATES, WYOMING
UVOL	UPPER VOLTA
VNTU	VANUATU
VNZL	VENEZUELA
VRGN	VIRGIN ISLAND (BRITISH)
VTCN	VATICAN CITY
VTMN	VIETNAM NORTH
VTMS	VIETNAM SOUTH
VTNM	VIETNAM
WLFT	WALLIS AND FUTUNA
WSAM	WESTERN SAMOA
WSHR	WESTERN SAHARA
YEMN	YEMEN
YUGO	YUGOSLAVIA
ZIMB	ZIMBABWE
ZIRE	ZAIRE
ZMBA	ZAMBIA

Table 2. Deposit-type Code Numbers

Type Number	Type
8d	serpentine-hosted asbestos
14a	W skarn
15a	W veins
17	porphyry Cu
18a	porphyry Cu, skarn-related
18b	Cu skarn deposits
18c	Zn-Pb skarn
18d	Fe skarn
19a	polymetallic replacement
19c	distal disseminated Ag-Au
20c	porphyry Cu-Au
21a	porphyry Cu-Mo
21b	porphyry Mo, low-F
22b	Au-Ag-Te veins
22c	polymetallic veins
24a	Cyprus massive sulfide
25a	hot-spring Au-Ag
25b	Creede epithermal veins
25c	Comstock epithermal veins
25e	epithermal quartz-alunite Au
26a	sediment-hosted Au-Ag
27a	hot-spring Hg
27c	silica-carbonate Hg
27d	simple Sb
28a	kuroko massive sulfide
30b	sandstone-hosted Cu
36a	low-sulfide Au-quartz veins
39a	placerAu

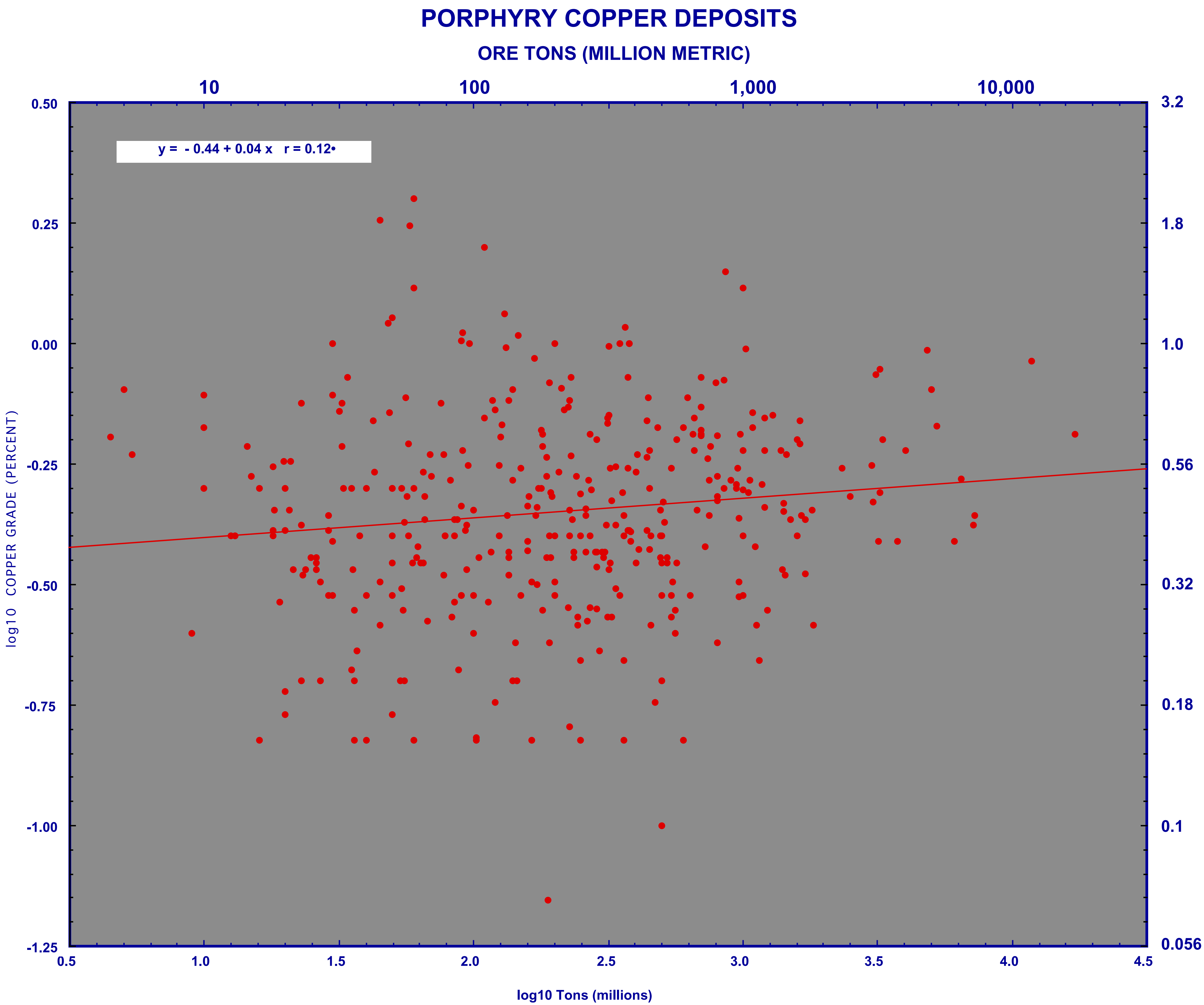

Figure 1. Average copper grade plotted against tonnage in all porphyry copper deposits.

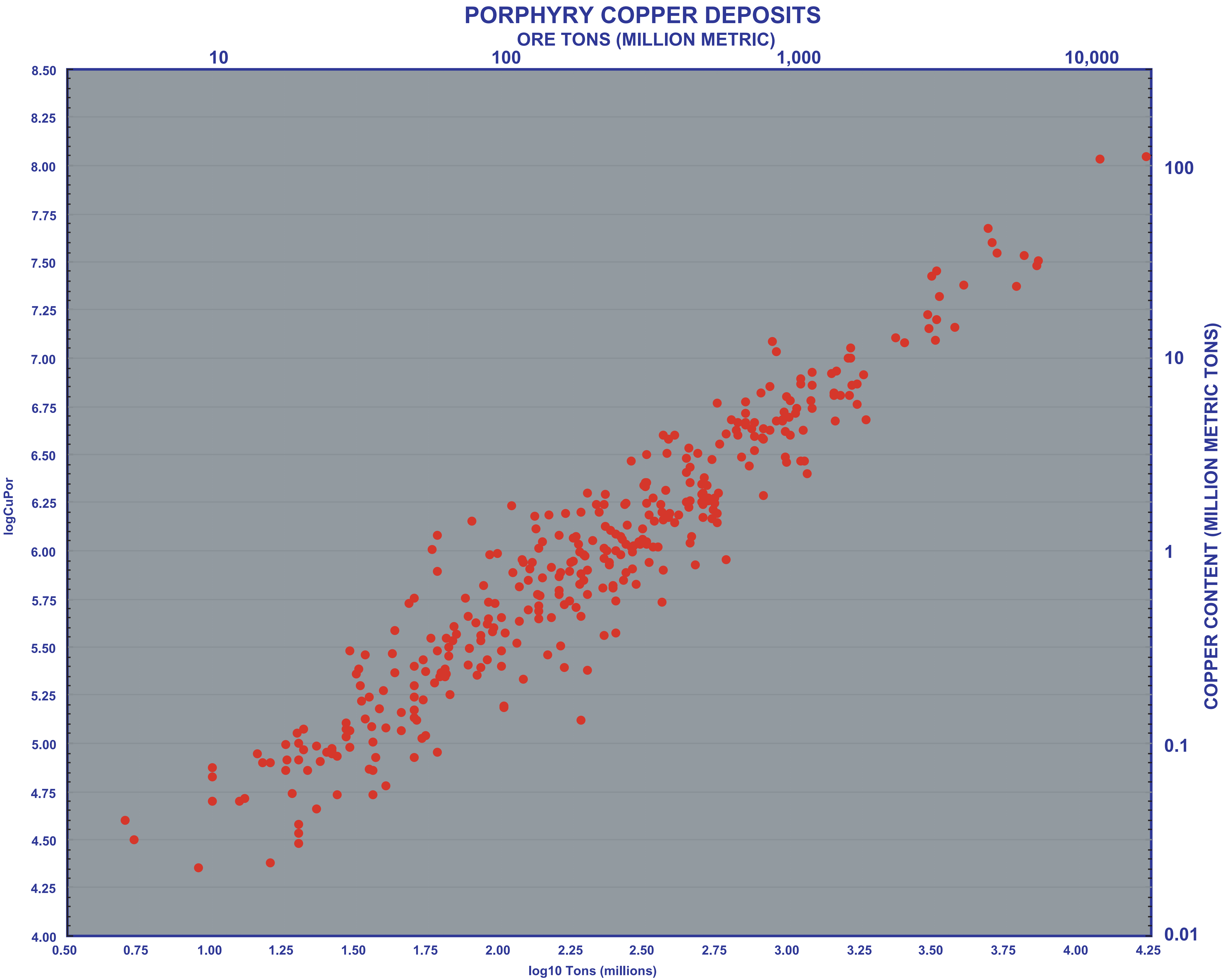

Figure 2. Copper content plotted against tonnage in all porphyry copper deposits.

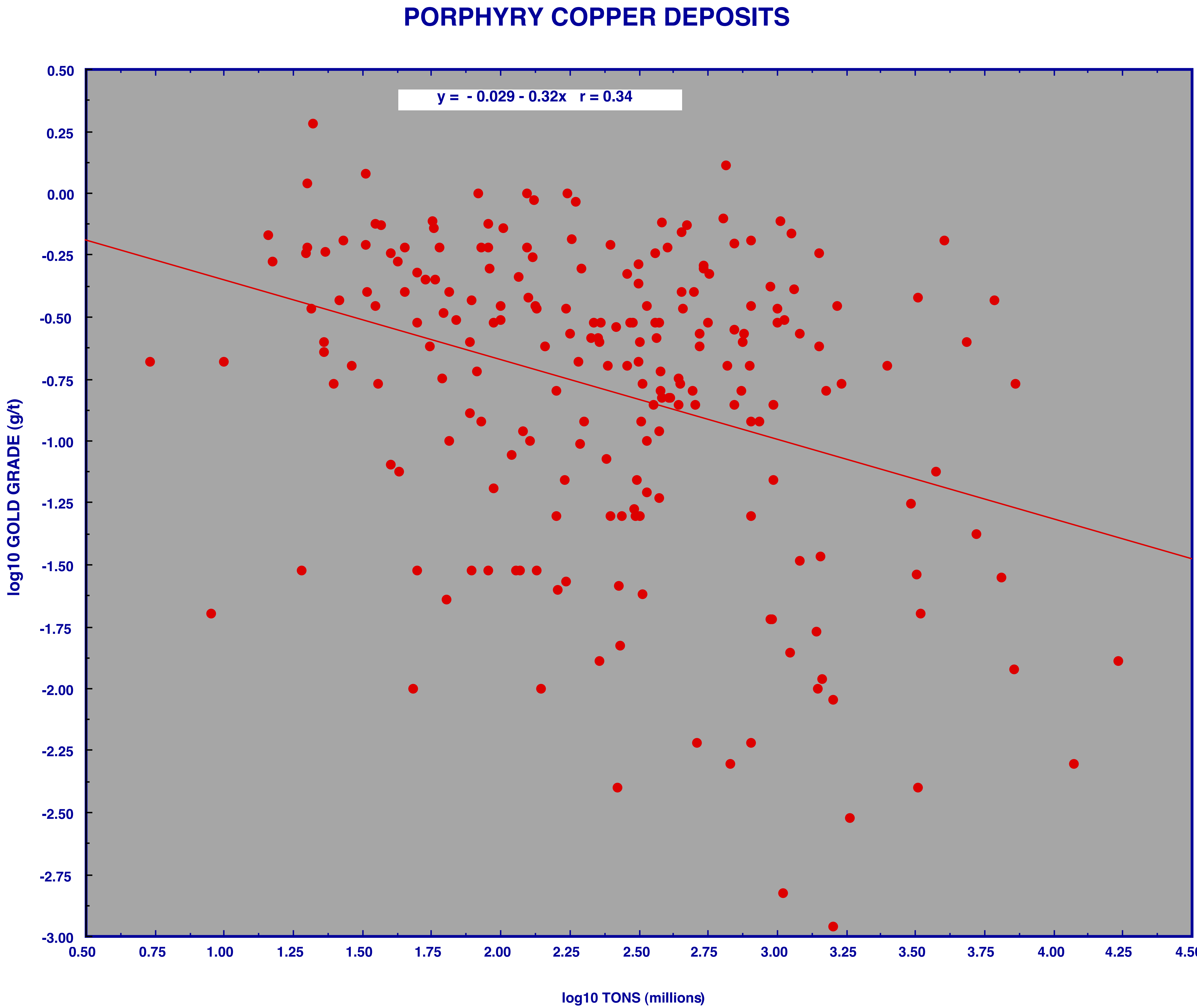

Figure 3. Average gold grade plotted against tonnage in all porphyry copper deposits.

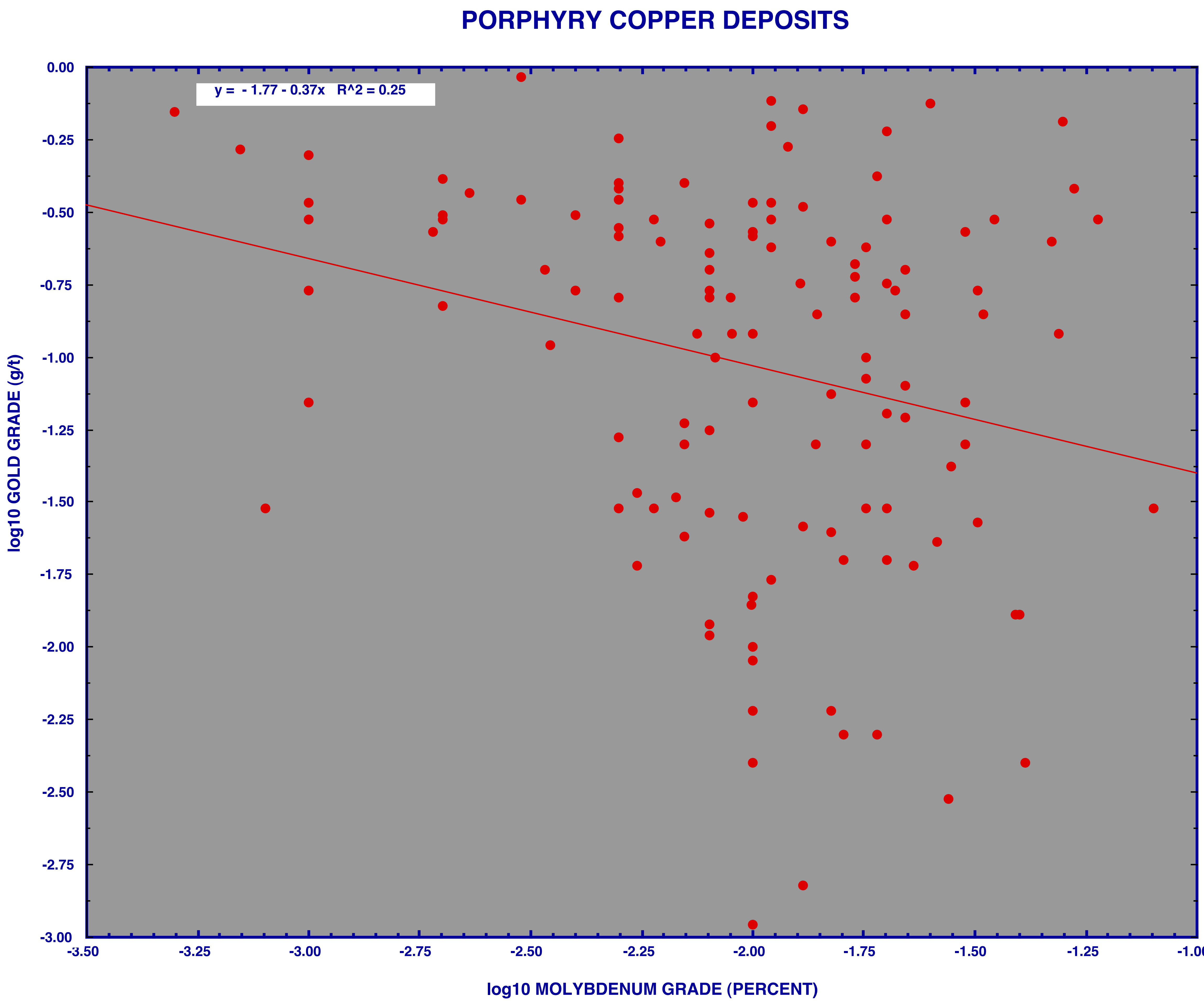

Figure 4. Average molybdenum grade plotted against average gold grade in all porphyry copper deposits.

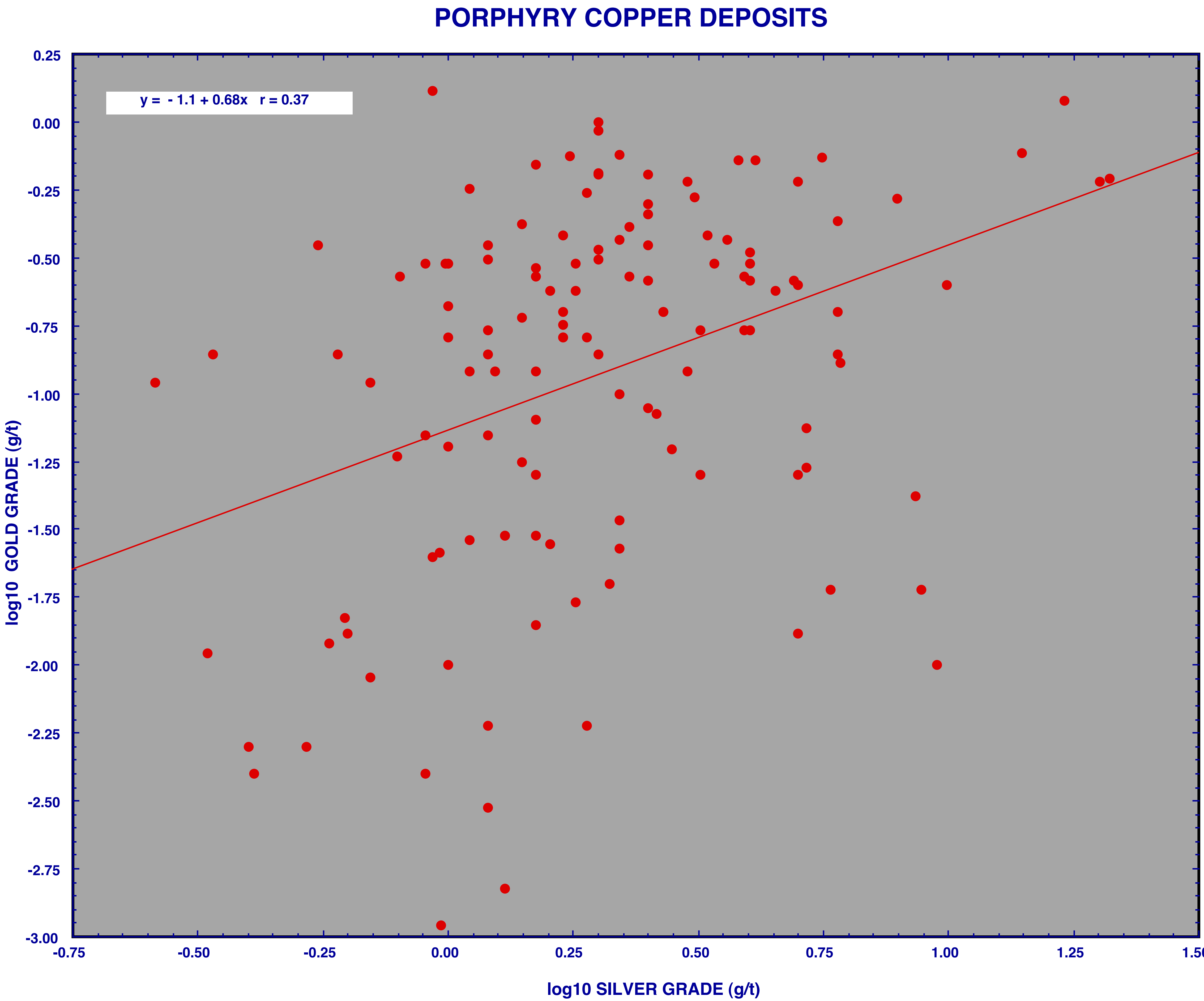

Figure 5. Average silver grade plotted against average gold grade in all porphyry copper deposits.

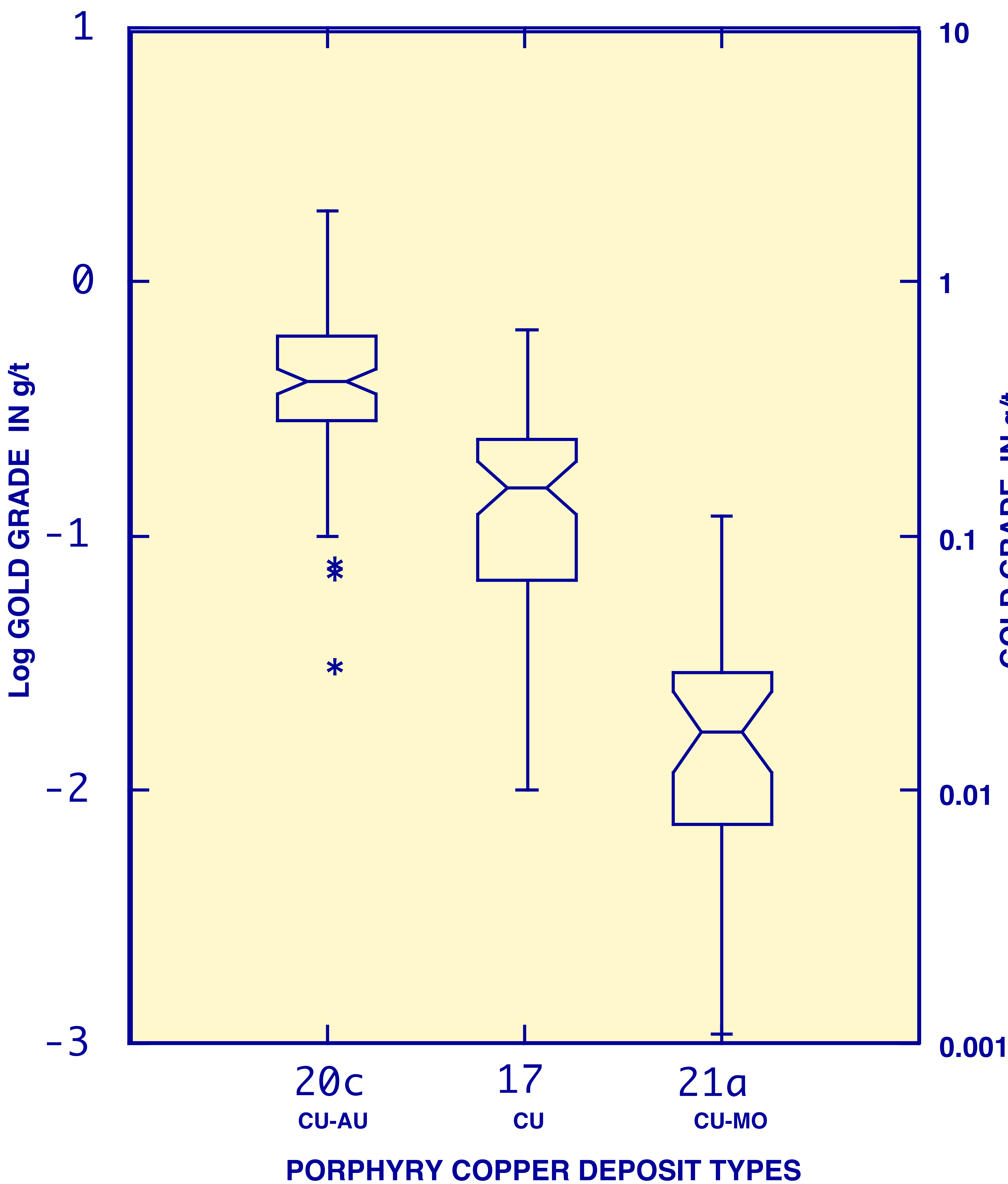

Figure 6. Notched box plot of average gold grade by grouped porphyry copper type. Median is the center line of box, 25th and 75th quartiles are top and bottom of box, and notches represent 95th confidence interval of median.

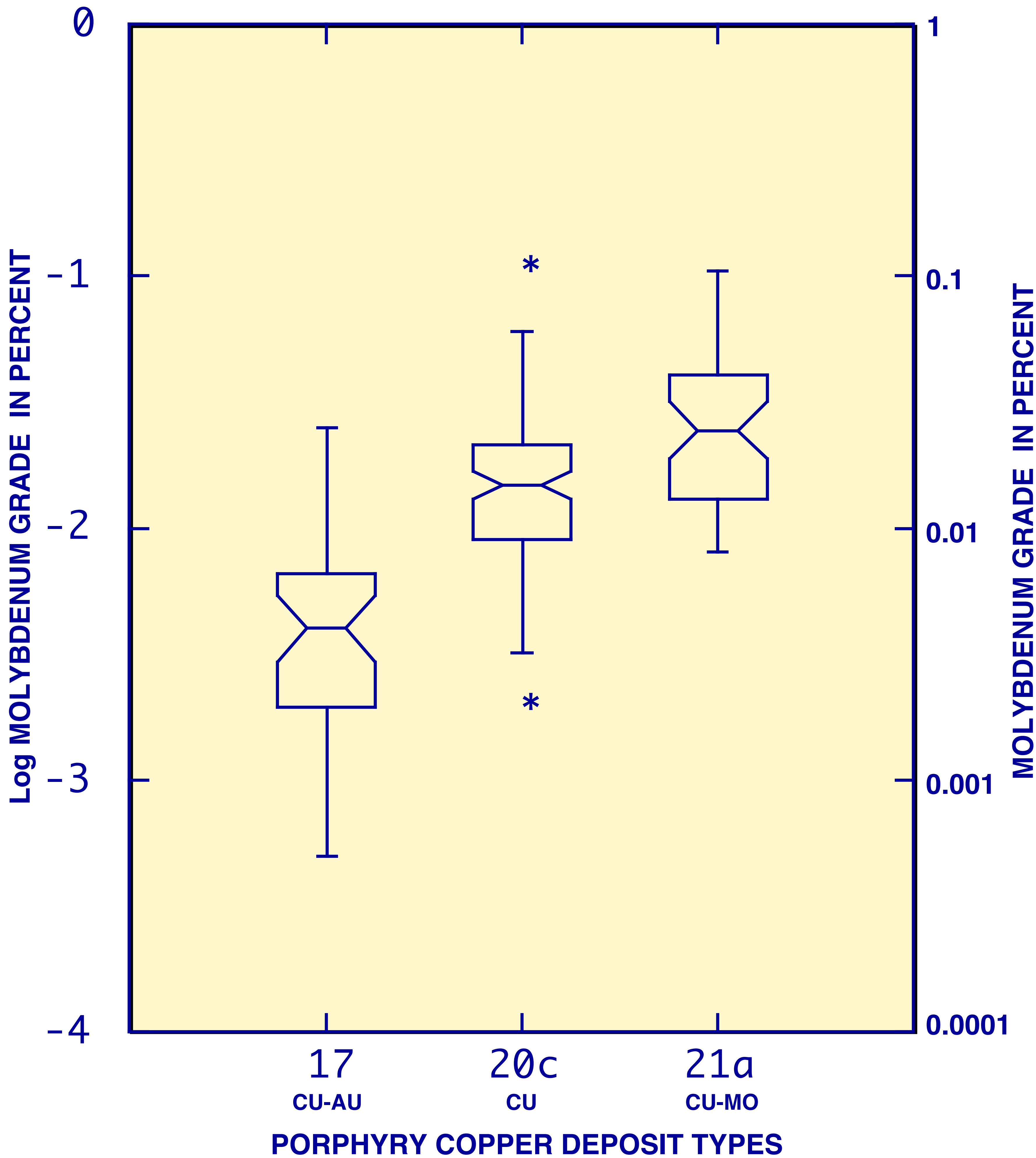

Figure 7. Notched box plot of average molybdenum grade grouped by porphyry copper type. Median is the center line of box, 25th and 75th quartiles are top and bottom of box, and notches represent 95th confidence interval of median.

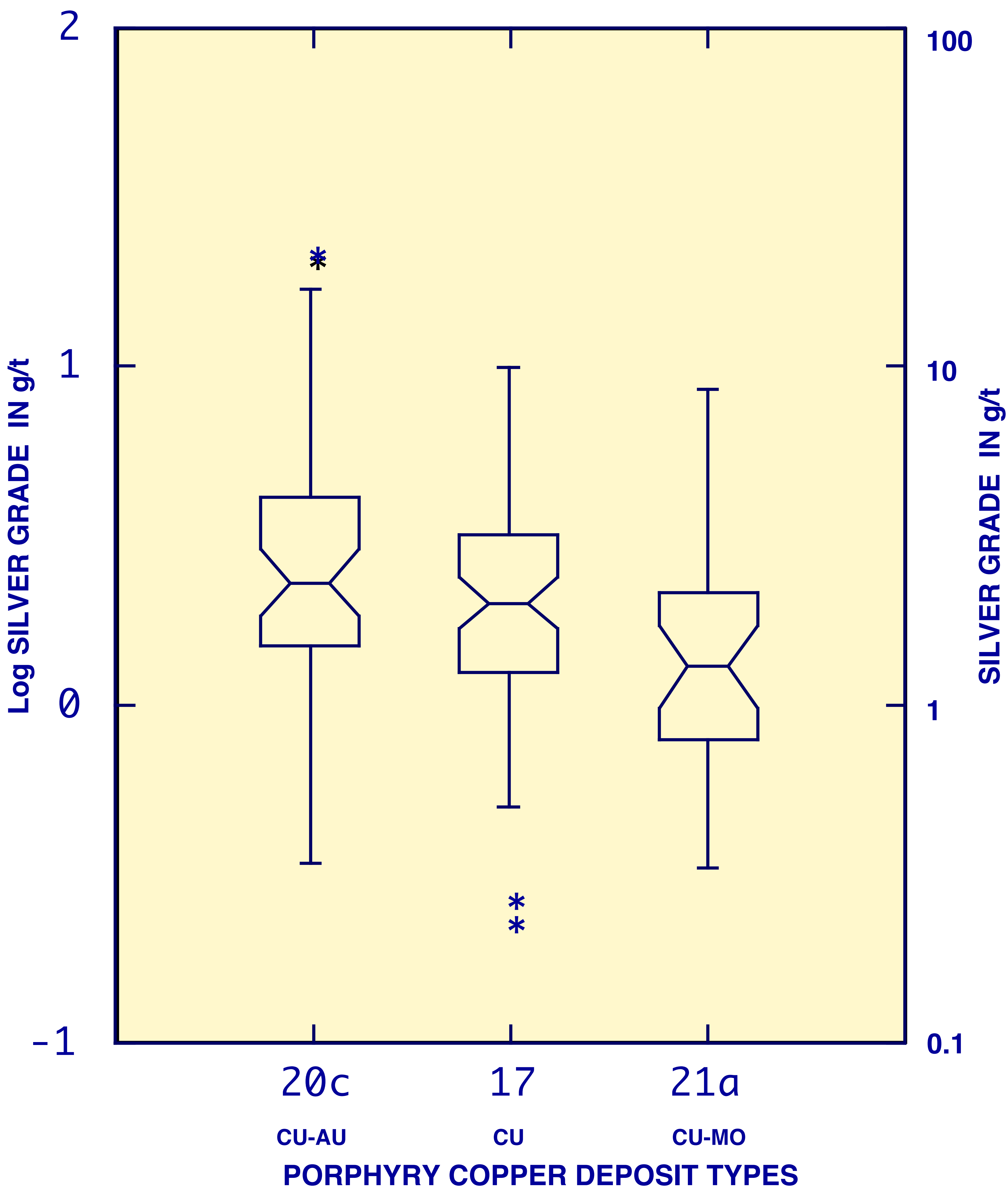

Figure 8. Notched box plot of average silver grade grouped by porphyry copper type. Median is the center line of box, 25th and 75th quartiles are top and bottom of box, and notches represent 95th confidence interval of median.

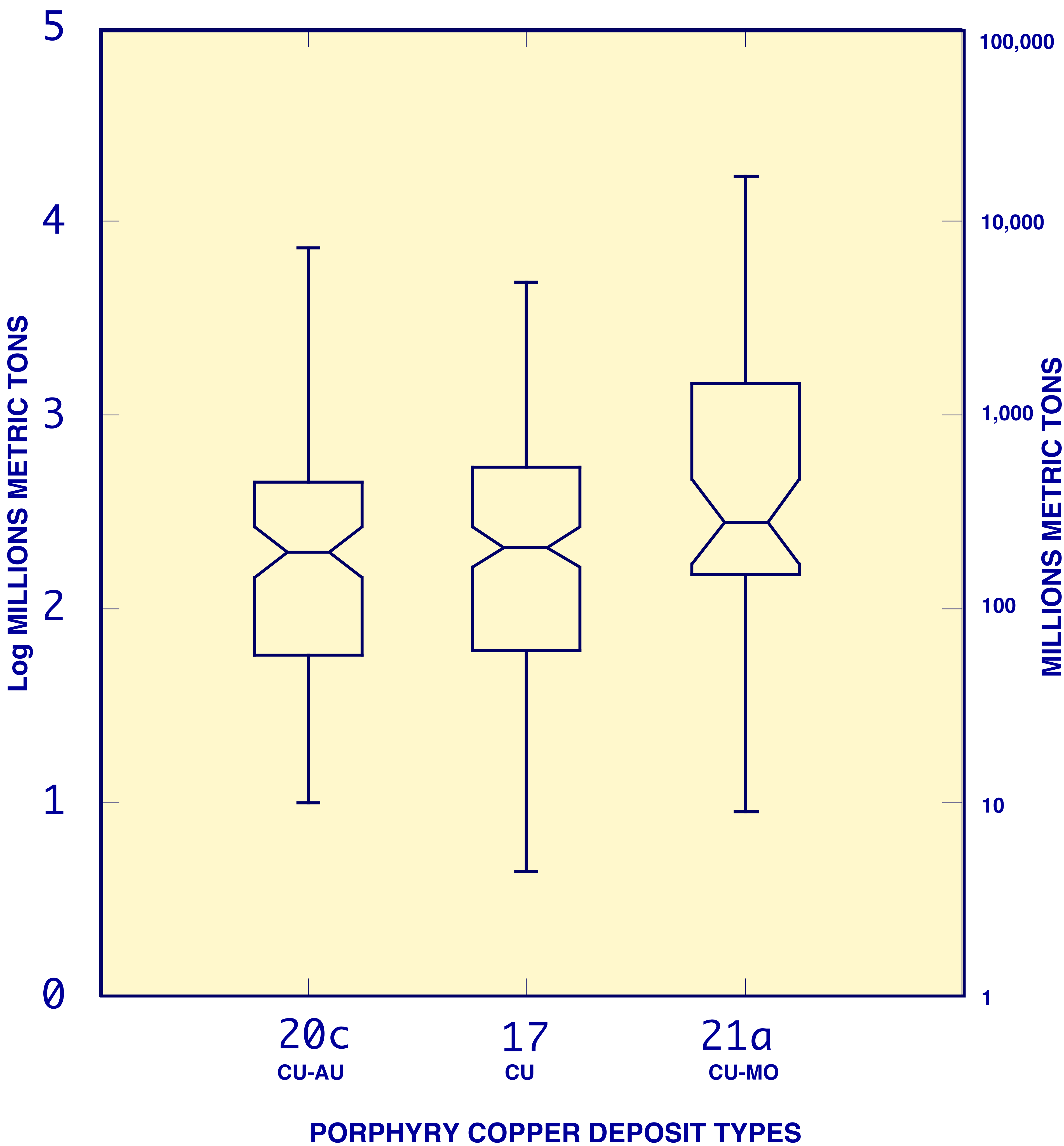

Figure 9. Notched box plot of tonnage grouped by porphyry copper type. Median is the center line of box, 25th and 75th quartiles are top and bottom of box, and notches represent 95th confidence interval of median.

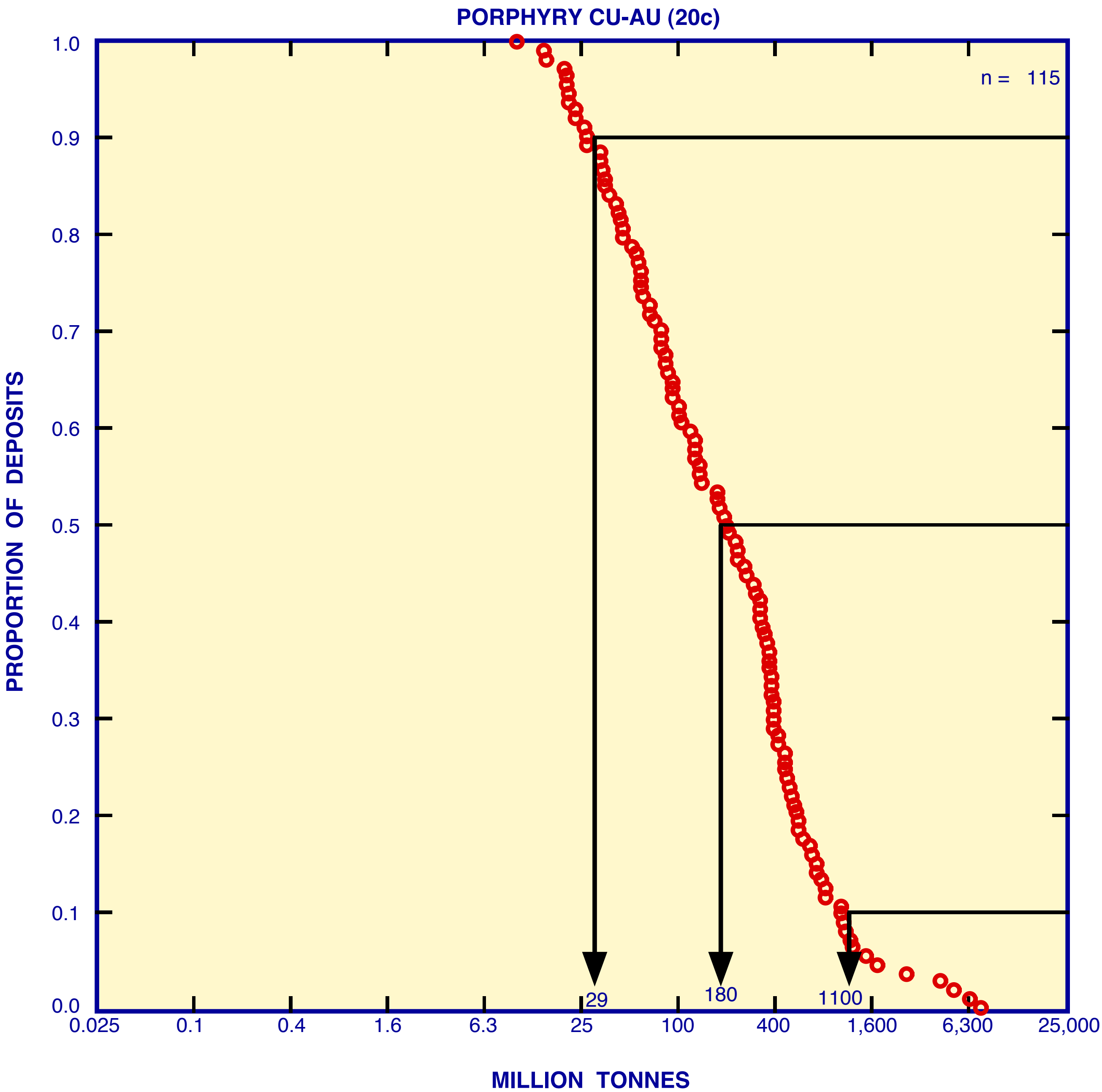

Figure 10. Cumulated frequency of ore tonnages of porphyry Cu–Au (model 20c) deposits. Each dot represents an individual deposit. Intercepts for the 90th, 50th, and 10th percentiles of the lognormal distribution are provided.

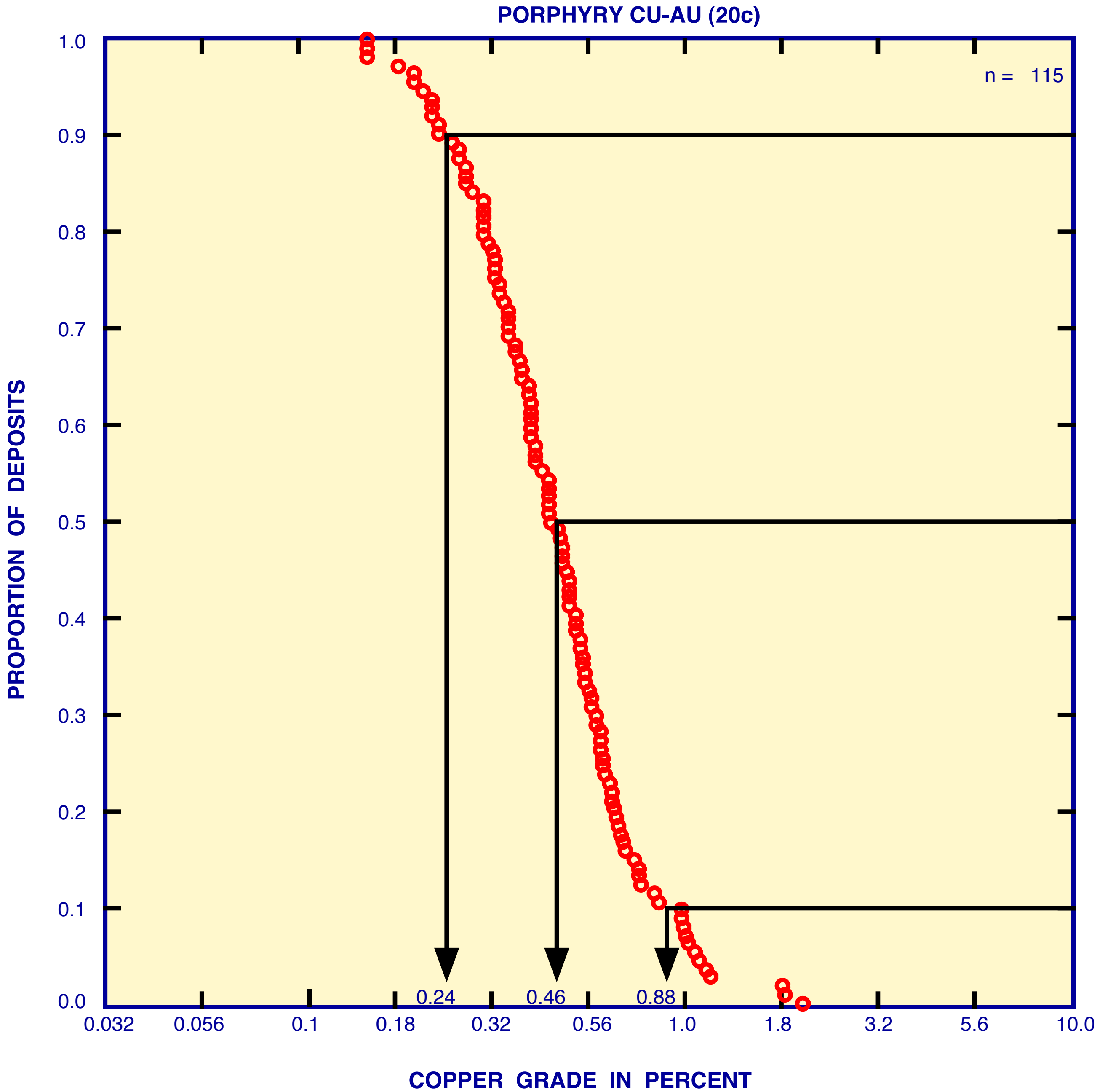

Figure 11. Cumulated frequency of copper grade of porphyry Cu-Au (model 20c) deposits. Each dot represents an individual deposit. Intercepts for the 90th, 50th, and 10th percentiles of the lognormal distribution are provided.

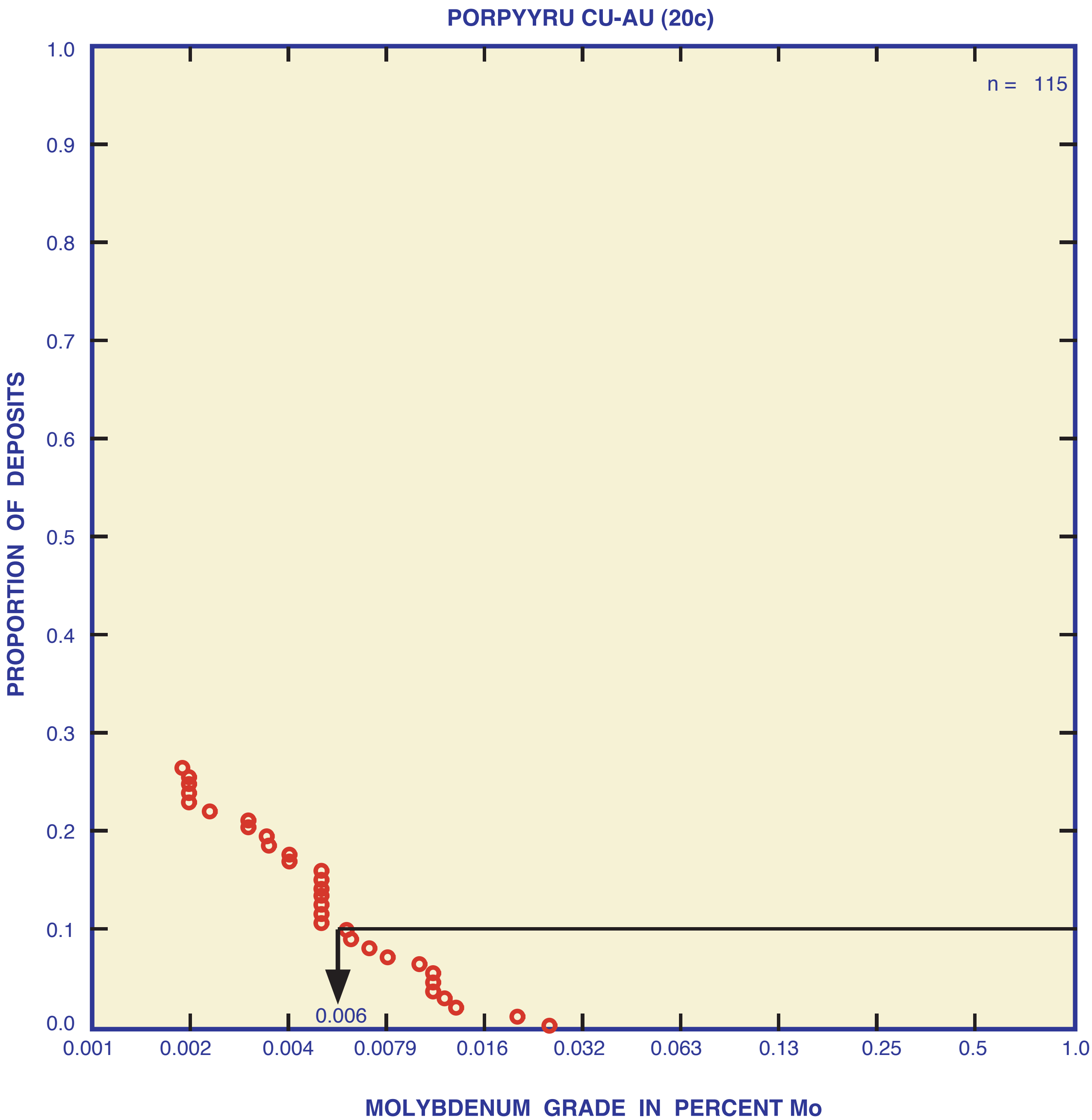

Figure 12. Cumulated frequency of molybdenum grade of porphyry Cu–Au model 20c) deposits. Each dot represents an individual deposit. Intercept for the 10th percentile of the lognormal distribution is provided.

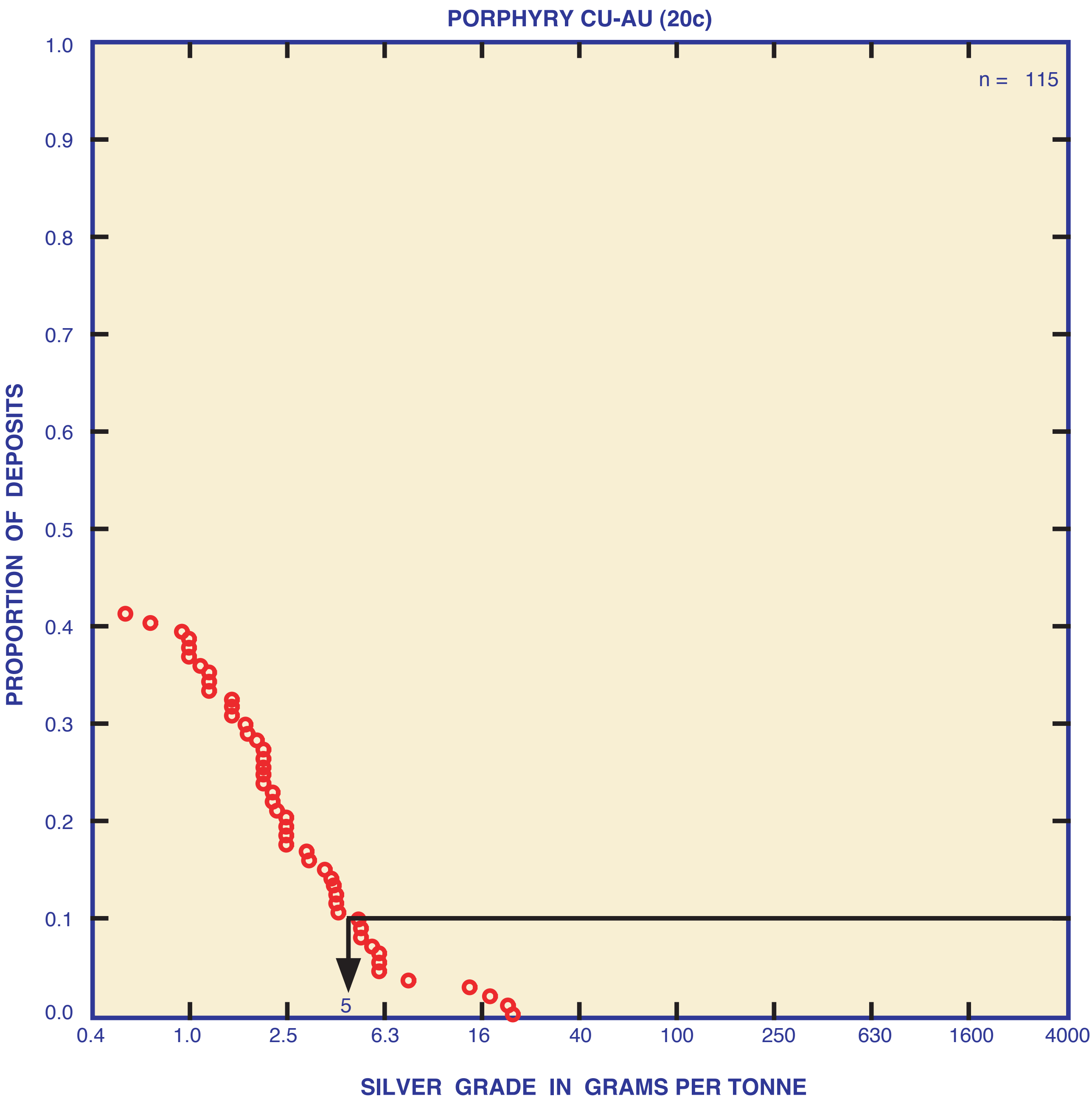

Figure 13. Cumulated frequency of silver grade of porphyry Cu–Au (model 20c) deposits. Each dot represents an individual deposit. Intercept for the 10th percentile of the lognormal distribution is provided.

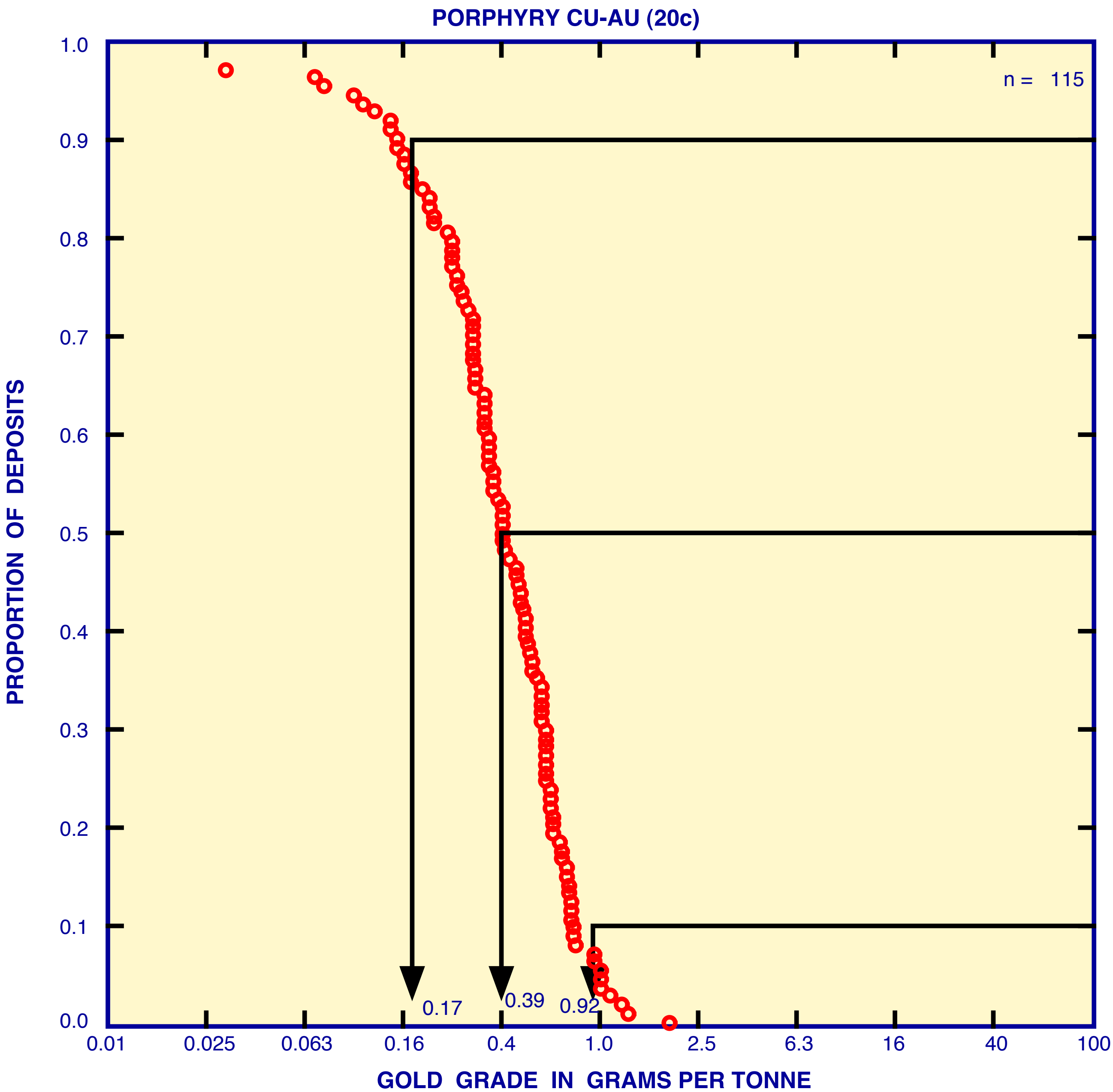

Figure 14. Cumulated frequency of gold grade of porphyry Cu–Au (model 20c) deposits. Each dot represents an individual deposit. Intercepts for the 90th, 50th, and 10th percentiles of the lognormal distribution are provided.

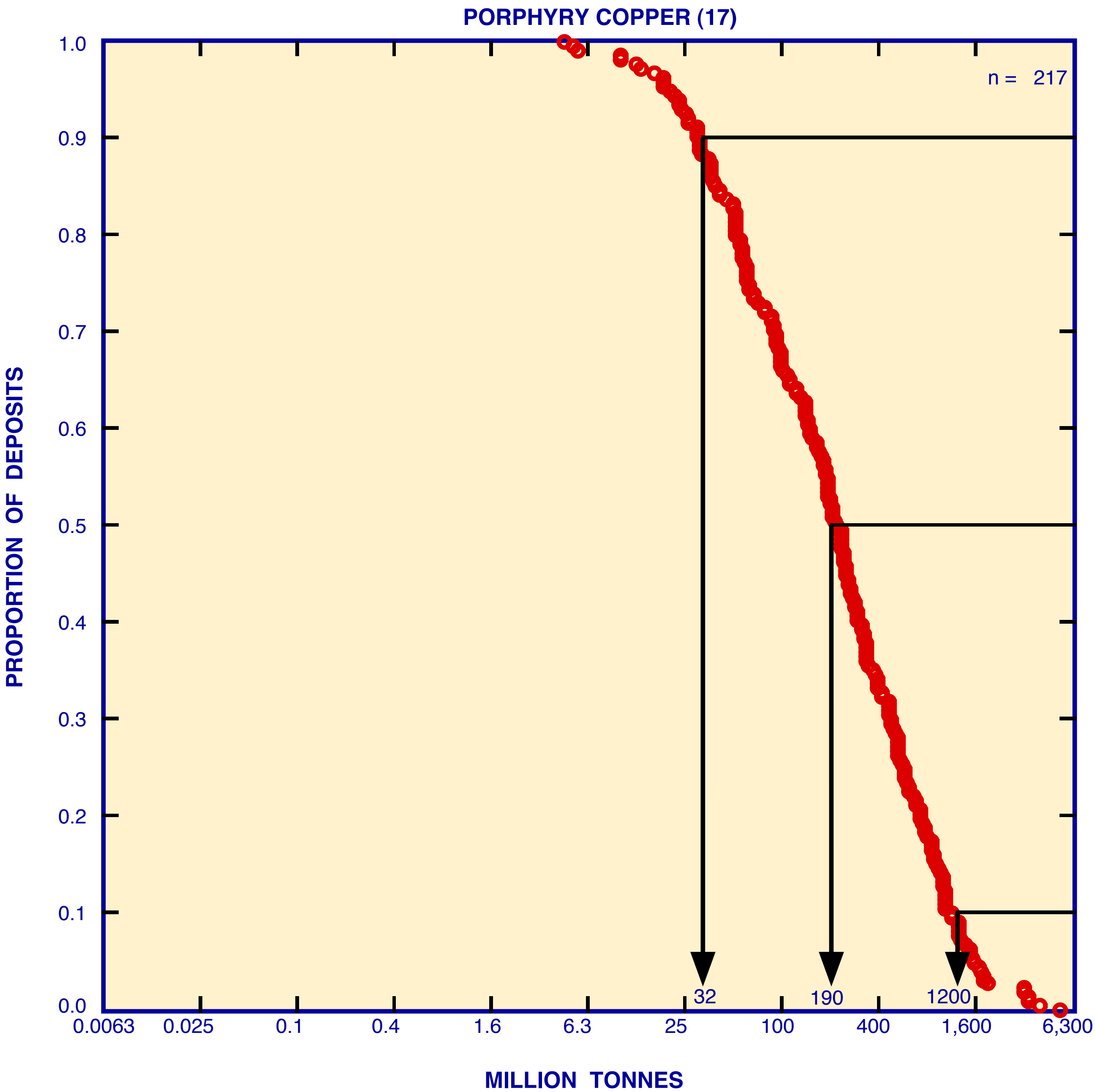

Figure 15. Cumulated frequency of ore tonnages of porphyry Cu (model 17) deposits. Each dot represents an individual deposit. Intercepts for the 90th, 50th, and 10th percentiles of the lognormal distribution are provided.

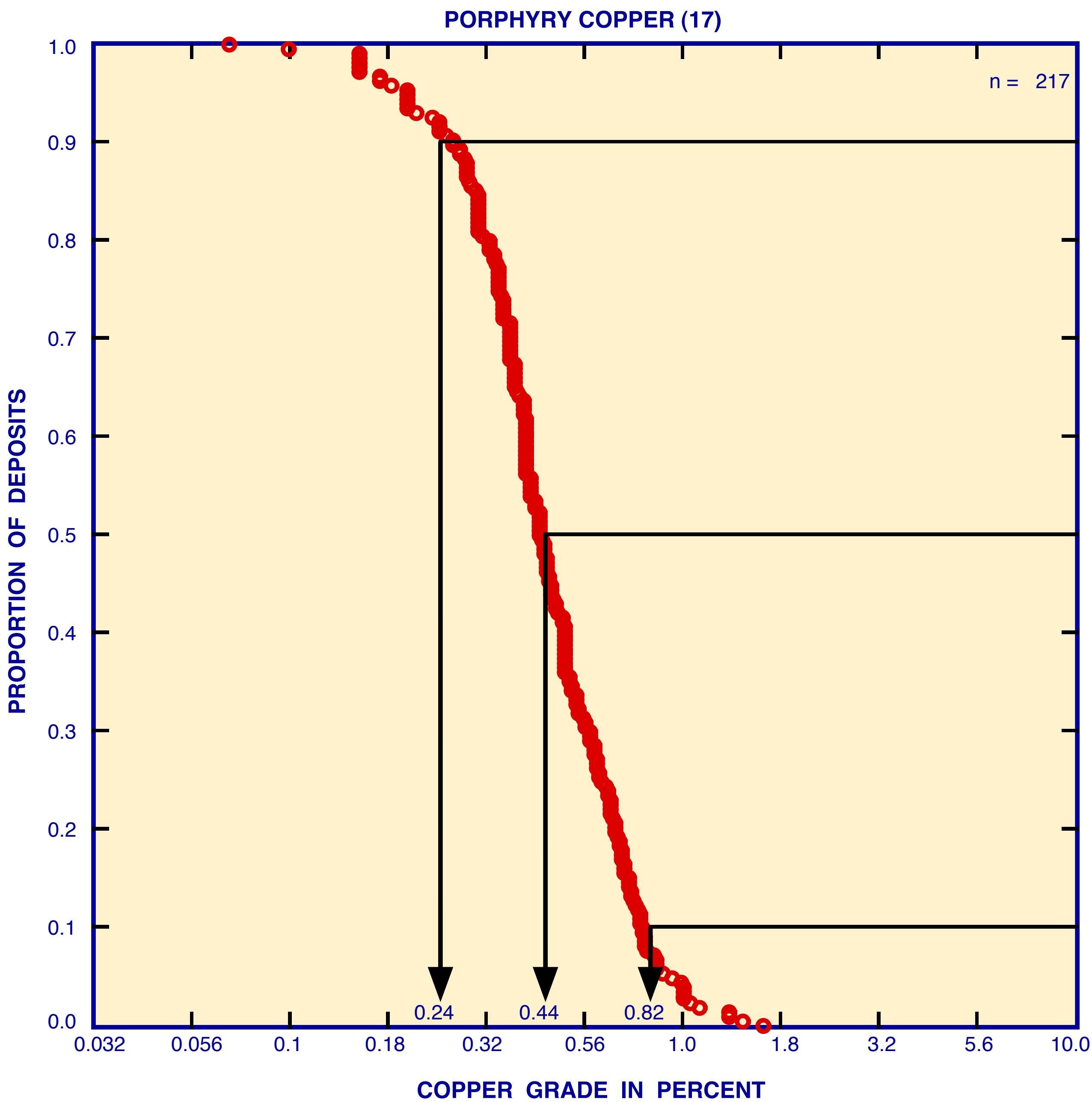

Figure 16. Cumulated frequency of copper grade of porphyry Cu (model 17) deposits. Each dot represents an individual deposit. Intercepts for the 90th, 50th, and 10th percentiles of the lognormal distribution are provided.

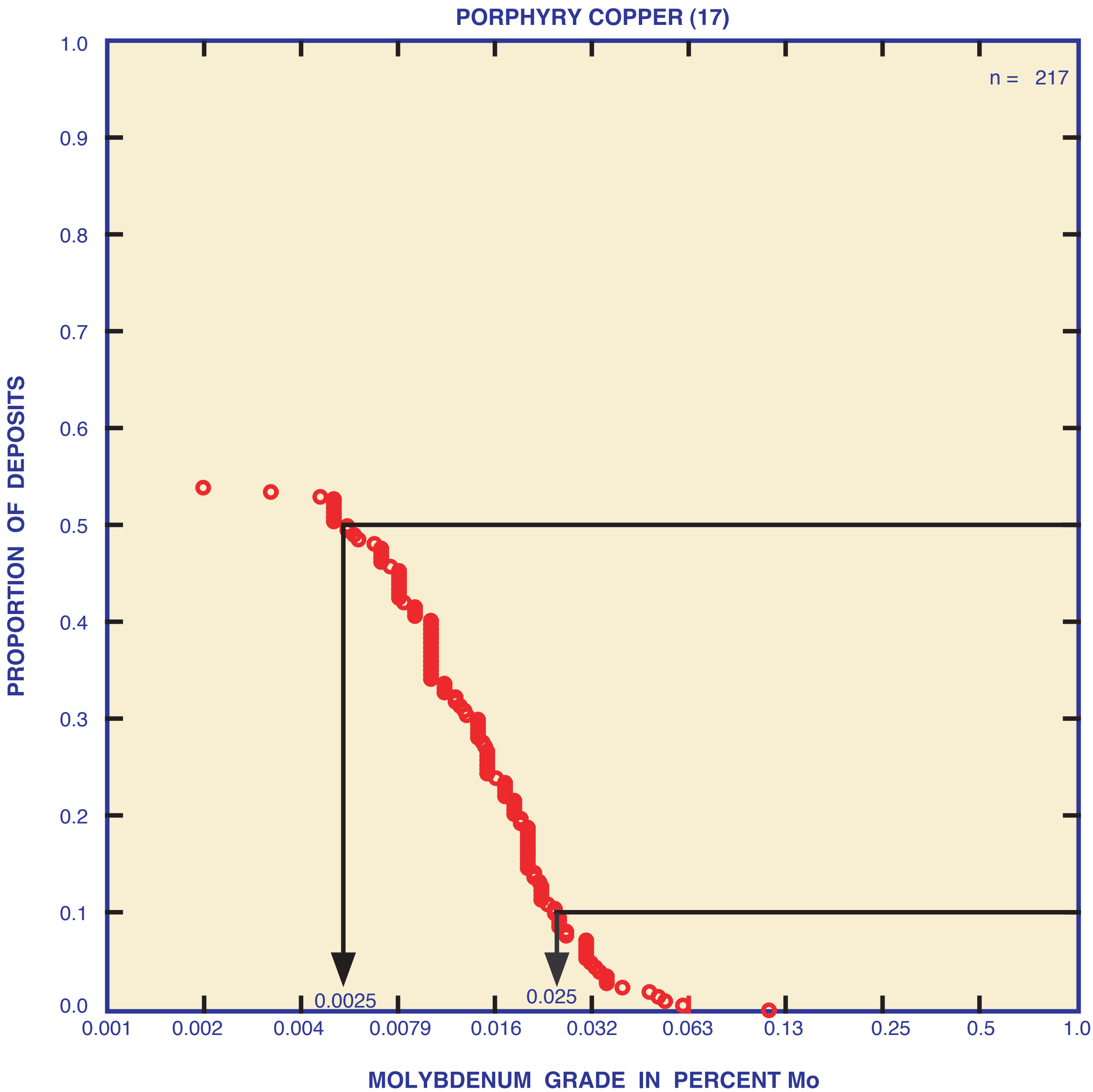

Figure 17. Cumulated frequency of molybdenum grade of porphyry Cu (model 17) deposits. Each dot represents an individual deposit. Intercepts for the 50th and 10th percentiles of the lognormal distribution are provided.

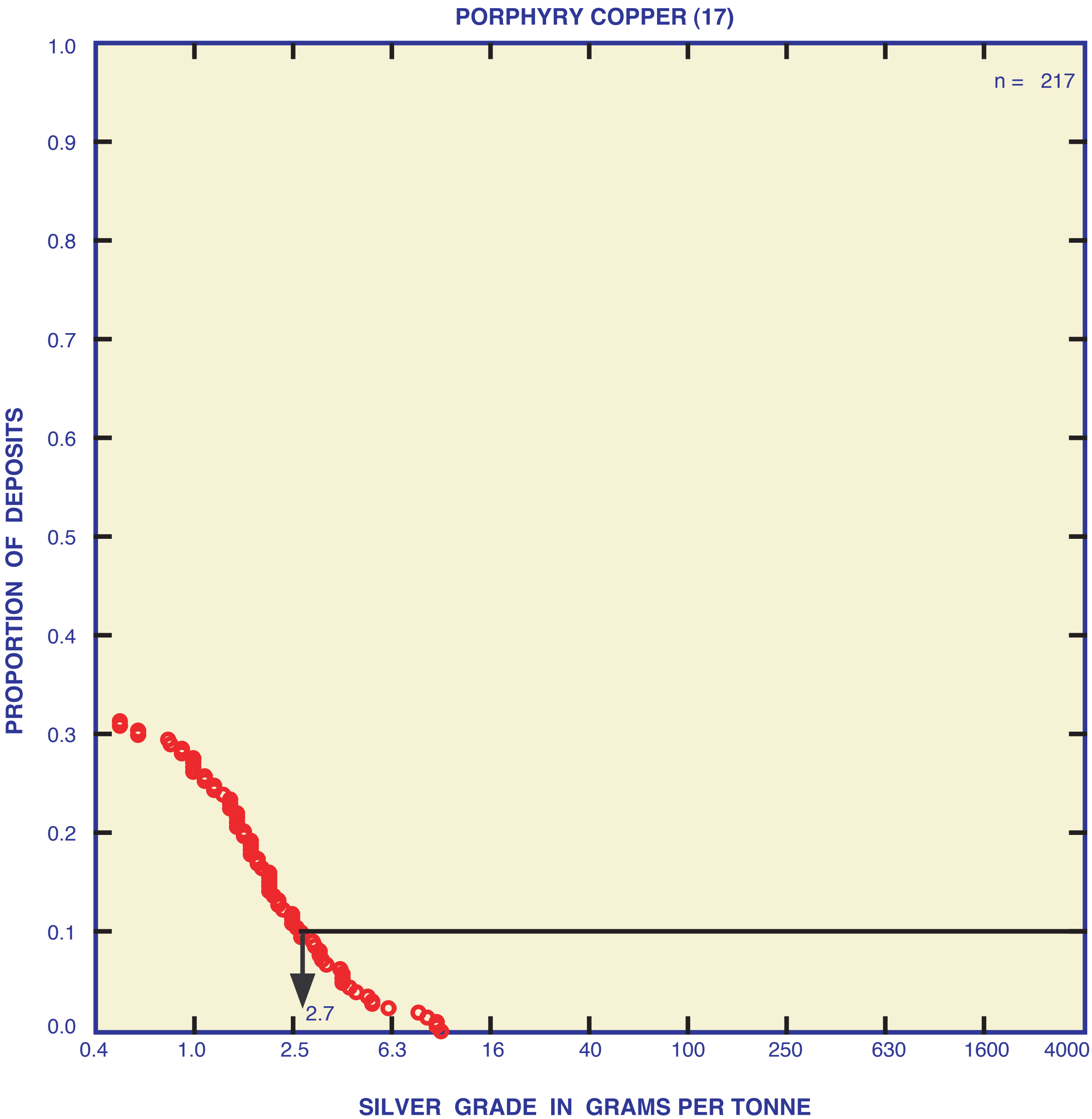

Figure 18. Cumulated frequency of silver grade of porphyry Cu (model 17) deposits. Each dot represents an individual deposit. Intercept for the 10th percentile of the lognormal distribution is provided.

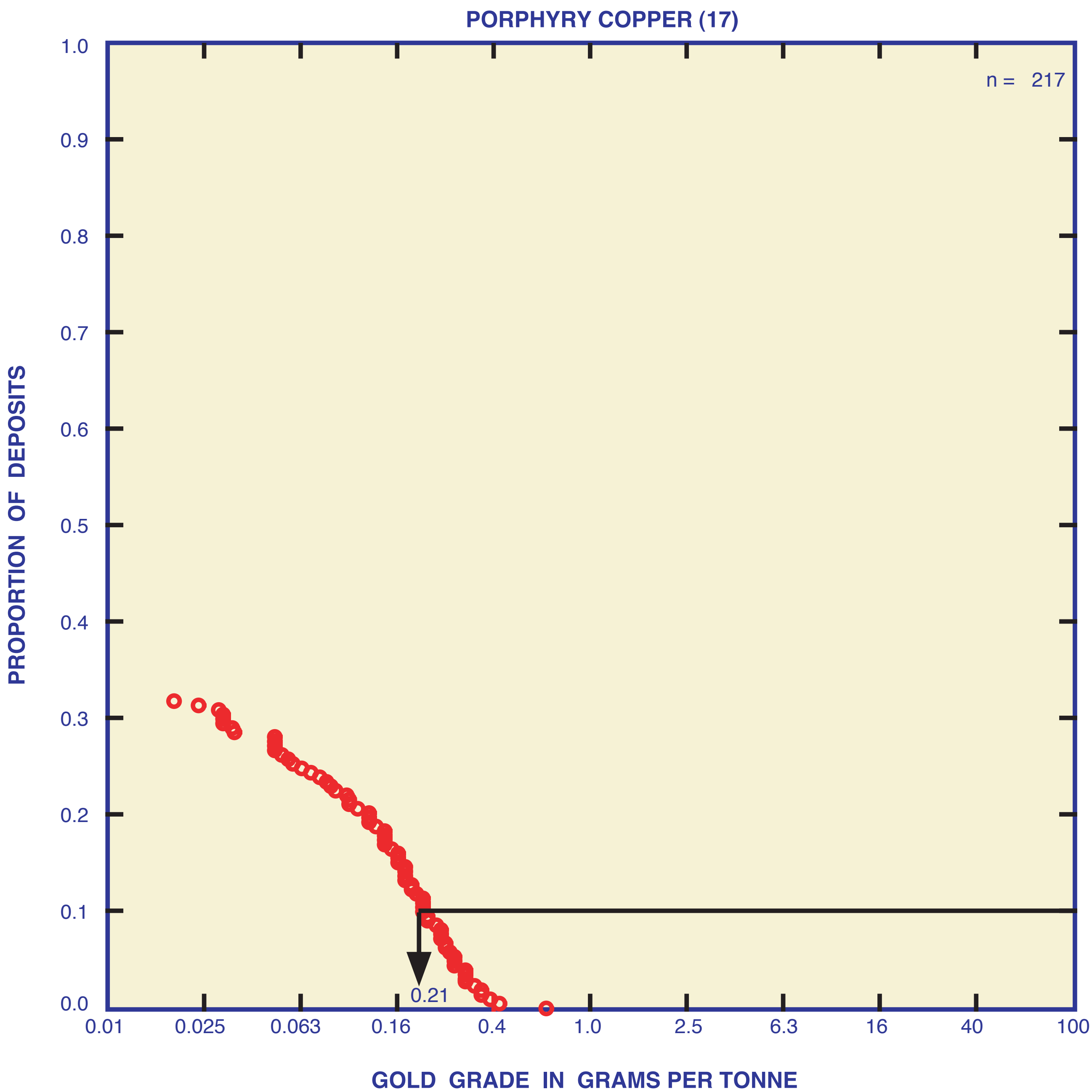

Figure 19. Cumulated frequency of gold grade of porphyry Cu (model 17) deposits. Each dot represents an individual deposit. Intercept for the 10th percentile of the lognormal distribution is provided.

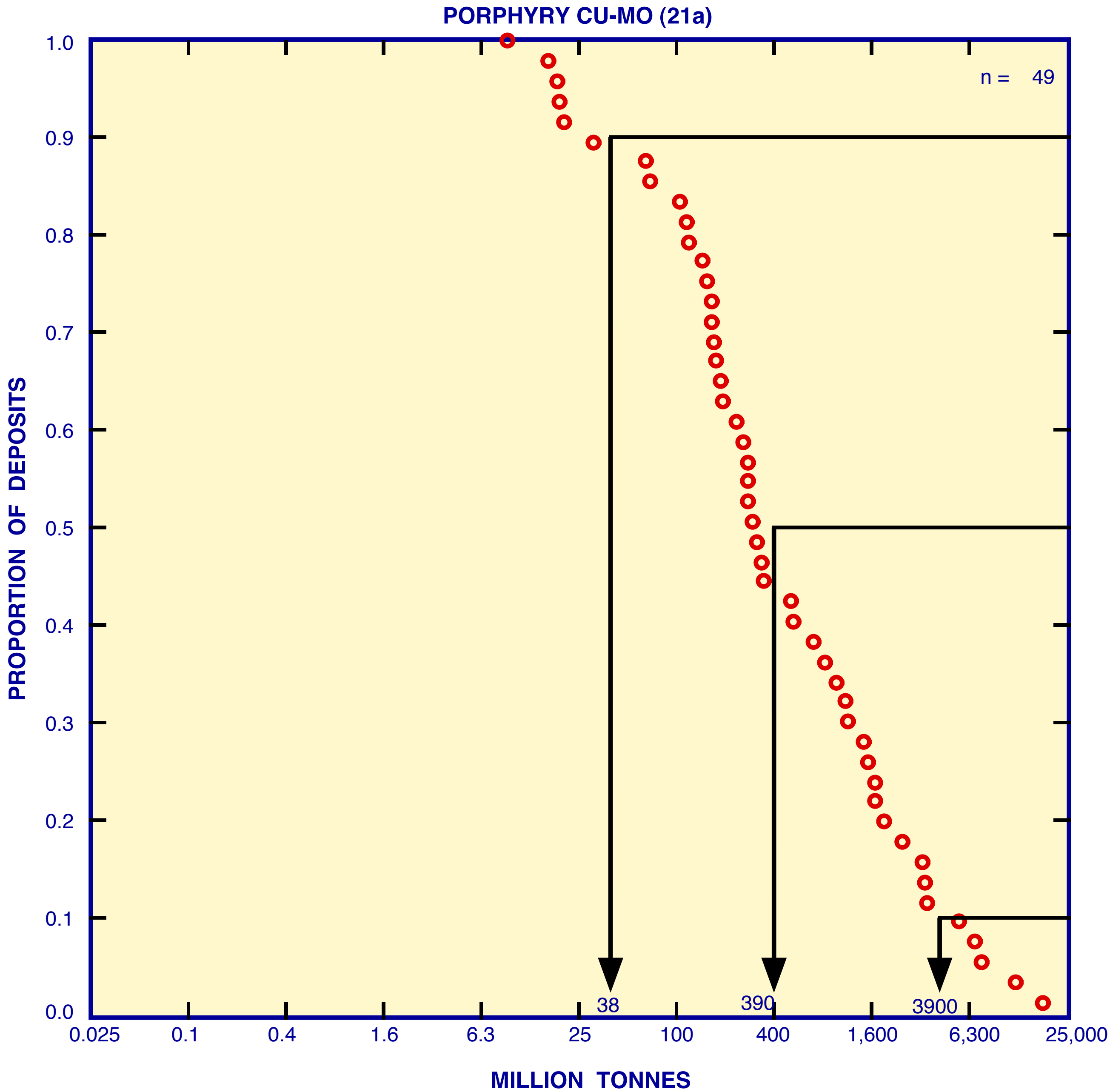

Figure 20. Cumulated frequency of ore tonnages of porphyry Cu–Mo (model 21a) deposits. Each dot represents an individual deposit. Intercepts for the 90th, 50th, and 10th percentiles of the lognormal distribution are provided.

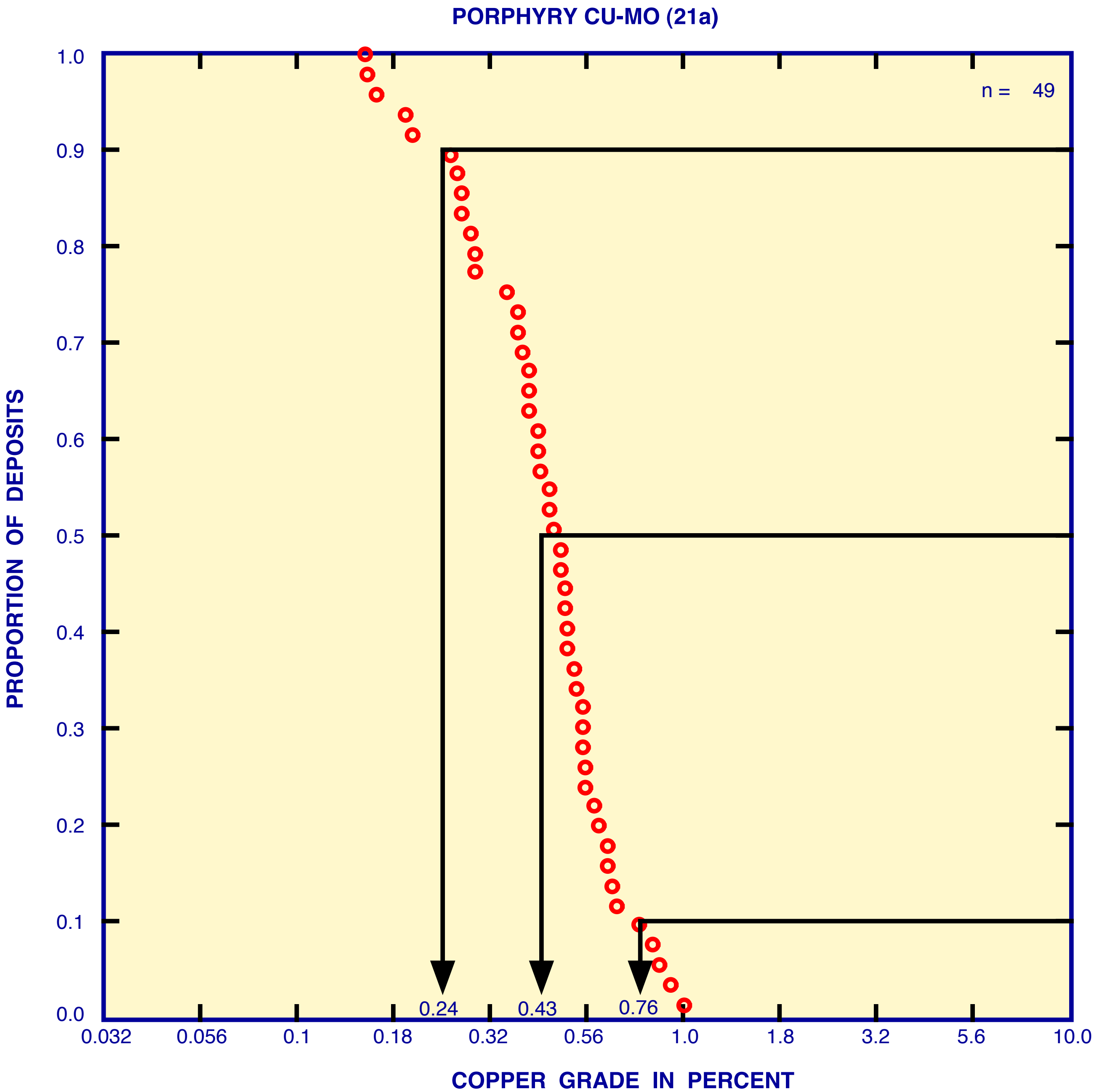

Figure 21. Cumulated frequency of copper grade of porphyry Cu–Mo (model 21a) deposits. Each dot represents an individual deposit. Intercepts for the 90th, 50th, and 10th percentiles of the lognormal distribution are provided.

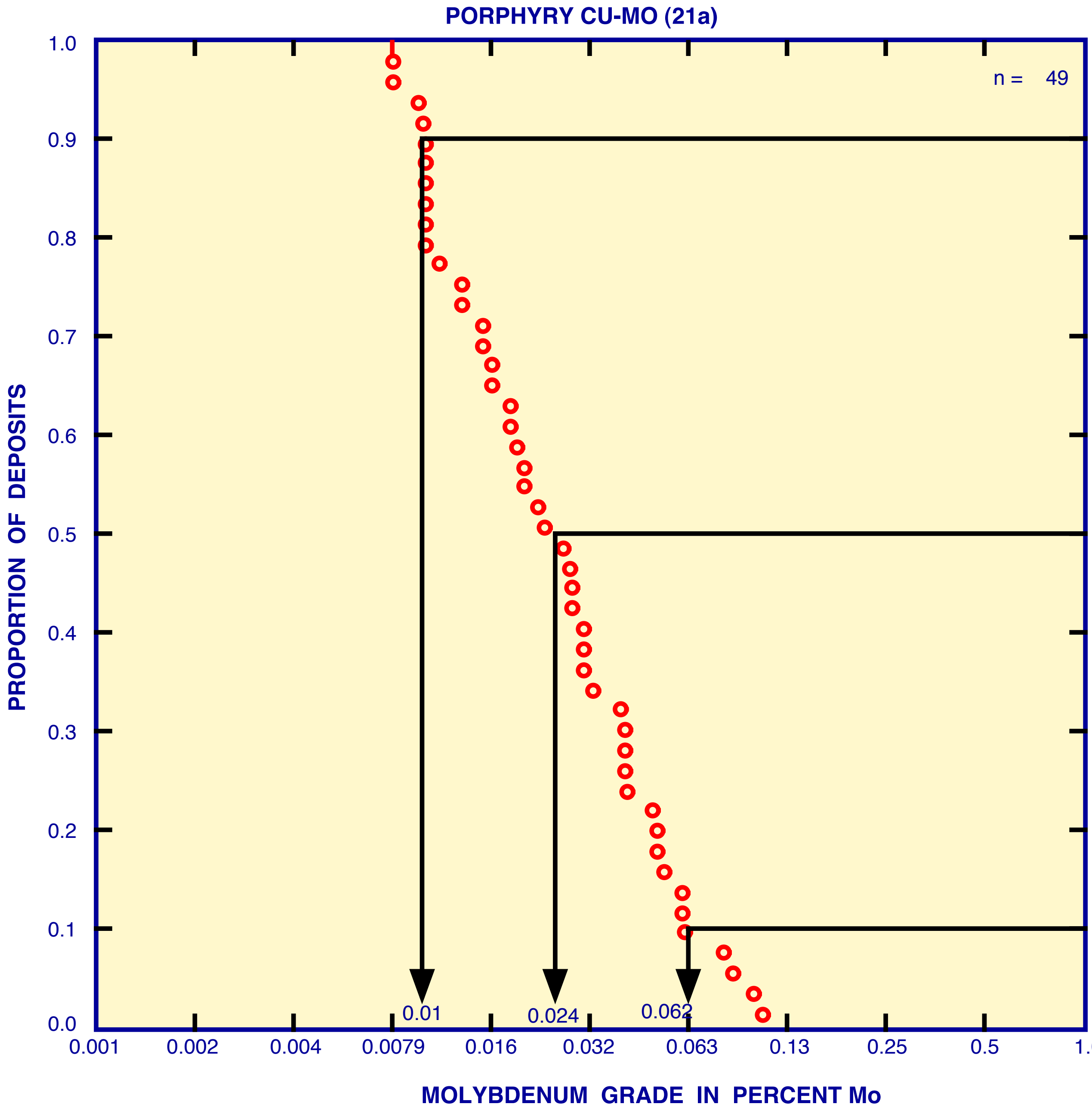

Figure 22. Cumulated frequency of molybdenum grade of porphyry Cu-Mo (model 21a) deposits. Each dot represents an individual deposit. Intercepts for the 90th, 50th, and 10th percentiles of the lognormal distribution are provided.

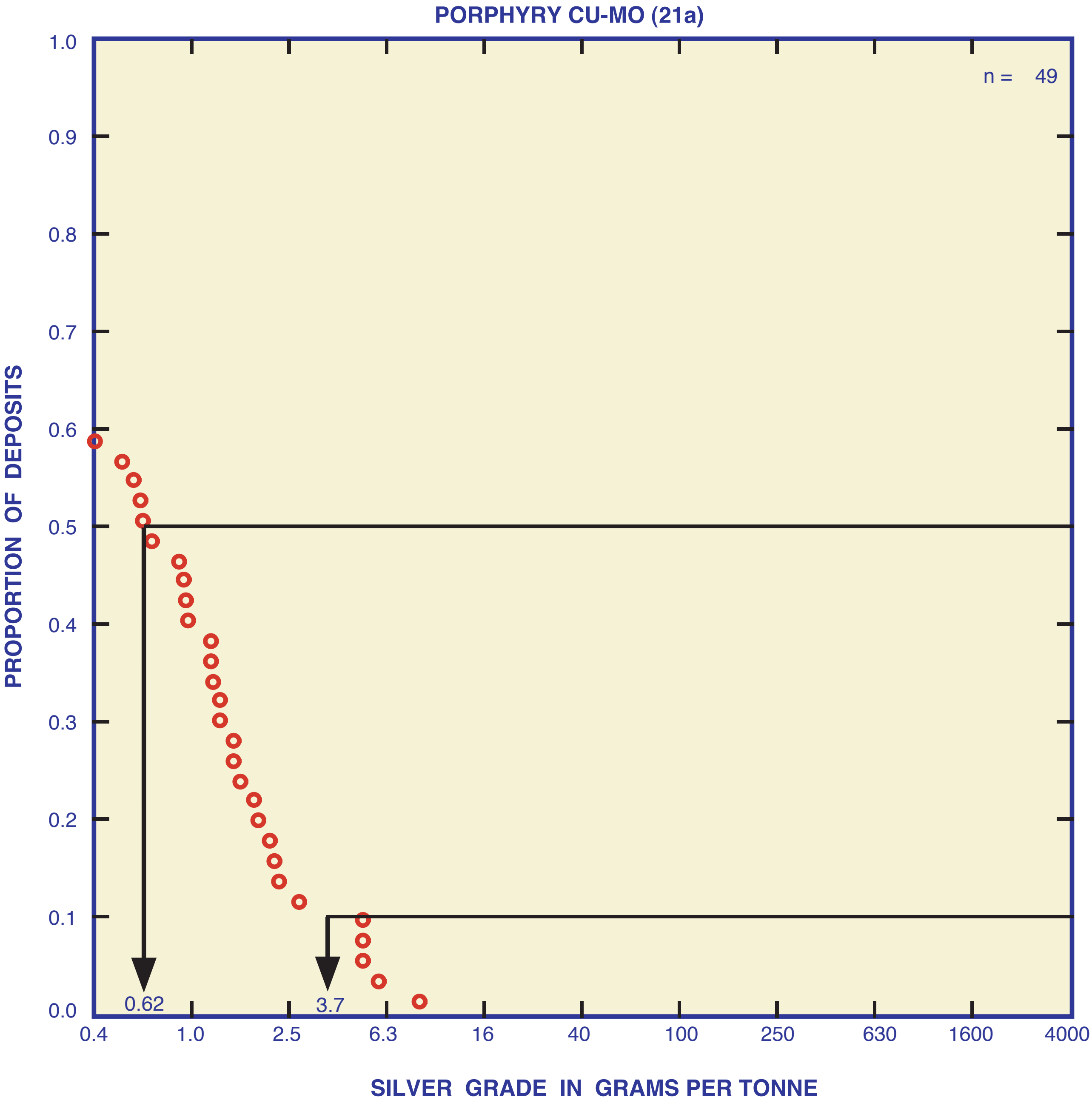

Figure 23. Cumulated frequency of silver grade of porphyry Cu–Mo (model 21a) deposits. Each dot represents an individual deposit. Intercepts for the 50th, and 10th percentiles of the lognormal distribution are provided.

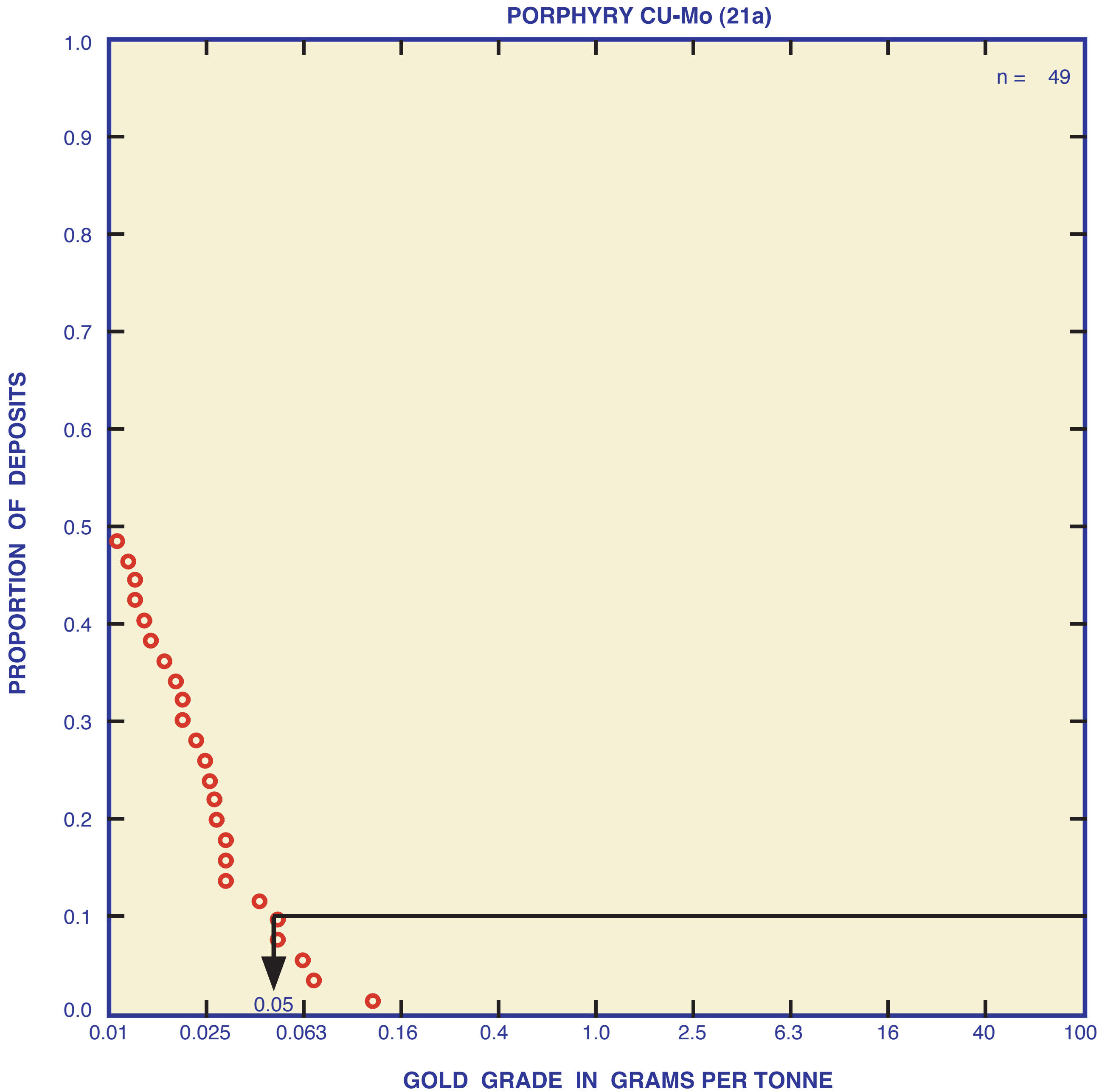

Figure 24. Cumulated frequency of gold grade of porphyry Cu–Mo (model 21a) deposits. Each dot represents an individual deposit. Intercept for the 10th percentile of the lognormal distribution is provided.

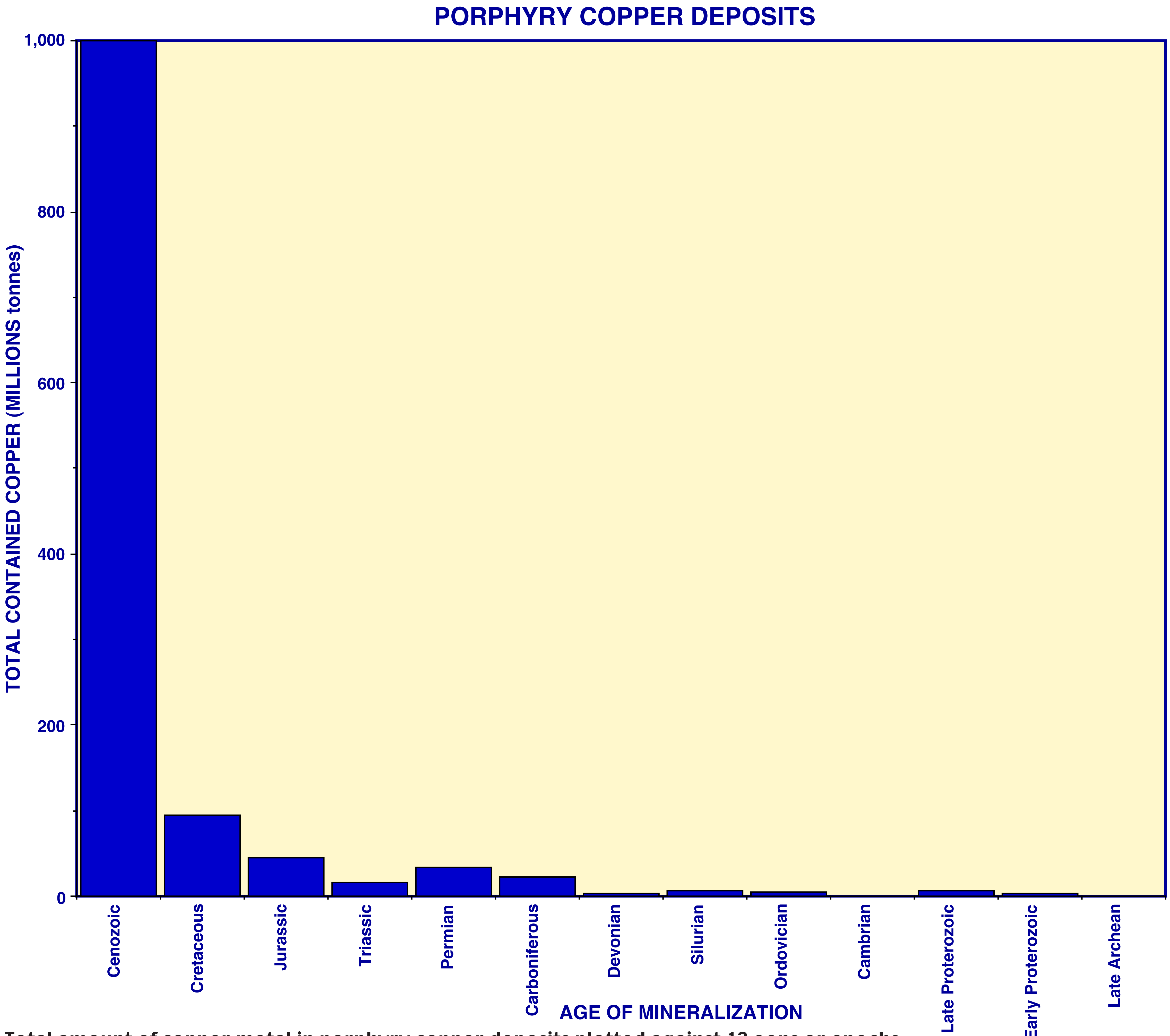

Figure 25. Total amount of copper metal in porphyry copper deposits plotted against 13 eons or epochs.

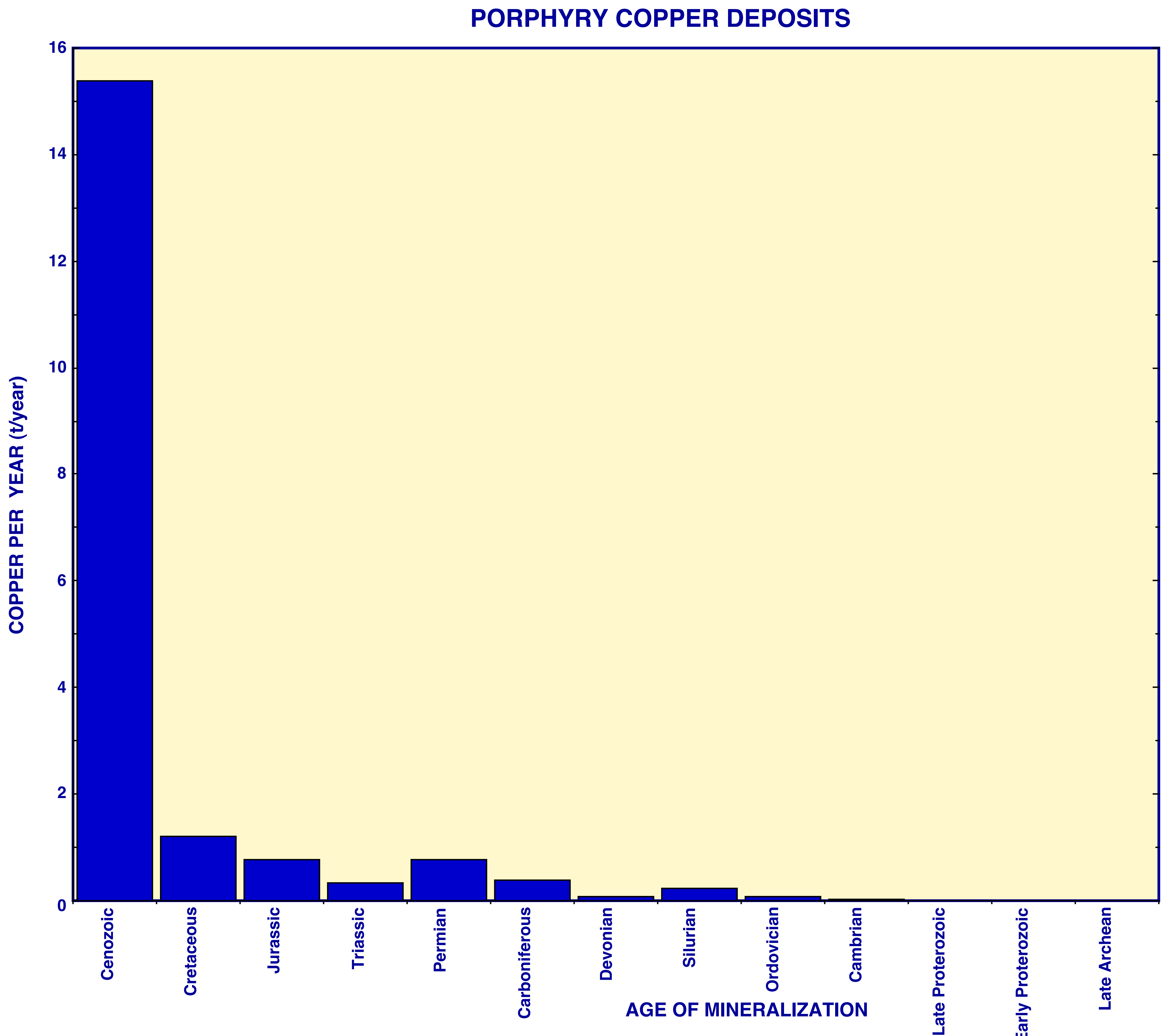

Figure 26. Total amount of copper metal in tons per year in porphyry copper deposits plotted against 13 eons or epochs.

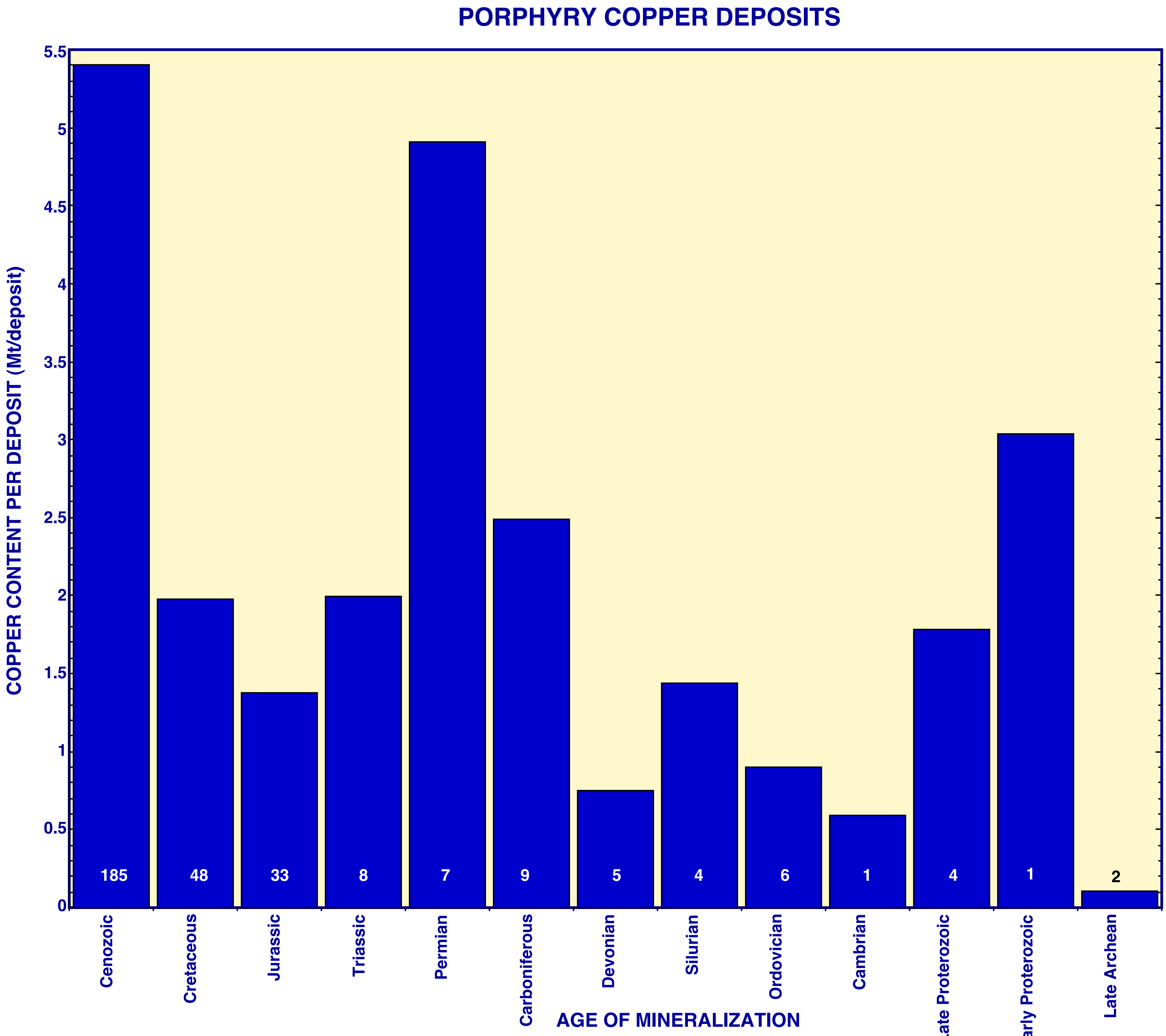

Figure 27. Total amount of copper metal in tons per deposit in porphyry copper deposits plotted against 13 eons or epochs.

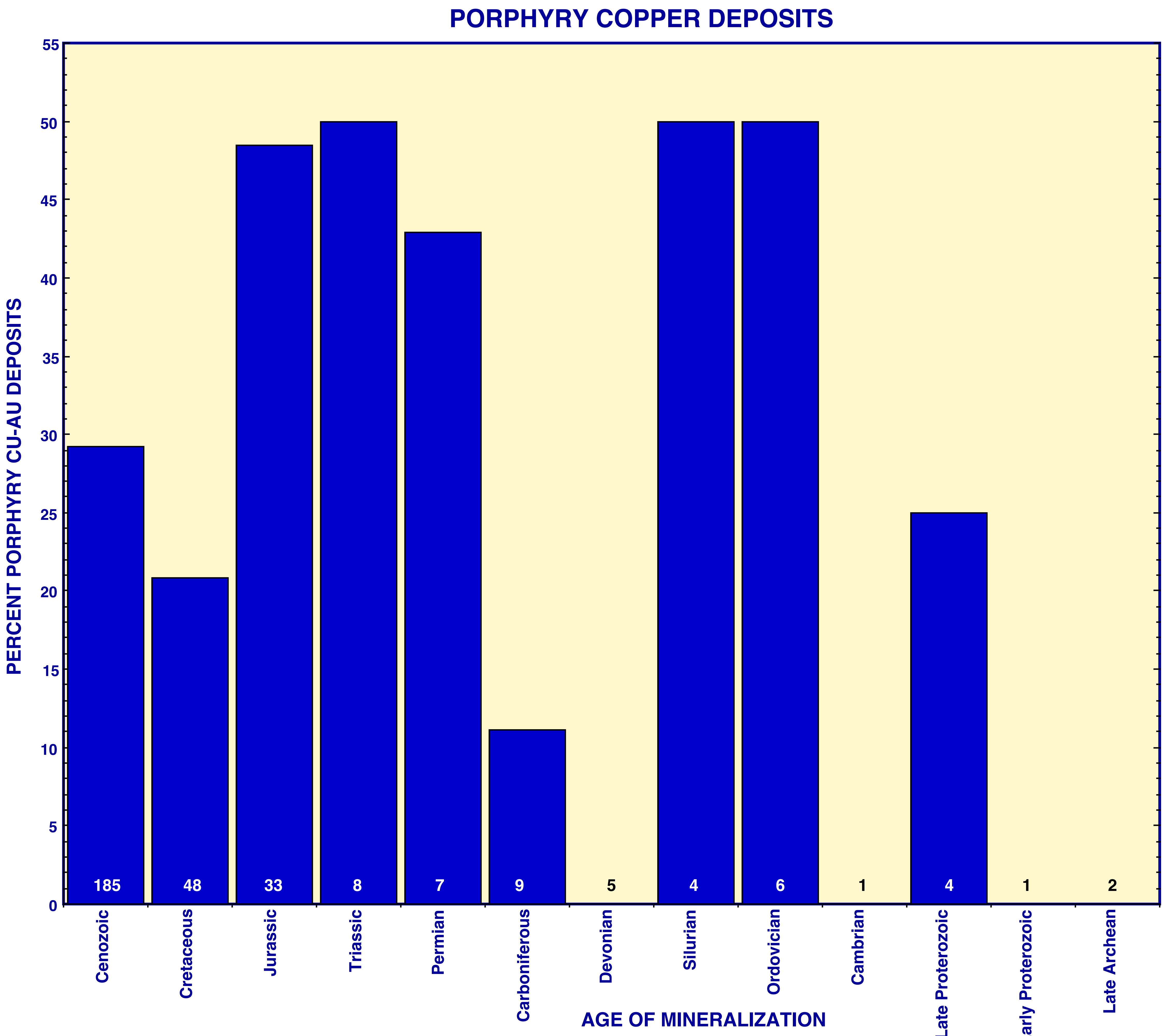

Figure 28. Percent of all porphyry copper deposits that belong to the gold-rich class plotted against 13 eons or epochs.

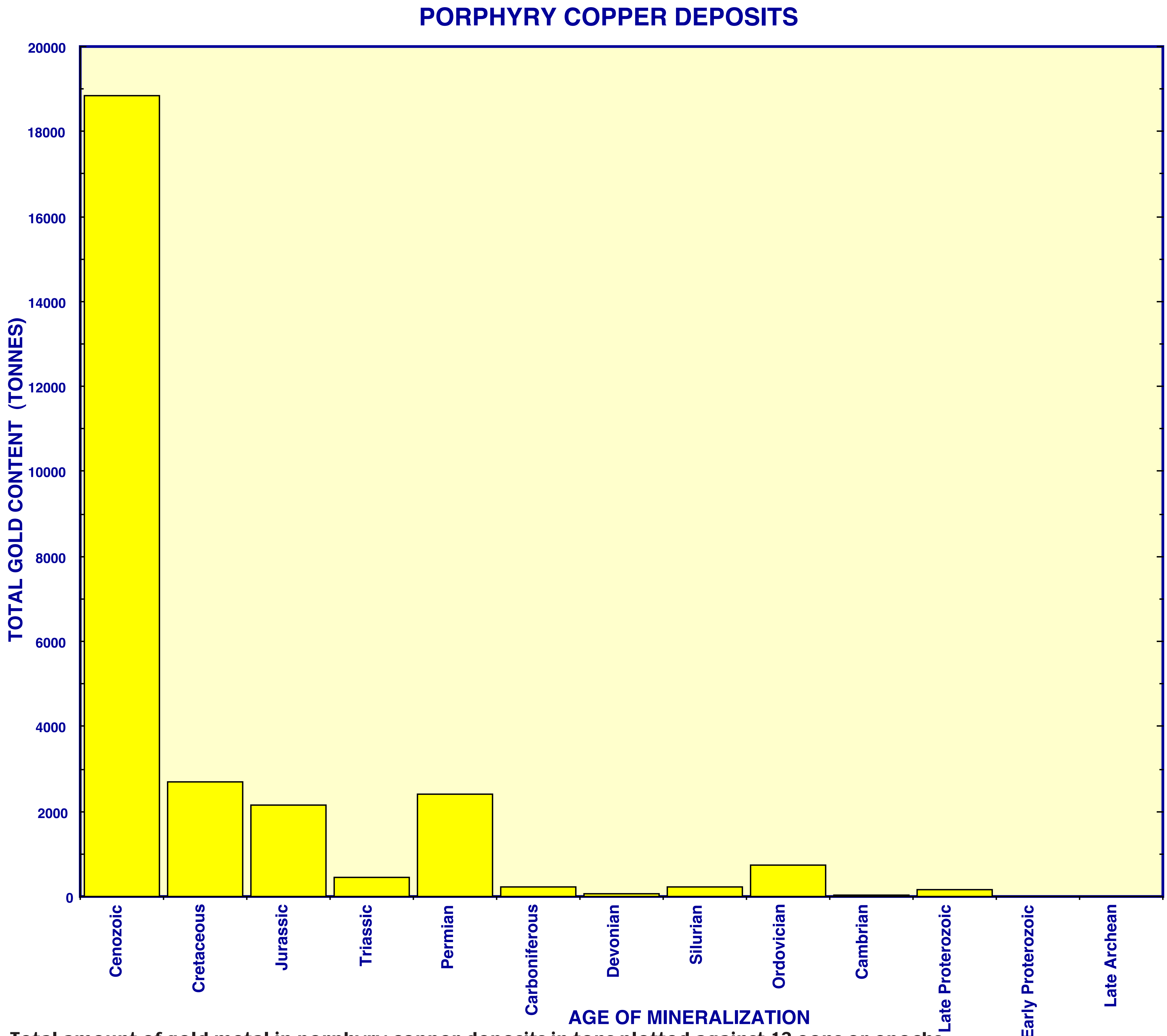

Figure 29. Total amount of gold metal in porphyry copper deposits in tons plotted against 13 eons or epochs.

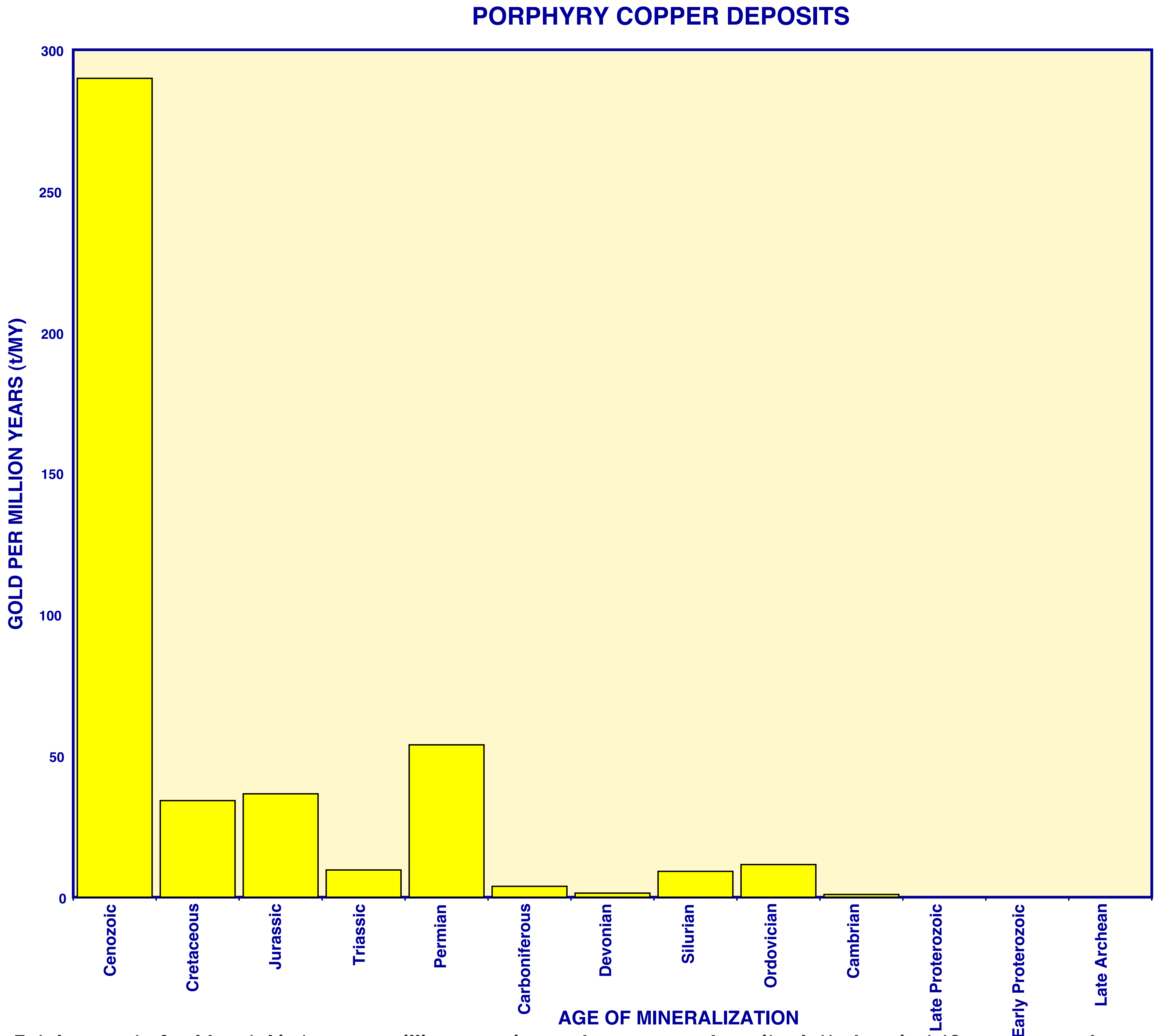

Figure 30. Total amount of gold metal in tons per million years in porphyry copper deposits plotted against 13 eons or epochs.

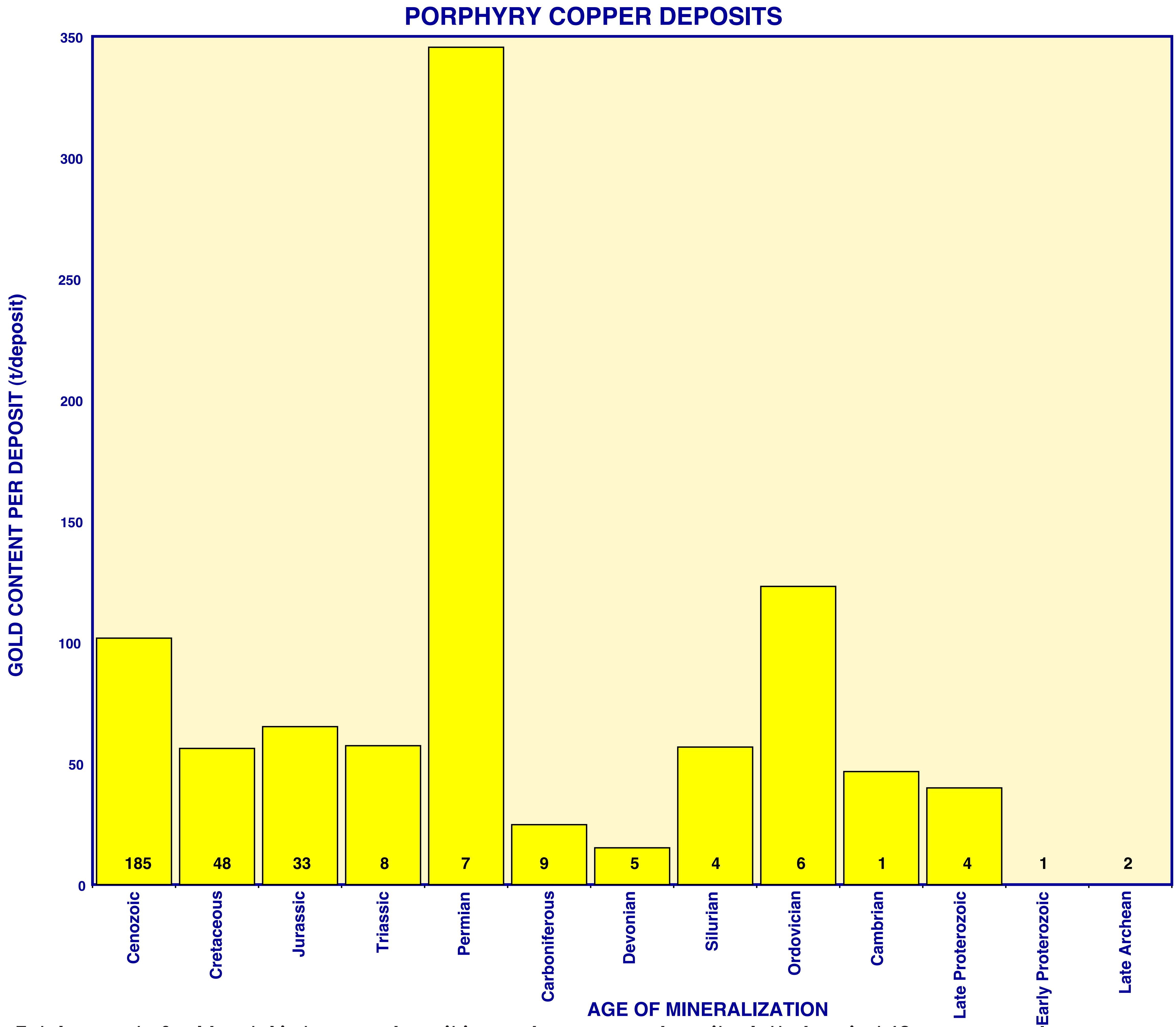

Figure 31. Total amount of gold metal in tons per deposit in porphyry copper deposits plotted against 13 eons or epochs.

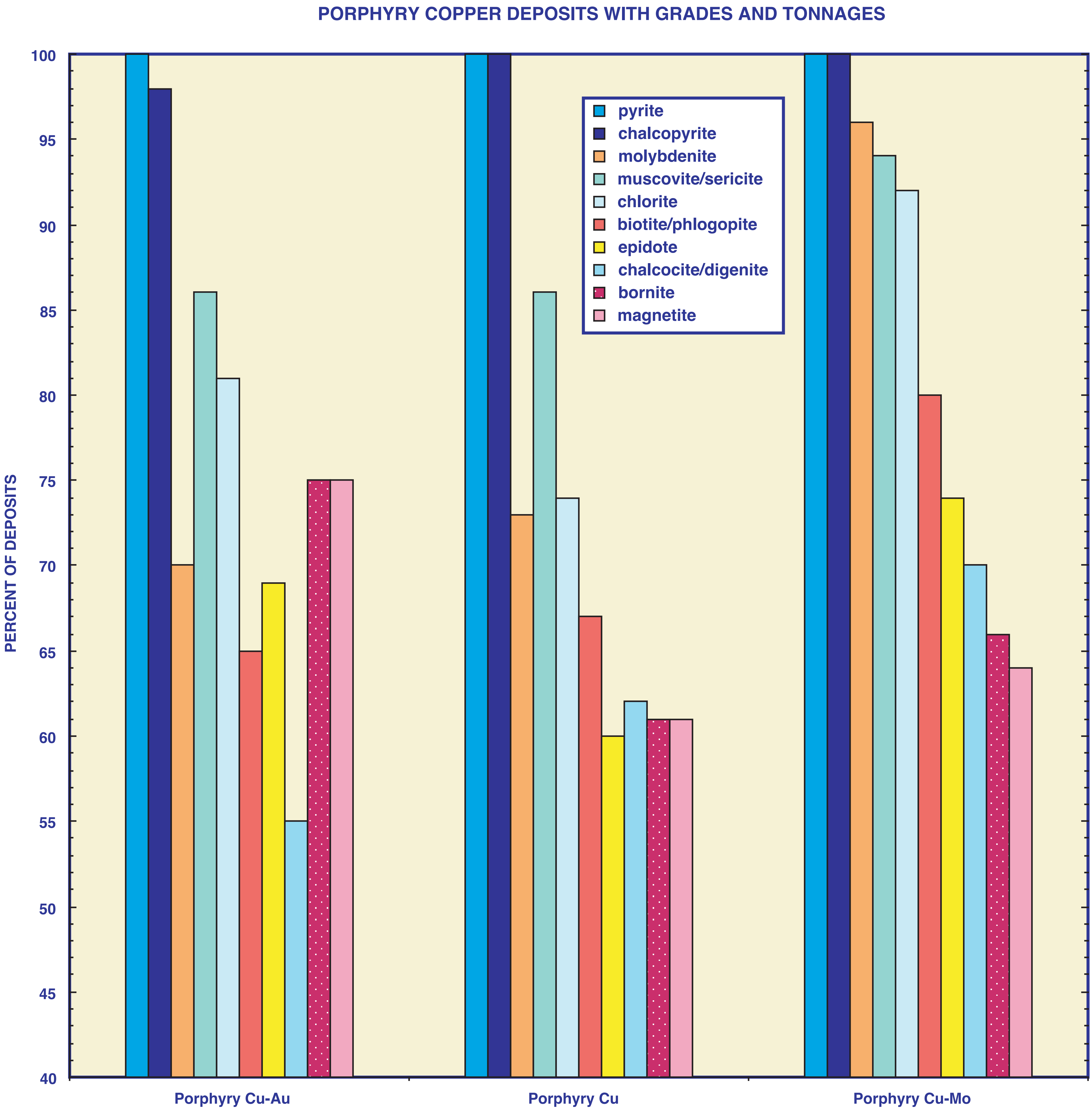

Figure 32. Frequency of reported minerals of porphyry copper deposits used in each grade and tonnage model by type.

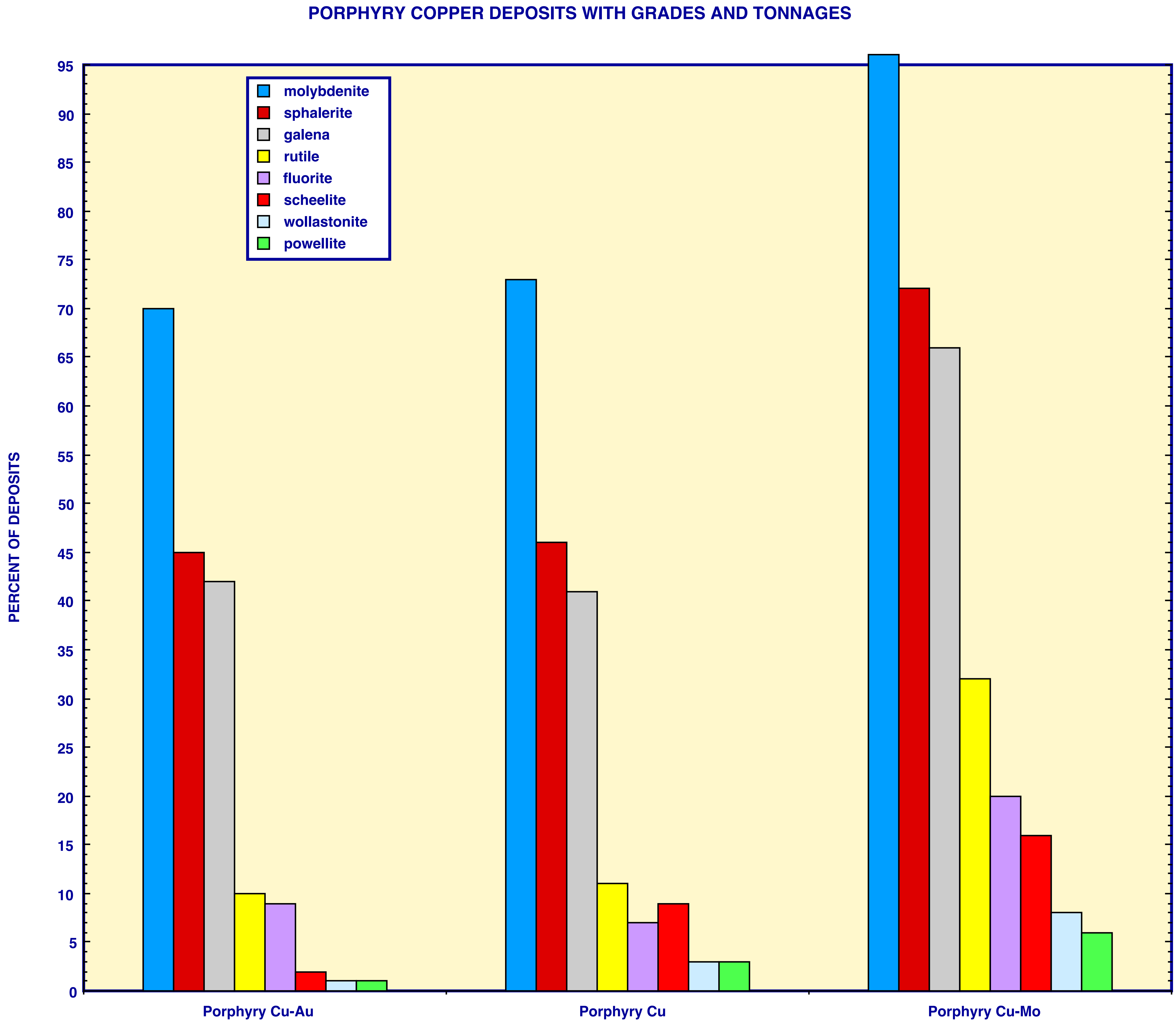

Figure 33. Frequency of reported minerals of porphyry copper deposits used in each grade and tonnage model by type.

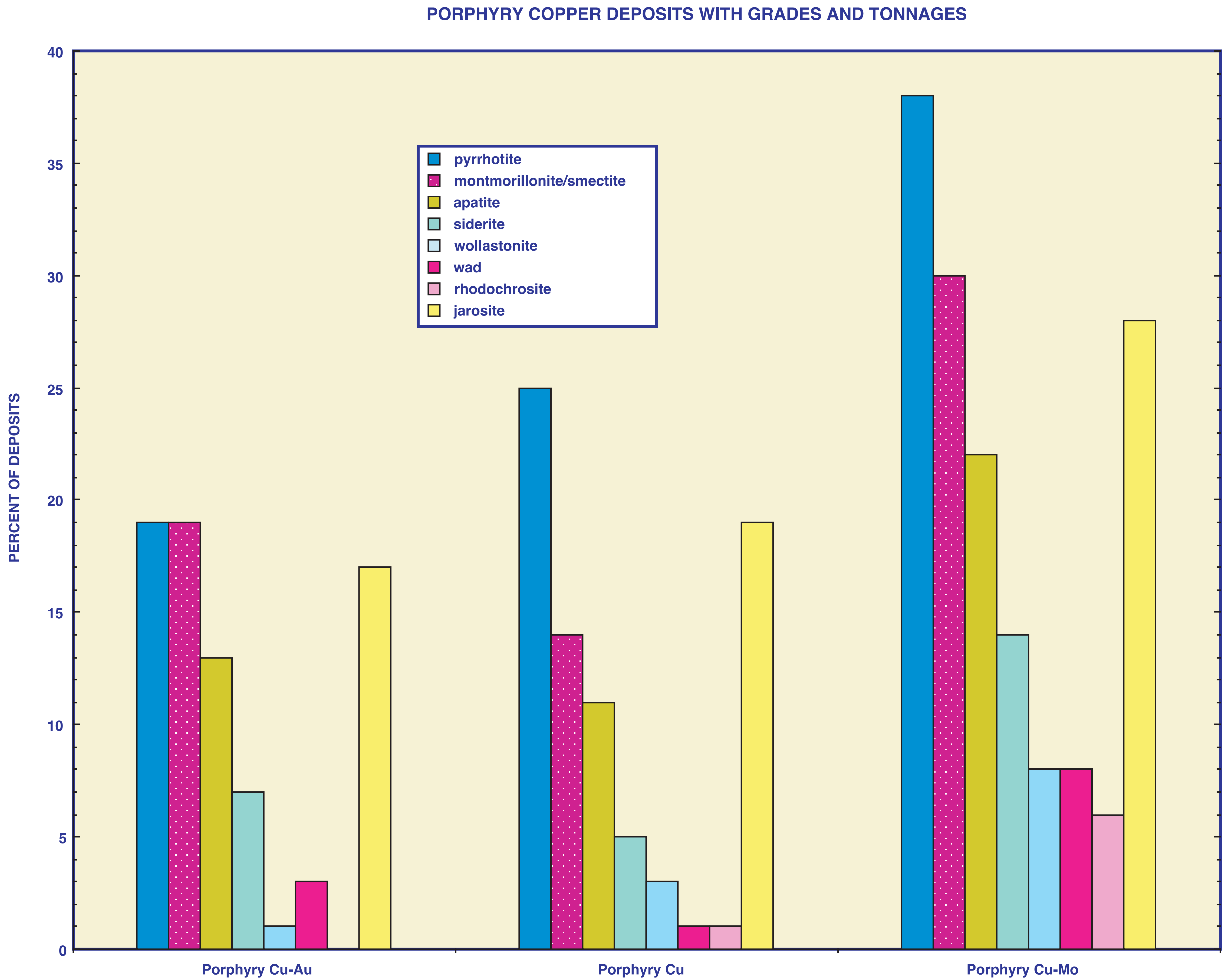

Figure 34. Frequency of reported minerals of porphyry copper deposits used in each grade and tonnage model by type.

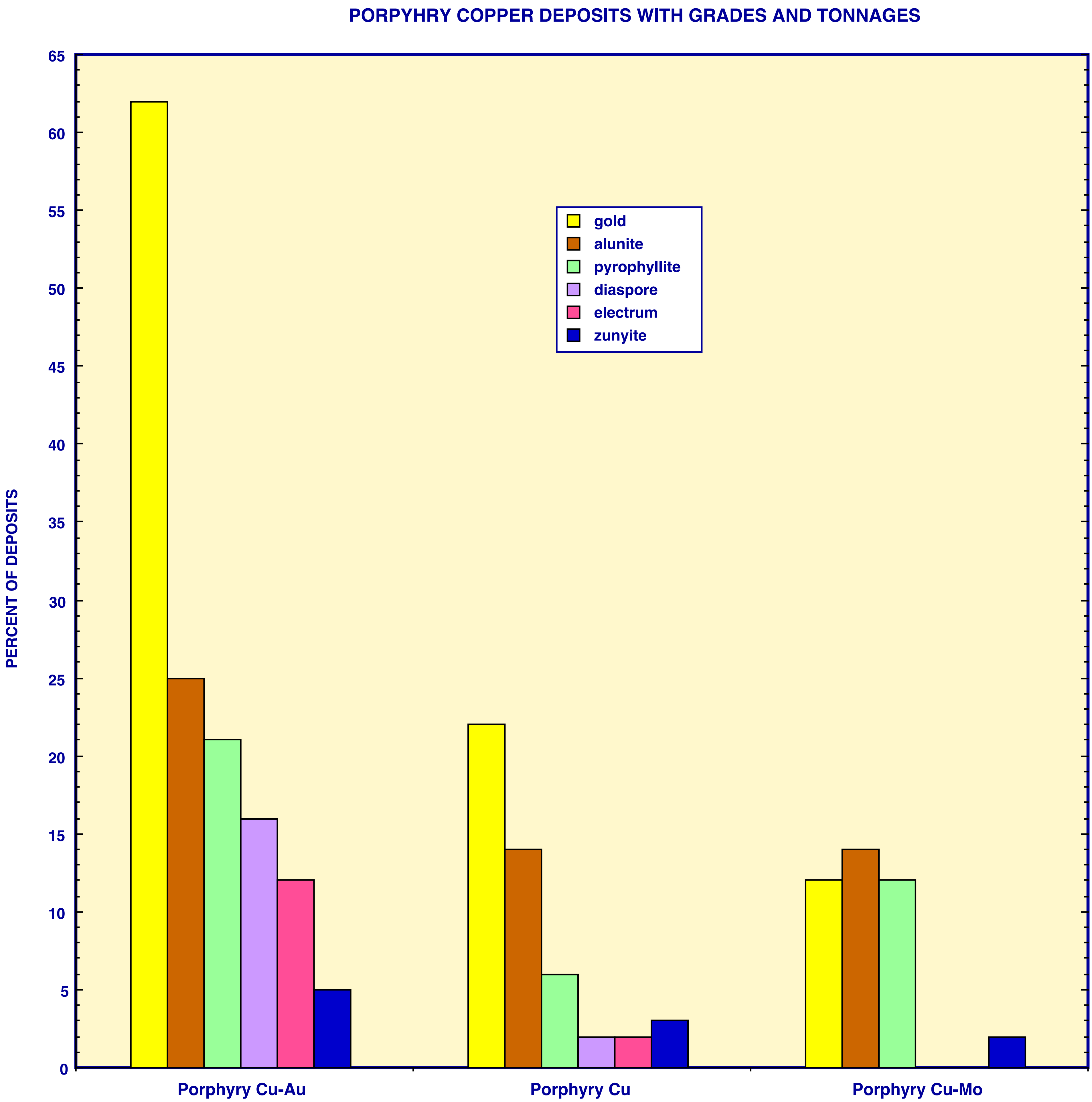

Figure 35. Frequency of some reported minerals of porphyry copper deposits used in each grade and tonnage model by type.

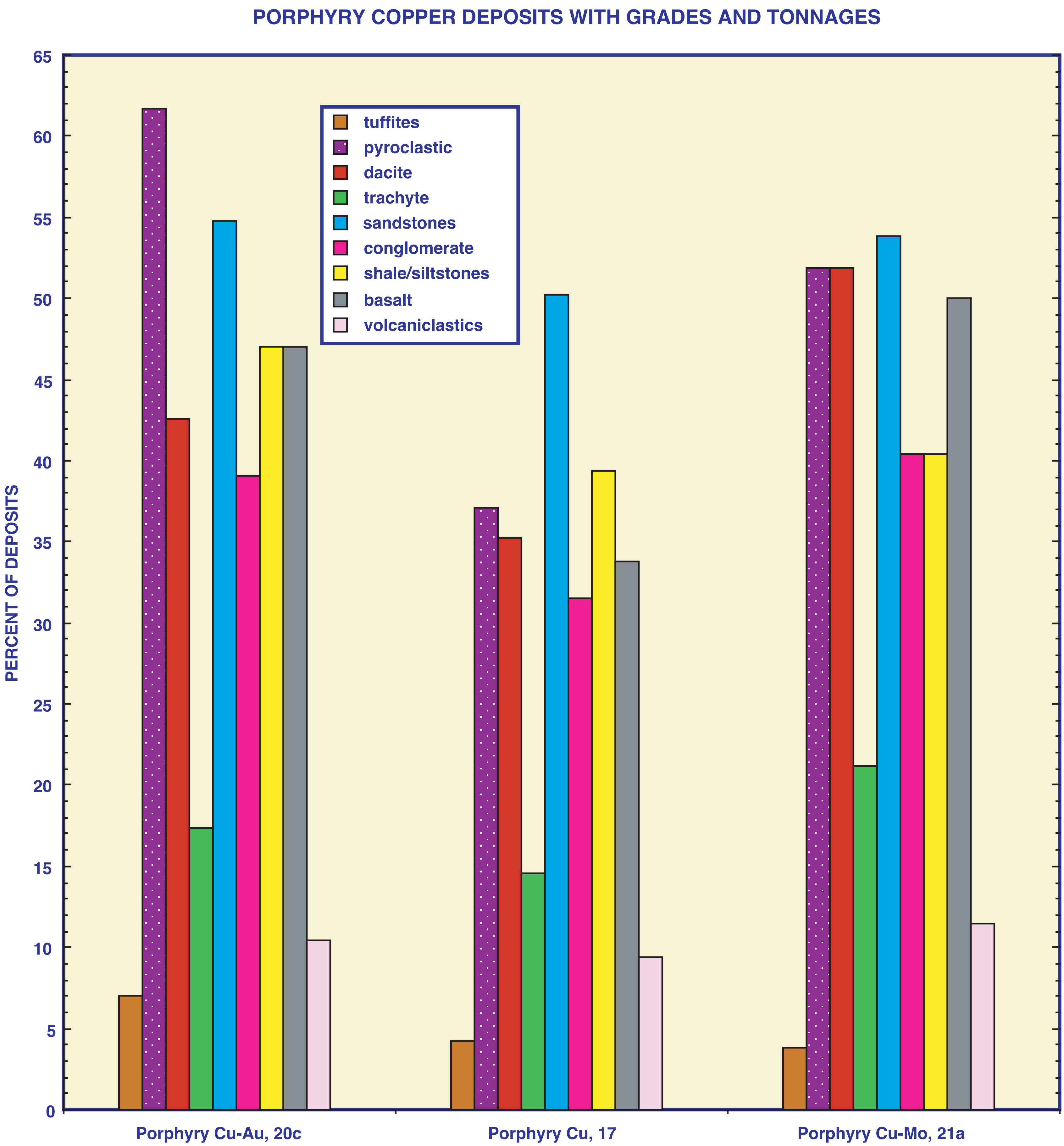

Figure 36. Frequency of reported sedimentary and some volcanic rocks associated with types of porphyry copper deposits used in each grade and tonnage models.

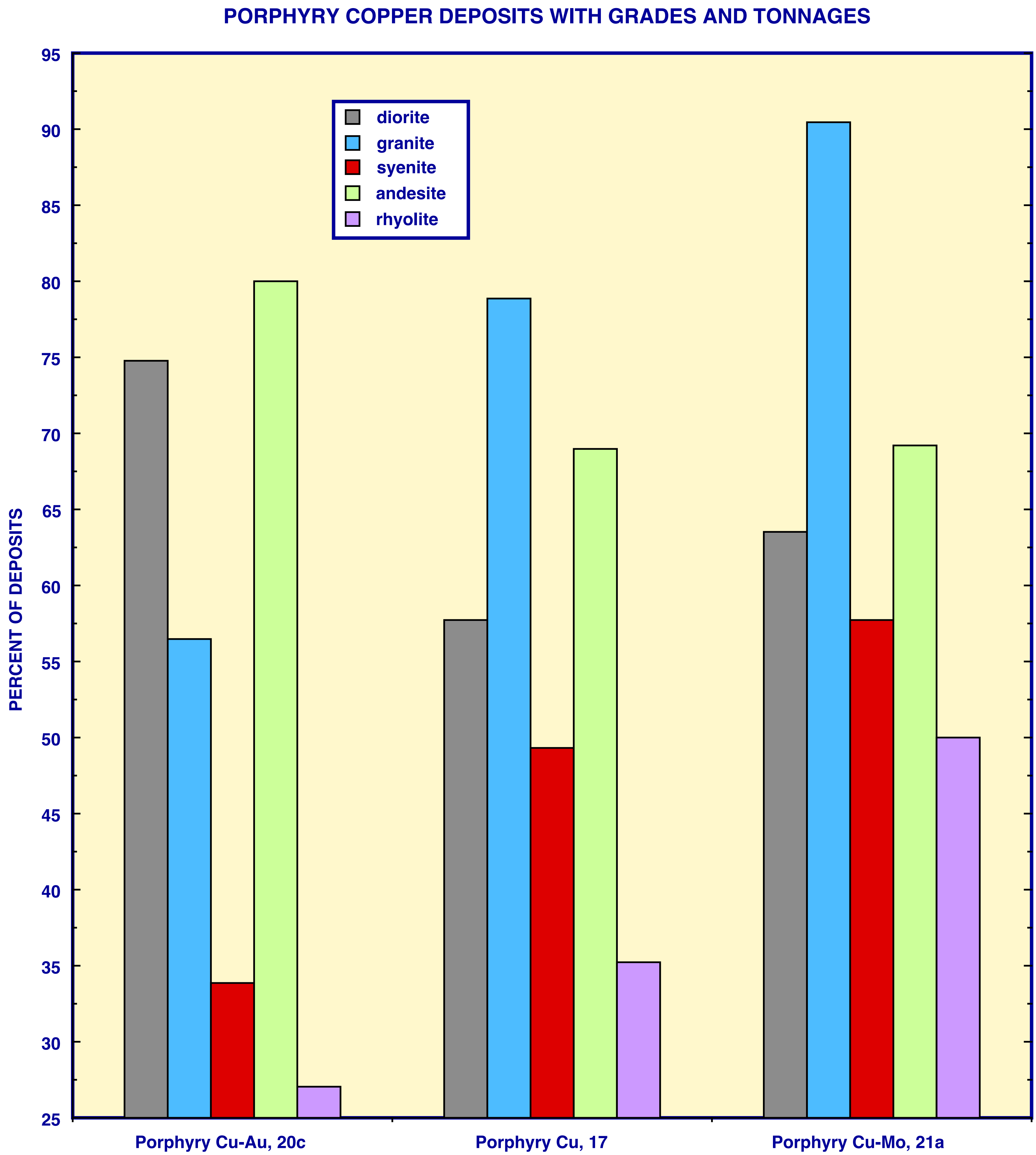

Figure 37. Frequency of reported some igneous rocks associated with types of porphyry copper deposits used in each grade and tonnage models.

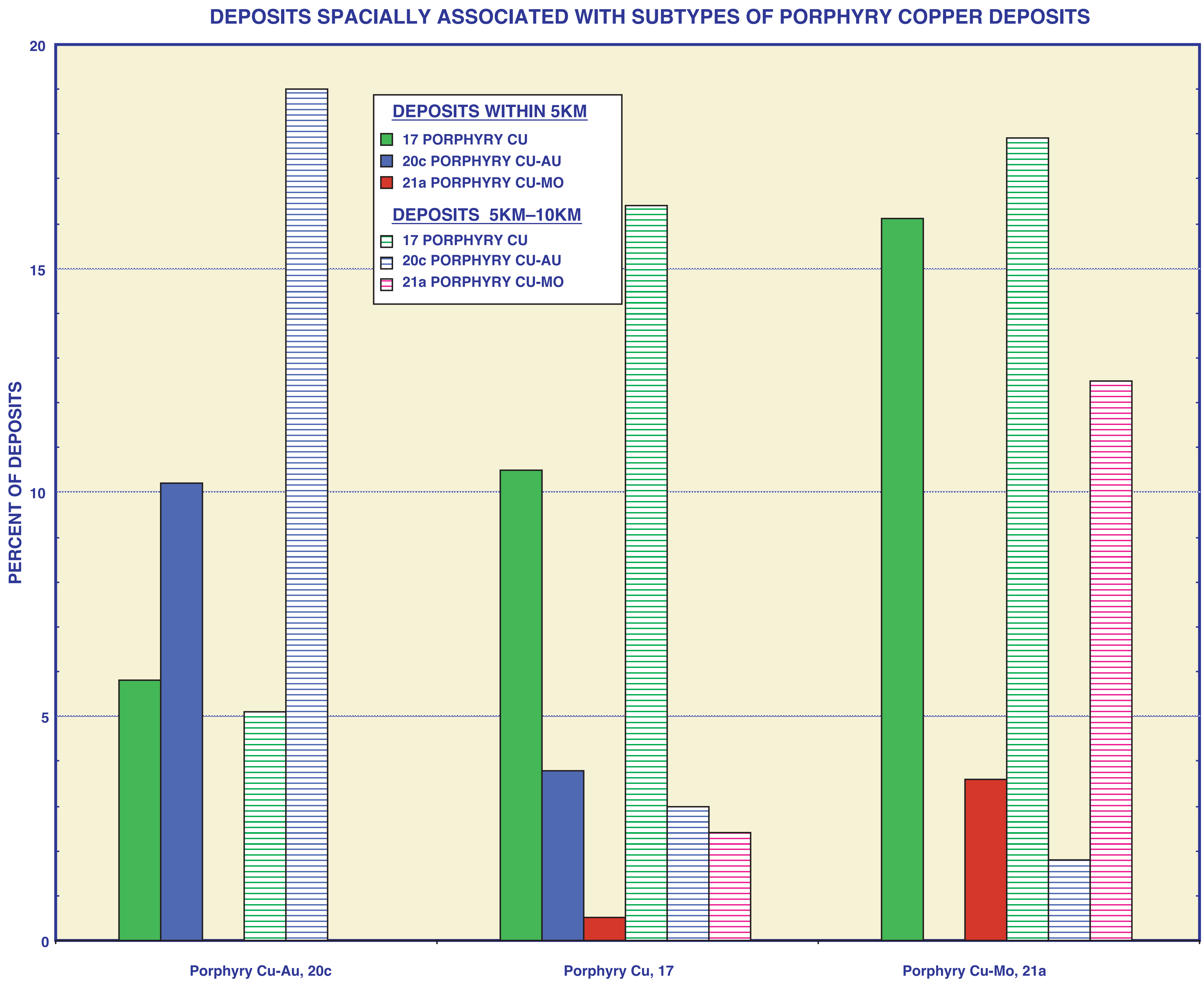

Figure 38. Frequency of kinds of porphyry copper deposits by type spatially within 5 and 10 kilometers of porphyry copper deposits. Plotted by type of porphyry copper deposit.

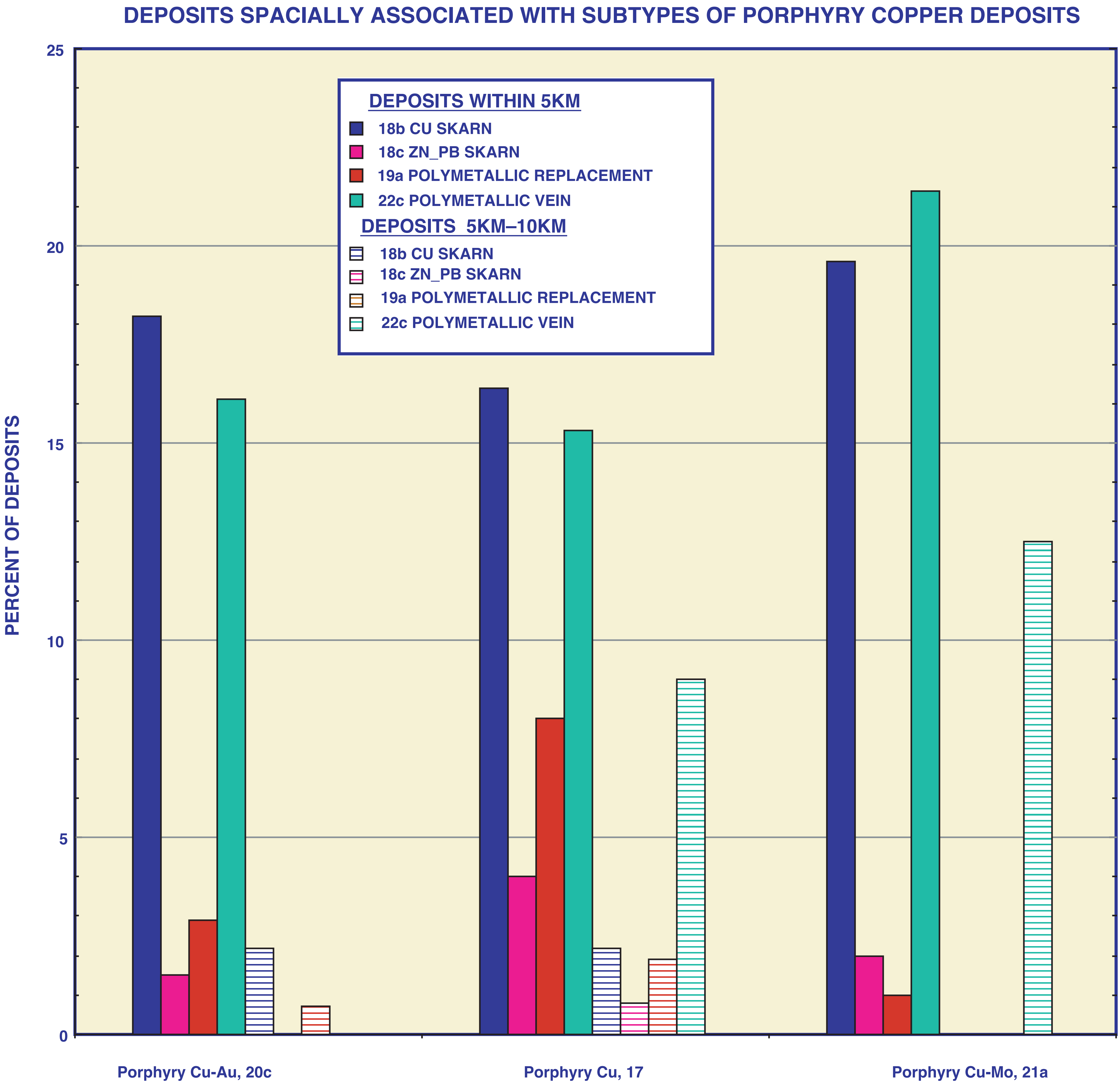

Figure 39. Frequency of kinds of skarn, replacement, and some vein deposits by type spatially within 5 and 10 kilometers of porphyry copper deposits. Plotted by type of porphyry copper deposit.

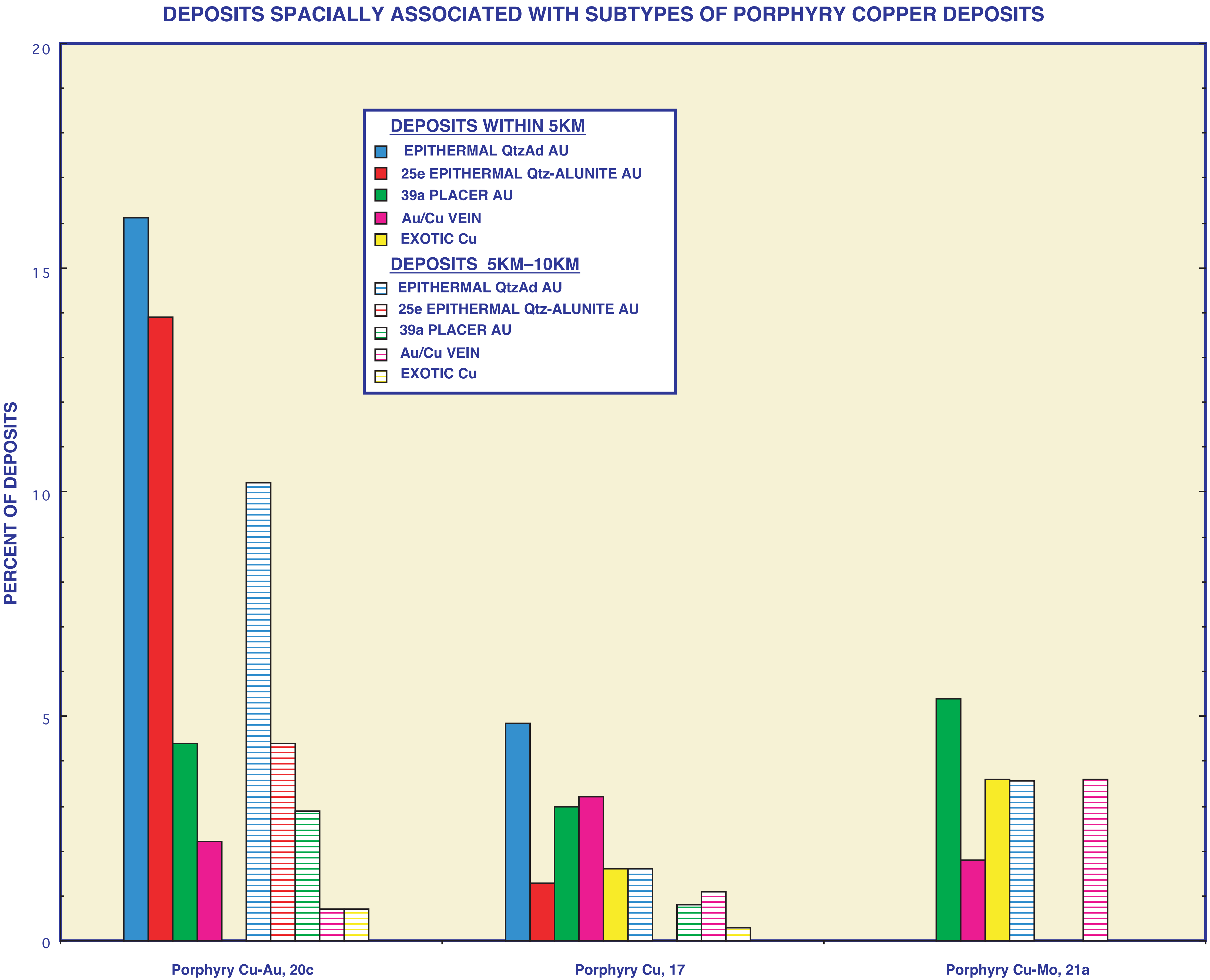

Figure 40. Frequency of some epithermal and other deposits by type spatially within 5 and 10 kilometers of porphyry copper deposits. Plotted by type of porphyry copper deposit.

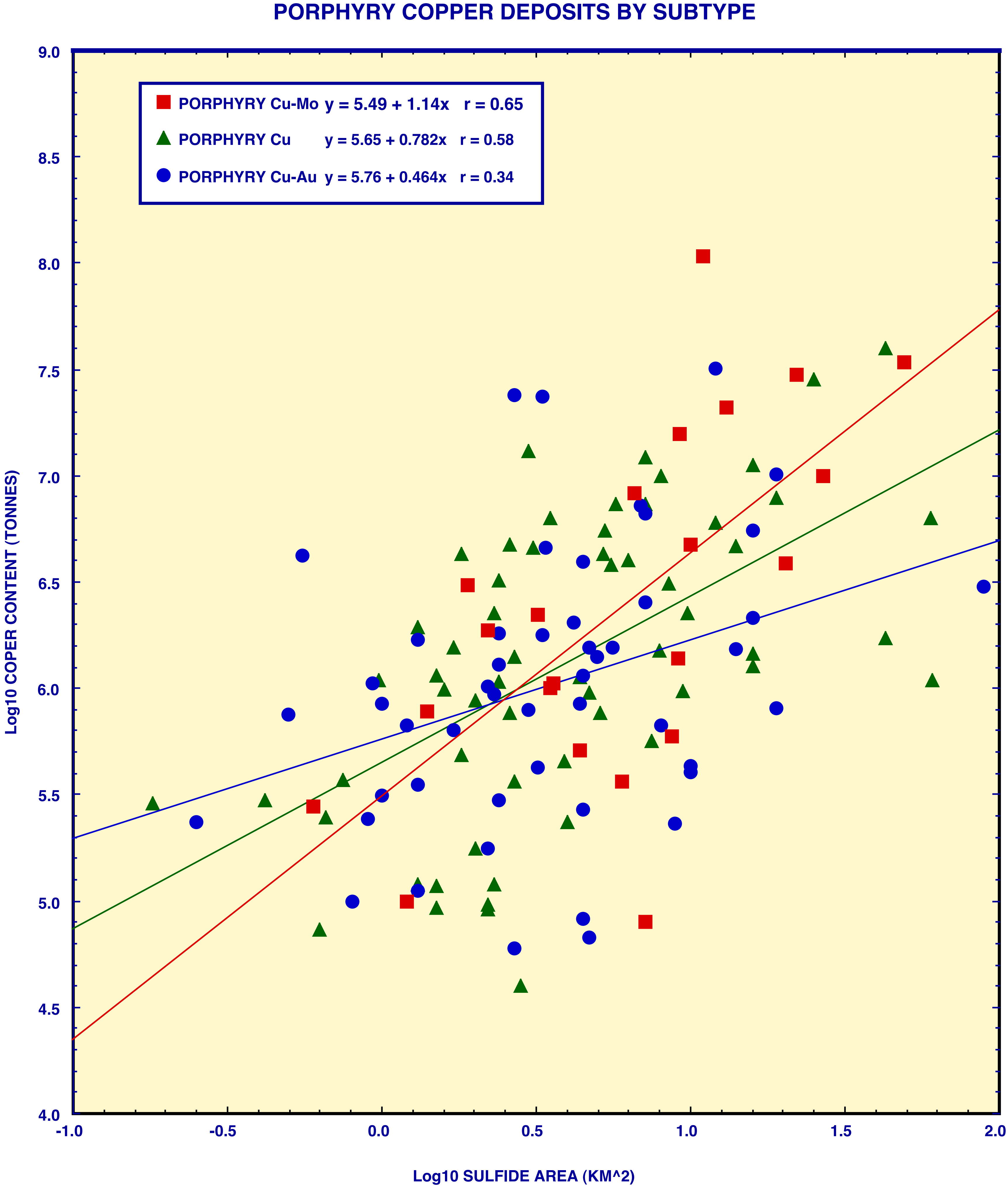

Figure 41. Extent of sulfides (in square kilometers) associated with porphyry copper deposits is plotted against the contained copper in the deposits. Data and regressions are plotted by type of porphyry copper deposit.