Porphyry Copper Deposits of the World: Database, Map, and Grade and Tonnage Models

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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. 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 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 porphyry copper deposits.

This report is an update of an earlier publication about porphyry copper deposits (Singer, Berger, and Moring, 2001). In this report we have added 84 new porphyry copper deposits and removed 12 deposits. In addition, some errors have been corrected and a number of deposits have had some information, such as grades, tonnages, locations, or ages revised.

This publication contains a computer file of information on porphyry copper deposits from around the world. It also presents new grade and tonnage models for porphyry copper deposits and for three subtypes of porphyry copper deposits and a map showing the location of all deposits. The value of this information and any derived 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 provide new grade and tonnage models.

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 mineralized rock or alteration within two (2) kilometers was combined into one deposit. Thus if the alteration zones of two deposits are within two kilometers of each other, they were combined. Such an operational spatial rule is necessary for defining deposits because we must be able to classify deposits in regions with highly variable geologic information and to avoid bias in estimating undiscovered deposits in resource assessments in areas where detailed information is lacking such as under cover. The two-kilometer rule was developed to try to insure that deposits in grade and tonnage and spatial density models correspond to deposits as geologic entities. Rules such as the two-kilometer rule used here are essential in order to have an internally consistent assessment system where the estimate of number of undiscovered deposits is consistent with the grade and tonnage model. For example, El Pachon in Argentina and Los Pelambres in Chile are here reported as one record (deposit) because of the two-kilometer rule, but with El Pachon in Argentina acting as a placeholder 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.FP6 and PorCu.txt which are FileMaker Pro 6 and tab-delineated text files respectively. The fields in both files are described below.

Deposit Name

The most recent deposit name, "NameDeposit", 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 "StartupDate" 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. Deposits that are known to be only partially drilled are considered as prospects and do not have their grades and tonnages reported in the grade and tonnage fields in order to avoid introduction of biases. The "Comments" field contains supplementary information about incompletely explored deposits and 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 feldspar and quartz are not included.

Types 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.

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 the known deposits in a region into types 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.

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. The grade and tonnage models are the frequency distributions of tonnage, copper grade, molybdenum grade, silver grade, and gold grade for each porphyry Cu type as represented in Table 1 by their 90^{th}, 50^{th}, and 10th percentiles. Percentiles of grades that contain unreported values, such as Mo, Ag, and Au, were estimated using the lognormal distribution. On the basis of the Lillifors test, the distributions of the logarithm of tonnage and copper grade are not significantly different (at the one percent level) than those of lognormal distributions for all porphyry copper deposits and for each of the types classed here.

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 grades or tonnages. Analysis of variance tests of differences in mean (logarithms) tonnage, copper, molybdenum, gold, and silver grades by type of porphyry copper deposit reveal significant differences in gold and molybdenum grade as expected because of how subtypes were defined. In addition, tonnages of the molybdenum-rich porphyry copper subtype are significantly larger than the porphyry copper and the porphyry copper-gold subtypes (Table 1).

Table 1—Grade and tonnage models of porphyry copper-gold, porphyry copper, porphyry copper-molybdenum, and all subtypes of porphyry copper deposits.

		Number deposits	10th percentile of deposits	50th percentile of deposits	90th percentile of deposits
Cu-Au (20c)	Tons	112	1,100	220	32
	Cu grade	112	0.83	0.44	0.24
	Mo grade	112	0.006	0.002	0.0005
	Ag grade	112	4.5	1.4	0.5
	Au grade	112	0.79	0.4	0.15
Cu (17)	Tons	215	1,100	220	30
	Cu grade	215	0.79	0.44	0.26
	Mo grade	215	0.024	0.010	0.0045
	Ag grade	215	3.0	1.2	0.44
	Au grade	215	0.24	0.077	0.025
Cu-Mo (21a)	Tons	53	4,500	270	63
	Cu grade	53	0.73	0.45	0.19
	Mo grade	53	0.062	0.028	0.01
	Ag grade	53	4.6	1.5	0.5
	Au grade	53	0.047	0.012	0.003
All Cu	Tons	380	1,400	230	32
	Cu grade	380	0.80	0.44	0.25
	Mo grade	380	0.03	0.008	0.002
	Ag grade	380	3.8	1.3	0.40
	Au grade	380	0.57	0.095	0.016

		Number deposits	10th percentile of deposits	50th percentile of deposits	90th percentile of deposits
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	Cu grade	112	0.83	0.44	0.24
	Mo grade	112	0.006	0.002	0.0005
	Ag grade	112	4.5	1.4	0.5
	Au grade	112	0.79	0.4	0.15
Cu (17)	Tons	215	1,100	220	30
	Cu grade	215	0.79	0.44	0.26
	Mo grade	215	0.024	0.010	0.0045
	Ag grade	215	3.0	1.2	0.44
	Au grade	215	0.24	0.077	0.025
Cu-Mo (21a)	Tons	53	4,500	270	63
	Cu grade	53	0.73	0.45	0.19
	Mo grade	53	0.062	0.028	0.01
	Ag grade	53	4.6	1.5	0.5
	Au grade	53	0.047	0.012	0.003
All Cu	Tons	380	1,400	230	32
	Cu grade	380	0.80	0.44	0.25
	Mo grade	380	0.03	0.008	0.002
	Ag grade	380	3.8	1.3	0.40
	Au grade	380	0.57	0.095	0.016

Relationships among variables are important for simulations of grades, tonnages and estimated number of undiscovered deposits, for their affect on our understanding of how deposits form, and for their affect on our assumptions about resource availability. Average copper grade versus tonnage of all 380 porphyry copper deposits has a slight positive correlation that is not significant at the one percent level. Within the Cu group, tonnage has a low but significant correlation with copper grade (r = 0.18). The independence of grade and tonnage is expected when the relationship between copper content and tonnage of ore is examined—the two are highly correlated and grade is a ratio of the two. Ratios of highly correlated variables tend to be independent of each either. Tonnage is correlated with gold grade (r = -0.33, n = 229) and gold is correlated with molybdenum (r = -0.24, n = 135) and with silver (r = 0.36, n = 133).

For the porphyry Cu-Au group, silver grades are correlated with tonnage (r = -0.40, n=48). In the porphyry Cu-Mo group, molybdenum grade is related to tonnage (r = -0.45, n = 53) and silver grades are correlated with molybdenum grades (r = 0.55, n = 31). Gold grades are correlated with molybdenum grade (r = 0.60, n = 62) in the porphyry Cu group.

LOCATION MAP

A map showing the locations of the deposits is provided in Map 1. The numbers on the map match the numbers in the "Map Number" field of the data file.

REFERENCES

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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.

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FILES

of2005-1060.pdf (PDF file describing all contents.)

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

PorCu.FP6 (A FileMaker Pro6 file containing the porphyry copper database.)

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

PorCu.xls (An Excel file containing the porphyry copper database.)

Map_1.pdf. Locations of all porphyry copper deposits in the PorCu.FM5 file plotted on a world map.

PorCu_meta.txt (metatdata in FGDC format)