The Use of Mineral Occurrence and Geologic Databases in Quantitative Mineral Resource Assessment

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Introduction

Quantitative mineral resource assessments of undiscovered mineral deposits in a regional setting are relatively new in geology. The U.S. Geological Survey (USGS), among others, has pioneered this activity and has developed a procedure known as the three-part quantitative assessment of undiscovered mineral resources (Singer, 1993).

Input into the three-part assessment consists of a variety of mineral-resource-related thematic data. Ideally, the following information is evaluated for a quantitative assessment: mineral occurrence data, to locate known mineral localities and their attributes; geologic map data, to determine geologic history and the current disposition of genetically related geologic map units; geophysical data, including both gravity and aeromagnetic data, to interpret lithologies and geologic structure beneath the surface; geochemical data, to locate anomalies of metallic or pathfinder elements at the surface; and exploration history, to determine if commodities of a particular mineral deposit type previously have been explored and to what result. These datasets, when compiled systematically, constitute databases.

Different aspects of these databases become important depending on the commodity and type of deposit being assessed. For example, geophysical data for an area may show positive gravity and magnetic anomalies combined with geologic data that show that mafic-ultramafic units are important in assessing specific mineral deposit types, such as chromite deposits. Other databases (for example, stream sediment geochemical data) may be important in the assessment of Carlin-type gold deposits.

This paper describes the use of databases of two different themes, mineral occurrences and geology, in performing a preliminary mineral resource assessment of porphyry copper deposits in Peru. This preliminary assessment of porphyry copper deposits in Peru was prepared for use in a workshop on mineral assessment conducted in Lima, Peru (unpub. data, February 27–March 1, 2001). In the following discussion, we will describe and compare the mineral and geologic databases, then review successes and challenges in how these databases were used.

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USGS Mineral Databases

The USGS is in the process of combining two large mineral resource databases, MRDS (Mineral Resources Data System) and MAS/MILS (Minerals Availability System/Minerals Industry Location System). MRDS was created and is maintained by the USGS, and MAS/MILS was created and maintained by the former U.S. Bureau of Mines (USBM). Both databases were started around 1970 and have evolved through many different formats over the years. In 1996, Congress eliminated the Bureau of Mines, and MAS/MILS was transferred to the USGS.

The two databases were compiled for different purposes and contain very different information. For example, MAS/MILS contains information on mining and development costs, details of mining methods, and results from feasibility studies. In addition, MAS/MILS contains records for fossil fuel deposits and for mineral processing plants (mills and smelters) that are not in MRDS. MRDS has mineralogical and geologic data that are not contained in MAS/MILS. Because MRDS and MAS/MILS are mineral databases, they also contain some information in common, such as location, name(s) of sites, and commodities present.

Both databases are international in scope but have an emphasis on the United States. MRDS contains over 110,000 records, of which about 80,000 pertain to the United States, and MAS/MILS contains about 220,000 records, of which 210,000 pertain to the United States. Because the USGS and the USBM had limited resources, neither database has been systematically updated on a periodic basis. Both organizations added to or corrected records in the databases by a variety of means that included hiring contractors, entering into cooperative agreements with State geological surveys in the United States and national geological surveys in other countries, and entering data from areas in which there were ongoing USGS or USBM projects. The result of this approach is that each record is a snapshot of a given deposit at the time the data were either first entered or last updated. If a deposit has undergone a significant change in status since the data were entered, but we have not had reason to revisit the area in which the deposit lies, then we commonly do not have updated information.

The USGS has merged the data in the two databases into one Oracle format with the goals of cleaning the data and eliminating duplicate records. The new structure has about 250 available fields for data. Because of increasing emphasis on environmental aspects of mining, information on mineral processing plants in the MAS/MILS database was retained. The USGS did not retain data on energy resources from the old USBM database because the USGS already has energy databases that cover those deposits. The USGS published a CD-ROM set containing the original MRDS and MAS/MILS databases (McFaul and others, 2000) and has the MRDS online (USGS, 2005).

Other Relevant Mineral Databases

As part of a study to determine if a global quantitative mineral resource assessment is feasible using the USGS three-part form of assessment, a preliminary assessment of porphyry copper deposits in Peru was initiated. INGEMMET, the Instituto Geológico Minero y Metalúrgico of Peru, provided their unpublished geology and mineral deposits databases. Most countries have good databases for deposits within their borders but do not keep information on other countries.

The following mineral resource databases were used for the preliminary quantitative mineral resource assessment of Peru:

- MRDS and MAS/MILS (USGS, McFaul and others, 2000)
- Peru database of mineral deposits (INGEMMET, unpub. data)
- Giant porphyry-related camps of the world—A database (Mutschler and others, 1999)
- World distribution of porphyry, porphyry-associated skarn, and bulk-tonnage epithermal deposits and occurrences (Kirkham and Dunne, 2000)
- An informal, unpublished database compiled by D.A. Singer (USGS). The database was subsequently released as USGS Open-File Report 02–268 (Singer and others, 2002)

Other sources included the following:

- Peru database of geology (INGEMMET, unpub. data, scale 1:1 million)
- Database of exploration targets compiled from press releases and various trade magazines (D.R. Wilburn, USGS, unpub. data)
- Many published reports on copper deposits and geology of the Andes

The INGEMMET database of mineral deposits in Peru has a structure similar to that of MRDS because of a cooperative agreement between USGS and INGEMMET when the Peruvian database was first developed. However, there are several important differences among the four mineral resource databases (MRDS, INGEMMET, Mutschler and others, and Kirkham and Dunne) used in the preliminary assessment of Peru. First, the USGS and INGEMMET databases have many more data fields than the other two (MRDS, ~230; INGEMMET, ~140; Mutschler and others, ~30; and Kirkham and Dunne, ~50). This disparity exists because databases compiled by geological surveys are usually used for many different purposes, whereas databases compiled by individual researchers are commonly designed for specific purposes. Moreover, compilers of the USGS and INGEMMET databases tried to capture everything from the small occurrences to the largest producers, whereas compilers of the other two databases concentrated on giant or significant deposits; this difference also reflects a difference in the philosophy of the compilers. The result is that the USGS and INGEMMET databases have more records of small occurrences classified as porphyry copper deposits. Many of these identified porphyry copper occurrences never have been, and probably never will be, mined.

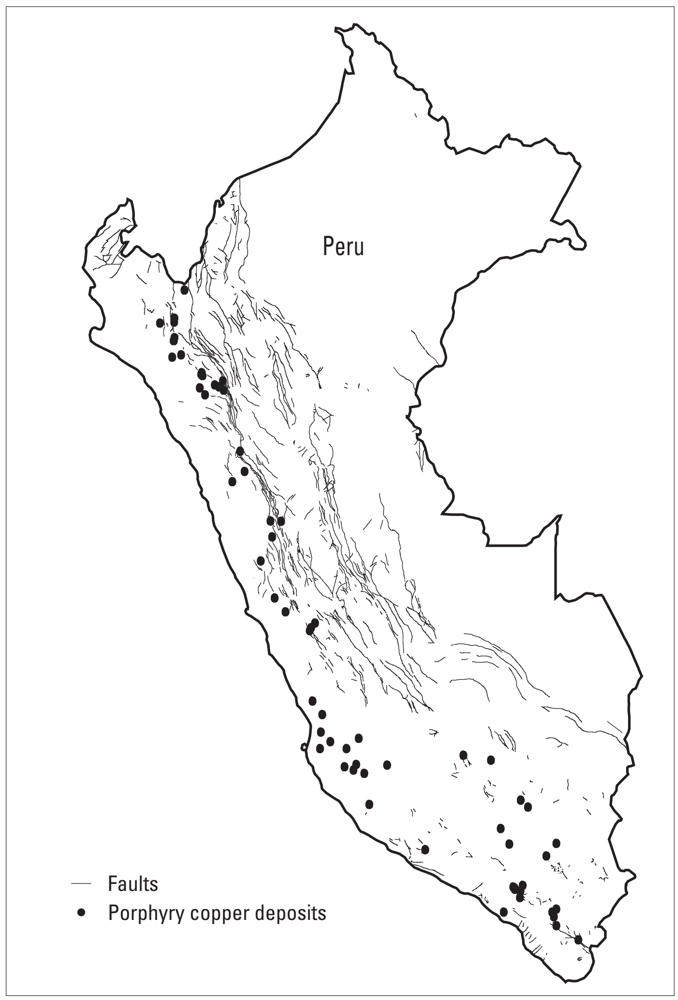

Figure 1. Map showing locations of porphyry copper and porphyry-copper-related deposits in Peru used in the preliminary quantitative mineral resource assessment.

The most obvious difference among the databases is that the USGS and INGEMMET databases cover all types of mineral deposits, whereas the other two were designed to cover only porphyry and related deposits. All the databases were useful because of some unique piece of information they contained and because of the confirmation of deposit type classifications from multiple sources. When there was disagreement among the databases, the references provided were useful in resolving them. Sixty-four deposits were identified as porphyry copper or porphyry copper related. The locations of these deposits are depicted in figure 1.

Geologic Database

Although geologic maps have been available for many years as paper products, the relatively recent advent of digital geologic maps and associated databases has brought a new era to their application in fields such as land use planning and mineral exploration. This technology is new and evolving quickly; thus, standards for development have not yet been fully established and accepted.

In the first phase of evolution of digital geologic maps, they simply are representations of previously published paper maps. The databases and attribute tables that accompany these digital maps reflect only the information contained within the hardcopy media. A typical geologic map for an area would contain geologic map units, including stratigraphic units and geologic ages; structural data, including faults and strike and dip symbols; and regional tectonic and depositional settings. Digitizing paper maps can convey only the information that was on the paper originally. Thus, digitized maps are not superior to paper maps in quality or accuracy.

The geologic data provided by INGEMMET were contained in two files, geology and faults, that together represent the geology of Peru. These were compiled at a scale of 1:1 million. The digital geology contains 113 different map units, which are attributed to approximately 6,700 polygons. The fault coverage contains attributes reflecting movement and the degree of exposure or level of confidence in fault location. This amount of information, although important for many types of studies, is far too detailed for a countrywide mineral resource assessment. For instance, the original data set showed 19 different types of Cretaceous intrusions. These were combined into a single category because it was concluded that their common age range was enough information for the purposes of the mineral resource assessment. Therefore, the geologic map units are combined into 10 time–stratigraphic units on the basis of their temporal relations to episodes of porphyry copper deposit formation in Peru. The simplified map is displayed in figure 2. The 10 time-stratigraphic units formed before, during, between, and after the various episodes of porphyry copper formation. Aside from the ease of manipulation of digital geologic maps to create other derivative maps, all of these maps are easily combined with other thematic data as layers, such as aeromagnetic data, gravity data, geochemical anomalies, remote sensing images, and of course mineral occurrences.

Challenges and Successes

Before discussion of challenges and successes, a brief explanation of the three-part mineral resource assessment is in order. This is a procedure for a quantitative assessment of the mineral resources of a given area. Singer (this volume) states the following, “In three-part assessments, (1) areas are delineated according to the types of deposits permitted by the geology, (2) the amount of metal and some ore characteristics are estimated by means of grade and tonnage models, and (3) the number of undiscovered deposits of each type is estimated.” Deposit models play a very important role in the first two parts of the process. In the first part, we use descriptive mineral deposit models to determine what types of deposits are permissible in the area. In the second part, we use grade and tonnage models of each deposit type. By building databases of mineral deposits that contain the attributes of the deposits (such as age, host rock(s), ore minerals, gangue minerals, structural setting, grade, and tonnage), we are able to develop the required descriptive and grade and tonnage models to carry out the three-part assessments. In addition, we may be able to classify individual deposits if sufficient information is contained in a database.

The first challenge for the Peru assessment was the interpretation of the mineral deposit databases. Some deposit types may be spatially and genetically related to porphyry systems, such as skarns, manto deposits, polymetallic veins, and epithermal gold deposits. However, it is not mandatory that those deposit types be related to porphyry systems. In addition, many copper deposits in the USGS and INGEMMET databases were classified as either stockwork or disseminated, which are descriptive terms but not very helpful in assigning them to a specific mineral deposit model. The other three porphyry databases were of some assistance in this effort because they pointed to literature that confirmed that some of the stockwork and disseminated deposits were indeed porphyry or porphyry-related deposits. However, many of the deposits labeled stockwork or disseminated were small nonproducers and were not included in the databases by Mutschler and others (1999), Kirkham and Dunne (2000), or Singer and others (2002). Additional work was needed to classify these small deposits, including examining such data as ore mineralogy, host-rock type, associated-rock type, and mineralization age and consulting many published references. Through this effort we were able to better classify some of the small deposits. Nonetheless, some deposits in both the USGS and INGEMMET databases remain unclassified because of insufficient data; these are being examined in conjunction with INGEMMET.

All the databases were in substantial agreement on almost all the significant deposits with respect to name, deposit type,

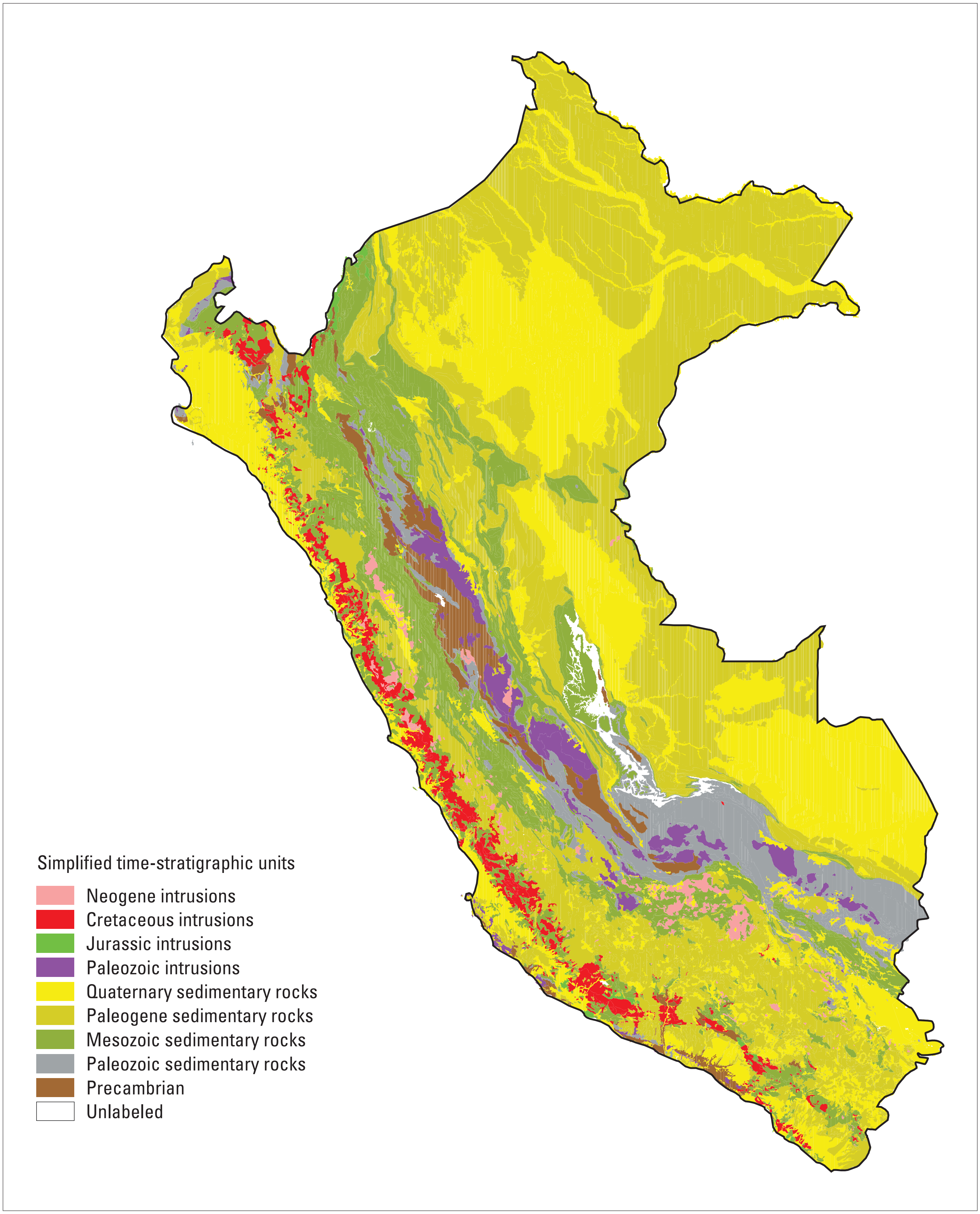

Figure 2. Simplified time-stratigraphic map of Peru.

and location. Many locations were close but not exactly the same among the databases. Because mines tend to be large, one location may be based on the entrance to the mine, and another may be based on the location of the headframe. Both locations are correct but different. Many of the discrepancies were small, however, commonly a few seconds or less (a second is about 185 meters at the Equator). This was considered an acceptable level of uncertainty at a scale of 1:2 million, which was the scale at which the assessment was conducted. In cases where significant discrepancies existed, we deferred to locations used in the INGEMMET database.

The geologic map and fault databases were useful in matching rock type to known deposits. They also can be useful in identifying structural settings of deposits and their proximity to various types of faults as a way of trying to predict where other, perhaps hidden, deposits may occur. However, in the case of the fault file provided by INGEMMET, plotting the porphyry and related deposits with the faults did not show any direct relation, possibly because, at the 1:1 million scale at which it was compiled, smaller faults of significance to the deposits are not included. Satellite images are being used at a much larger scale to further examine the structural setting of some of the porphyry deposits.

The unpublished worldwide exploration database compiled by D.R. Wilburn (USGS, Denver) was found to be very helpful in the assessment. The exploration database contains information on items such as the number of meters drilled on exploration sites and status of exploration (from early prospecting to final feasibility study). Thus, it is possible to judge the chances of a given porphyry prospect becoming a producer. Another value of the exploration database was that it provided information on whether a prospect was in a known mining district or in an area in which few, if any, deposits had been found. A major challenge in this dataset was getting accurate locations because press releases and articles in trade journals, which are the sources for most of the records in this database, use location descriptions such as “400 kilometers NE of Lima” and rarely give precise locations. If a porphyry prospect is in an area that has not previously been explored or in which no other deposits were known to exist, it can have a profound effect on the estimate of the number of undiscovered deposits.

Conclusions

This exercise to assess the porphyry copper deposit potential in Peru by using the three-part form of assessment has been very helpful. A great deal was learned about the usefulness of different types of data and the limitations of existing databases. Priorities now can be established for the type of information needed about mineral deposits and occurrences for future assessments of a country or group of countries. For mineral occurrence databases, the priorities are—

- Accurate locations of mineral occurrences
- Previous names of deposits for matching and reconciling data from different sources
- Host-rock type and age
- Associated-rock type and age (we distinguish between host rock and associated rock in that a porphyry-related skarn may be hosted by a limestone and the associated rock may be a porphyritic monzonite)
- Ages of mineralization
- List of ore and non-ore minerals
- Genetic, descriptive, and grade and tonnage characterization of the known deposits in the region of interest

For geology databases, the priorities are—

- Digitized records of all information on paper maps (because one cannot predict what data may be useful)
- Lithologic descriptions of all map units
- Geologic ages of map units
- Types of faults and apparent movement
- Relative ages of map units, including whether they formed before, during, between, or after the various episodes of ore formation
- Map projection parameters to allow combining a geologic map with other thematic datasets

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