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Predictive mapping for copper–gold magmatic-hydrothermal systems in NW Argentina: Use of a regional-scale GIS, application of an expert-guided data-driven approach, and comparison with results from a continental-scale GIS

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Abstract

Geographic Information Systems (GISs) are very useful tools for managing, checking, and organizing spatial information–from many sources and of many types–in thematic layers. Processing of these data enables exploration-oriented GISs to produce potential and predictive maps for a given commodity, which constitute documents of real use in decision-making. Integration of all information in a single reference system enables a better understanding of the parameters controlling a region's metallogeny, in terms of both time and space. But what scale should be used for developing a mineral exploration GIS? Should preference be given to systems with high spatial resolutions (scale <1:500,000), or to more general systems with scales of around 1:1,500,000 or 1:2,000,000? Will the gain be worthwhile relative to the additional work generated by compilation at a higher scale? In order to make greater use of previous predictive studies performed on gold-rich epithermal and porphyry systems at the scale of the entire Andes, an expert-guided data-driven approach is now applied to a regional-scale GIS of NW Argentina, between the Puna and the Sierrras Pampeanas, where known deposits like Bajo de la Alumbrera, Agua Rica, and others, account for a metal potential of over 10 Mt Cu and 750 t Au. In developing this new predictive map, three criteria that were likely to be connected to the mineralizing event were selected and quantified: (i) lithostratigraphy, because of its role as a favourable environment for the development of mineralization, based on its physico-chemical properties; (ii) lithostratigraphic contacts, based on the rheological properties of the formations in contact; and (iii) the orientation of structural discontinuities, which channel source magmas and encourage the circulation of hydrothermal fluids. Assigning a score enables classification of the favourabilities calculated for each of the criteria considered. This approach is employed here to check and standardize the statistical results obtained by methods such as Weight of Evidence Modelling or an algebraic approach. For each criterion, four classes were distinguished: very favourable: score = 3; favourable: score = 2; slightly favourable: score = 1; and unfavourable: score = 0. The predictive map is obtained by adding the scores for the three favourable criteria defined above.

The regional-scale work identified 20 anomalous envelopes with cumulative scores greater than 5. They correspond to mining areas that are active (e.g., Bajo de la Alumbrera), under development (e.g., Agua Rica), or abandoned (e.g., La Mejicana), or to new

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areas (e.g., the Vicuña Pampa Volcanic Complex). Structural analysis of the region, integrating the orientation of the favourable envelopes, suggests that the mineralizing fluids were emplaced under extensional conditions, sub-parallel to the principal directions of shortening: (i) WNW–ESE, found along the southern edge of the Puna; and (ii) E–W, seen in the Sierra de Famatina. It appears that a regional-scale information system is a tool that is well suited to the definition of areas for mineral prospecting, and to the study and confirmation of metallotects usable for mineral exploration.

Comparison with work conducted on the basis of a 1:2,000,000 geological compilation shows that the principal mining districts can indeed be found at continental scale. On the other hand, the lack of detail inherent at a scale of 1:2,000,000 may lead to inaccuracies, in particular fictitious favourabilities assigned to formations that are genetically unrelated to the mineralization, but that contain, for example, small Tertiary intrusive bodies that cannot be recorded at this scale. This comparison therefore shows that the use of a continental-scale GIS is effective, and well suited to the definition of prospective areas at a strategic level.

Keywords: GIS; Multi-criteria processing; Metallogeny; Gold; Andean tectonics

1. Introduction

Geographic Information Systems (GIS) are very useful tools for managing spatial information. Coming as it does from sources of many kinds, such information is often heterogeneous in nature, quality, distribution, and density. However, once it has been checked and organized into thematic layers, an exploration-oriented GIS can produce predictive maps for a given commodity, and can be of great value in decision-making (e.g., Bonham-Carter et al., 1989; Bonham-Carter, 1994; Burrough and McDonnell, 1998; Billa et al., 2004). A GIS can also be a tool for research: once all the information is under a single reference system, the user can better explore the interactions between the various parameters that control the mineralization, and better define the laws governing the distribution of mineral concentrations in space and time (e.g., Cassard et al., 2003, 2004).

What is the best scale for developing a GIS for mineral exploration? Should one aim for good spatial resolution, at a detailed scale (>1:500,000) over a limited area (say, thousands of km^2); or should one take a more general view, at 1:1,500,000 or 1:2,000,000, covering a much larger area but including well-studied sites and zones of poorer information? Recent studies of multi-representational geographic bases, at multiple resolutions, have shown that the problems of changing scale are not trivial and are still far from being solved (Parent et al., 2000; Spaccapietra et al., 2000). To build a GIS, the user can choose between (1) the semi-continental approach, based on geodynamic criteria, an accuracy of the order of $\pm$2 km for geological contacts, deposits and prospects, and the plotting of calculations on pixels 10 km by 10 km square; or (2) the regional approach, which involves an accuracy much better than 1 km, detailed geology, detailed structural analyses, geophysical or geochemical surveys of limited areas (if available), and plotting on pixels 0.5 km by 0.5 km square.

In this paper, we describe a regional approach to studying the Famatina and Farallón Negro gold districts of NW Argentina with a two-fold objective:

1. In terms of methodology, we wished to investigate the predictive capacity of a regional GIS, as compared with that of a continental GIS. Using a similar methodology at continental scale, Billa et al. (2004) successfully identified the main Andean gold districts between Ecuador and Chile. At regional scale, would the resulting gain be worth the additional work of compilation? Although we might expect greater accuracy, when working on a smaller area, there will be fewer deposits for which information is reliable;
2. In terms of metallogeny, we wished to investigate the magmatic and structural controls on mineralization in a supra-subduction environment (Nelson, 1996). The continental approach had already yielded a strong positive correlation between (1) Neogene epithermal and porphyry gold deposits in the Central Andes and (2) gently dipping segments of the Benioff zone (Cassard et al., 2001; Billa et al., 2002). Would the regional approach yield a correlation with volcanic centres and with the major structural lineaments that are present in NW Argentina (Rossello et al., 1996b,c; Rossello, 2000)?

2. Geodynamic, geological, and metallogenetic setting of NW Argentina

2.1. Geodynamic setting of the Central Andes

From W to E, the main structural units of the Central Andes are the Cordillera Principal, the Pre-Cordillera,