GOLD AND SILVER DEPOSITS IN THE CENTRAL AND SOUTHERN ANDES

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The Andes Mountains were the source of large amounts of gold and silver from many deposits from northern Colombia to southern Chile. Early producers of these metals were Pre-Columbian Indians who mined the gold and silver sent to Spain by the Conquistadores. Still larger amounts of gold and silver were mined during Spanish Colonial times, from the early 16th century until independence in the early 19th century, and mining continued into Post-Colonial times. At present, the Andean region as a whole is the world's major silver producer and a significant gold producer.

Many gold and silver deposits occur in the Andean regions of Perú, Bolivia, Chile, and Argentina, in part in well-defined belts. For example, a large number of silver deposits are found in a belt extending from Hualgayoc, northern Perú, to the Sur Lipez region of southern Bolivia. Two of the world's largest silver deposits, Cerro de Pasco in central Perú and Cerro Rico de Potosí in southern Bolivia, are in this belt. Another belt to the west extends from the Salpo and Quiruvilca mining districts, northern Perú, to the Todos Santos district in west central Bolivia, near the Chilean border. This belt includes important silver deposits in the Cordillera Negra, northern Perú, the Arcata and Orcopampa mining districts, southern Perú, and the Choquelimpie deposit, northern Chile. Most of the deposits in these two belts are genetically related to hydrothermal systems in volcanic centers of late Tertiary age. Taken together, this region constitutes one of the world's greatest silver provinces.

Gold also occurs in well-defined belts in the central and southen Andes, of which one of the most important is that in which the recently discovered El Indio deposit is located. This belt, as yet incompletely explored, may be as much as 200 km long, extending both to the south and north of El Indio. Other well defined gold belts are in western Perú, extending from the Sol de Oro district in the north to the Andaray district in the south, and the Pataz-Parcoy-Buldibuyo region of the eastern Peruvian Andes. Ruiz and Ericksen (1962) defined a gold belt in the coastal region of Chile, extending from near Talca in the south to Taltal in the north. A recently discovered gold district in the vicinity of Salar de Maricunga, east of Copiapó is within still another longitudinal belt of significant economic potential. The pattern of distribution of hydrothermal gold deposits in Bolivia is not clear, buy most of the known deposits are associated with late Tertiary volcanic centers north of Potosí.

The potential for discovery of new gold and silver deposits in the central and southern Andes is excellent, as is indicated by the many discoveries made during the past decade. These discoveries have enhanced our knowledge of precious metal deposit models, particularly for deposits in Tertiary volcanic terrain. Application of new information about these deposits should be of great assistance in future exploration.

GEOLOGICAL, MINERALOGICAL, AND CHEMICAL CHARACTERISTICS OF EPITHERMAL PRECIOUS-METAL DEPOSITS IN SOUTHERN PERU

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The Cenozoic volcanic belt of the Cordillera Occidental, southern Peruvian Andes, is about 400 km long, 50 km wide, and has many precious metal deposits that belong to the silver-base metal sub-province of the Andes. These deposits are the result of hydrothermal mineralization associated with pulses of ig-

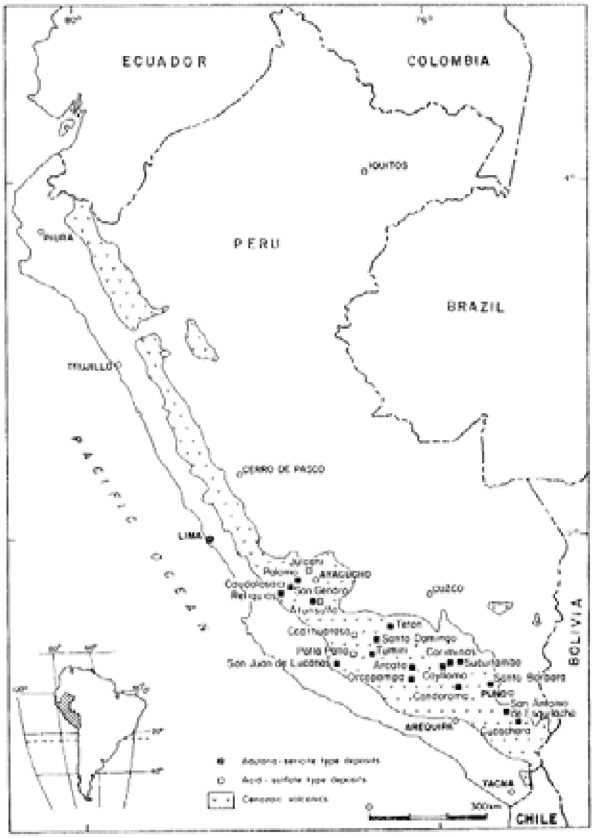

FIG. 1. Southern Perú epithermal precious-metal deposits in Cenozoic volcanics.

neous activity during three Neogene intervals called Quechua I, II, and III (19, 9.5, and 6 Ma). The volcanic host rocks are of late Oligocene of late Miocene age and include the Tacaza (30-17.5 Ma), Palca (16,9 Ma), Sillapaca (14-12.8 Ma) and Maure (12.6 Ma) Formations. Younger post-mineral volcanic rocks are of late Miocene to Pleistocene age and include the Barroso (6-1 Ma) and Ampato (1 Ma) formations (Fig. 1).

Two types of volcanic hosted epithermal precious-metal deposits are recognized in southern Perú: 1. Adularia-sericite (silver sulfosalts-gold type), and 2. Acid-sulfate (enargite-tetrahedrite-gold type). The first type is found chiefly in southern Perú and the second type in south-central Perú. Both types may be present in some mining districts, as they do in the Castrovirreyna (San Genaro, Reliquias, Caudalosa, and Bonanza) and Atunsulla districts.

Deposits of the first type represent the classic epithermal, silver-bearing sulfosalts and gold vein systems having phyllic alteration characterized by abundant adularia. The principal ore minerals are native silver, argentite, pyrargirite, polybasite, stephanite, miargirite, native gold, electrum, tetrahedrite, chalcocite, and base-metal sulfides. Gangue minerals are quartz, calcite, dolomite, rhodochrosite, adularia, and pyrite. Hydrothermal fluid temperatures range from 180° to 280°C (Arcata) or 255°C (Orcopampa), and salinities are 2 to 5 wt percent NaCl equiv. (Arcata). The deposits are associated with: 1. The resurgent caldera Nevado Portugueza (San Julián and La Libertad in Atunsulla), Chonta (Sucuitambo, Coriminas, San Miguel, Caylloma), Tumiri, Tetón (Tetón-Santo Domingo), San Martín (San Martín-Farallón); 2. Volcanic domes (San Genaro, Reliquias, Palomo in Castrovirreyna, Julcani, Orcopampa, Arcata, Santa Bárbara, and Cacachara); 3. Faults (Orcopampa, San Juan de Lucanas, Condoroma); 4. Intrusive bodies (San Antonio de Esquilache, Orcopampa, and Condoroma). Deposits have the following ages: Santa Bárbara (19.8 Ma), Orcopampa (17.0 Ma), Caylloma (17.1-15.8 Ma), Santo Domingo (11.7 Ma), Sucuitambo (11.4 Ma), Coriminas (10.5 Ma), Cacachara (7.1 Ma), Arcata (5.0-4.5 Ma), and Atunsulla (1.9 Ma).

Deposits of the second type are enargite-tetrahedrite-gold vein systems having advanced argillic alteration characterized by abundant alunite. The principal ore minerals are enargite, tennantite-tetrahedrite, native gold, electrum, bournonite, dismuthinite, silver-bismuth sulfosalts, stibnite, and base-metal sulfides. Gangue minerals are quartz, pyrite, barite, siderite, rejalgar, and orpiment. Hydrothermal fluid temperature range from 270° to 325° (Caudalosa) and from 295°C to 325°C (Julcani). Salinities are 4-18 (Caudalosa) and 5-24 (Julcani) wt percent NaCl equiv. The deposits are associated with: 1. The resurgent caldera at Nevado Portuguesa (Rosario in Atunsulla); 2. Stratovolcanos (Ccarhuaraso and Palla Palla); 3. Volcanic domes at Julcani and Castrovirreyna (Caudalosa, Candelaria, and Bonanza); and 4. Faults (Cerro Anta in San Juan de Lucanas). Radiometric ages are: Julcani (9.8 Ma) and Ccarhuaraso (1.2 Ma).

The deposits are located at distinct lineaments or fault zones. Precious metal ore in both types of deposits occurs chiefly in well defined veins, although some ore is in hydrothermal breccia bodies (Santa Bárbara, Ccarhuaraso, Caudalosa, and Anta in San Juan de Lucanas). The veins strike N25°-40°W, N40°-75°E, and E-W. The range from 200 m to 4 km in length, and are generally a few tens of centemeters to 1.5 m in width.

The Caudalosa Candelaria-Bonanza vein system in the Castrovirreyna district has an exceptional length of 9 km, whereas the Calera vein in the Orcopompa district and San Cristobal vein in the Caylloma distric have exceptional maximum widths of 10 and 25 m, respectively. Gold and silver ores extend to relatively shallow depths and gold increases with depth in some veins. Ruby silver ores give way to polymetallic base-metal ores at depths of 300-400 m (San Juan de Lucanas, Caylloma, San Genaro, Reliquias, Condoroma, San Antonio de Esquilache (they are zoned, and tetrahedrite persists at depths in the Julcani and Castrovirreyna districts.

HYDROTHERMAL SYSTEMS RELATED TO A PALEOGENE CALDERA COMPLEX IN NORTHERN CHILE; EL GUANACO, CACHINAL DE LA SIERRA AND EL SOLDADO MINING DISTRICTS, ANTOFAGASTA REGION

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The epithermal precious metal deposits El Guanaco (Au, Cu), Cachinal de la Sierra (Ag) and El Soldado (Ag) are aligned along 69°32'W for a distance of 27 km between 24°52.1' and 25°06.5'S. They are genetically related to a Paleocene-Eocene volcanic arc that formed after a major reorganizing tectonic phase in middle Cretaceous (Subhercynian) time, as a first intracontinental arc after a fore-arc, arc, back-arc system of Late Triassic to Early Cretaceous time. The Paleogene volcanic rocks are subalkaline, ranging in composition from basalts to rhyolites, but with andesites and dacites predominant. Eroded eruptive centers showing volcanic necks or subvolcanic bodies with radial dikes have been recognized in this unit. A two-resurgent caldera model is proposed as the source of the volcanic sequence that crops out in the area between El Soldado and El Guanaco districts. This model is supported by detailed geologic mapping, by petrographic studies, and by K-Ar dating of 26 mineral concentrates of hydrothermally altered and unaltered volcanic rocks of the area.

The El Guanaco, Cachinal de La Sierra, and El Soldado deposits are in rocks of the caldera complex and were formed by hydrothermal systems related to the final phase of the caldera evolution. El Soldado, in the northern part of the area, consists of veins along faults striking N15°W. Silver and minor amounts of gold have been mined from 0.5-3.0 m wide and 600 m long quartz veins containing argentiferous galena, sphalerite, chalcopyrite, cerusite, proustite, argentite, pearceite, calcite, siderite, native gold, and copper oxides. The Cachinal de La Sierra deposit, to the south, consists of at least 14 veins having vertical ore shoots in a zone 20 m wide and 200 m long, which extends to a depth of 120 m. Hydrothermal alteration is