Porphyry Copper Deposits of Southern Central America

CARL E. NELSON

Consultant, Boulder, Colorado

ABSTRACT

Porphyry copper deposits in southern Central America are associated with plutons which range in composition from quartz diorite to quartz monzonite. These plutons intrude a chemically primitive intraoceanic island arc composed of low-potassium tholeiites. Maturation of the arc during Miocene and Pliocene time is marked by a shift to calc-alkaline volcanism.

Extension across the entire northern margin of South America began roughly 9 million years ago as the Caribbean plate pushed northward away from South America. The change from compressional to extensional tectonics is marked by alkalic magmas of Pliocene and younger age which rose along the margins of the Nicaraguan depression. High-potassium to shoshonitic volcanism continues today in the Central Valley of Costa Rica. Several of the younger porphyry systems such as Cerro Colorado coincide spatially with alkalic volcanic centers.

Gold is associated with all of the porphyry copper deposits discovered to date. Gold forms a distal halo around copper at Cerro Colorado, overlaps the copper deposit at Petaquilla, and appears to coincide with copper mineralization at Cerro Chorcha. Other gold-bearing porphyry systems in Panama include Rio Pito and Cana. Although no porphyry deposits are currently in production, exploration efforts are encouraged by co-product gold and the large size of discoveries made to date. Cerro Colorado and Petaquilla each have a geologic resource in excess of a billion tonnes.

REGIONAL GEOLOGY OF SOUTHERN CENTRAL AMERICA

The oldest rocks in southern Central America are ultramafic fragments of Jurassic to Early Cretaceous sea floor deposited along a mid-ocean rift as North and South America drifted apart. These rocks are exposed in eastern Panama and on peninsulas accreted to the west coast of the isthmus (fig. 1).

Figure 1. Porphyry copper and epithermal gold prospects of Southern Central America. Shaded area shows the distribution of chemically primitive island-arc volcanic rocks. Epithermal gold prospects are shown as open circles. Porphyry copper prospects are shown as dotted circles. Porphyry copper deposits include Nari (1), Sukut (2), Cerro Chorcha (3), Cerro Colorado (4), Cerro Quema (5), Petaquilla (6), Cerro Azul (7), Rio Pito (8), and Cana (9).
Intracratonie island-arc volcanic rocks of Late Cretaceous to Oligocene age overlie oceanic crust and were probably emplaced above an easterly facing subduction zone off the west coast of the Americas. Rock types include low-potassium tholeiitic basalts and basaltic andesites (Kussmaul and others, in press). Similar, early island-arc volcanic rocks host the Pueblo Viejo Deposit in the Dominican Republic (570 tonnes of gold)

The chemically primitive intracratonic volcanic basement is overlain by a calc-alkaline volcanic arc. Widespread calc-alkaline volcanism of Miocene and younger age culminated during Pleistocene time with the formation of strato-volcanoes and the emplacement of ignimbrites (Alvarado and others, in press).

Regional, chlorite-carbonate alteration, which is probably the result of interaction with sea-water, affects both tholeiitic and cal-alkaline volcanic rocks; most than approximatly 2 million years. The contact with overlying unaltered volcanic rocks is marked by an unconformity. Maar craters surrounded by fragmental pyroclastic deposits are intermittently exposed along the unconformity. Fragmental pyroclastic rocks (tuff breccias) and associated carbonaceous sediments host epithermal precious metal deposits such as the Remance and Santa Rosa Deposits of Panama. The maar craters, shallow-water sediments, and absence of chlorite-carbonate alteration in overlying volcanic rocks suggest that this unconformity marks the emergence of the present-day island arc from the ocean.

Alkaline rocks are more widely distributed than was previously recognized. Regional maps show a few isolated exposures of rift-related alkaline volcanic rocks along the Caribbean coast of Costa Rica. However, alkaline volcanic rocks with modal analcime are reported from the Aguacate Formation at La Garita (Alvarado and others, 1988, and similar rocks have been observed by the author as far west as Cerro Cabuya!. Alkaline volcanic rocks are also present within the lithologically similar and probably coeval Canazas Formation of Panama. Trachyandesites overlie porphyry copper mineralization at Cerro Colorado, and analcime-bearing volcanic plugs have been reported from Cerro Cristal. These young (less than 5 million years old) alkaline magmas appear to follow the margins of the Nicaraguan depression, an apical rift developed over the subducting Pacific plate. Alkaline volcanism continues today in the Central Valley of Costa Rica. Pliocene and younger strato-volcanoes are composed of potassium-rich andesites (adakites) to shoshonites. Zeitina de Boer and others (1991) have attributed the magmas associated with these volcanoes to melting of subducted lithosphere warmed by the Galapagos Plume.

Compressional tectonism dominated southern Central America from Late Cretaceous through Middle Miocene time. About 9 million years ago compression gave way to extension across the entire northern margin of South America. Currently Panama and southern Costa Rica are pushing northward (Mann and Corrigan, 1990). Left-lateral strike-slip motion along normal faults which border the Nicaraguan depression can be documented as far north as central Honduras. These faults represent an important control on porphyry copper and epithermal gold mineralization throughout Central America.

EXPLORATION HISTORY

Alcoa explored for both bauxite and copper in Costa Rica during the early 1970s, but withdrew from the country after losing a political battle over the development of bauxite deposits in the San Isidro area. Cities Service and Mapco expanded Alcoa’s sampling program during the late 1970s but withdrew from Costa Rica in the mid 1980s because of falling copper prices and a burgeoning national park system.

Other groups active in southern Central America during the 1960s and 1970s included Canadian Javelin, St. Joe Minerals, ASARCO, Kennecott, TexasGulf, RTZ, the United Nations Development Program, the United Nations Revolving Fund, and a consortium of Japanese companies. Although several properties (including Rio Pito and Petaquilla in Panama) were drill tested, copper concessions other than Cerro Colorado were abandoned during the 1980s. Interest began to pick up again in 1990, and most of the known porphyry copper deposits are again under concession.

REGIONAL STREAM SEDIMENT SURVEYS

Costa Rica

Stream sediment surveys in Costa Rica began with a series of United Nations programs which targeted porphyry copper deposits in the early 1970s. These surveys covered the Nicoya Peninsula, the Santa Elena Peninsula, and part of the Talamanca region. None of the anomalies were drill tested.

Other stream sediment surveys include several student theses, a small study by the British Geological Survey, a 1987 survey conducted by Los Alamos Laboratories, and a 1989 survey conducted by the Maritime Energy Agency. The survey by Los Alamos is the largest and most comprehensive conducted in Costa Rica to date. It covers nearly half of the country at a sample density of one per 15 square kilometers and provides digitized data for 50 elements.

Privately-funded stream sediment surveys by Alcoa, Cities Service, and Mapco during the late 1970s and early 1980s focused on porphyry copper targets in the Talamanca region. More than 5,000 samples were collected and six new porphyry systems were identified, but only the Nari anomaly was drill tested.

Costa Rica has a total area of 51,200 square kilometers. Roughly 70 percent of the country has been sampled at least once. Table 1 provides a summary of the stream sediment surveys conducted to date.

Panama

The United Nations sponsored stream sediment surveys in Panama beginning in 1967 and continuing through the 1970s. These surveys targeted porphyry copper mineralization and resulted in the discovery of the Rio Pito and Petaquilla Deposits.

Since the 1960s a number of additional surveys have been conducted with increasing emphasis on precious metals. The most comprehensive is the Mineral Inventory conducted from 1988 to 1990 by Swedish Geological International. The Swedish survey covers much of the area not reached by the United Nations and includes precious as well as base metals.

A total of 50,197 square kilometers (two thirds of the country) has been sampled at least once. A summary of the stream sediment surveys completed to date is provided in table 2.
PORPHYRY COPPER DEPOSITS

The text which follows describes porphyry copper deposits of Costa Rica and Panama. Undrilled prospects are not included. Geologic maps are based on the best available information, but field reviews indicate that rock units have occasionally been confused with alteration types. The maps and the information provided on grade and tonnage should be considered preliminary.

Locations of porphyry copper deposits and prospects are plotted with epithermal gold deposits and prospects on figure 1. Table 3 provides available age dates.

Nari, Costa Rica

The Nari or Matama II Porphyry Prospect was discovered by INCO during a stream sediment reconnaissance program undertaken in the early 1970s. Alcoa purchased INCO's interest in the property and drilled 10 holes (3,200 meters) in 1974. Alcoa's main interest was bauxite, and the company withdrew from Costa Rica when the Legislative Assembly failed to approve an exploitation contract for aluminum in the San Isidro de General area. Cities Service worked in the Nari area in 1978 but closed its exploration division that same year. Mapco acquired all Cities Service properties in Costa Rica in 1979 and continued regional stream sediment work, geologic mapping, and sampling.

Country rocks in the Nari area include a calcareous clastic sedimentary sequence which is unconformably overlain by andesitic lapilli tuffs and flows. These units are cut by a north-south fault which is intruded by small quartz diorite porphyry plugs. Based on an aeromagnetic survey, the plugs appear to be part of a larger buried stock. MacKevett (1980) has divided the intrusive rocks into four units: Quartz diorite and quartz-diorite porphyry with equigranular groundmasses are cut by dacite and andesite porphyries with finer grained groundmasses.

Potassic alteration (potassium feldspar, biotite, quartz, pyrite, and sericite) covers an area of 0.7 square kilometer and is centered on a quartz diorite intrusion. Phyllic alteration surrounds the potassic core and is characterized by quartz-pyrite-sericite. An outer propylitic alteration zone is marked by quartz, calcite, epidote, actinolite, prehnite, zeolite, gypsum, pyrite, hematite, and magnetite. A large pyrite halo extends over a minimum area of 3 square kilometers.
Table 2. Results of stream sediment surveys of Panama.

<table>
<thead>
<tr>
<th>Program</th>
<th>Location</th>
<th>Area</th>
<th>Number of stream sed samples</th>
<th>Density samples per km²</th>
<th>Elements analyzed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mineral Inventory</td>
<td>Azuero Peninsula</td>
<td>17,000 km²</td>
<td>5,750</td>
<td>0.34</td>
<td>Cu, Pb, Zn, Mo, Cu, Co, Mn</td>
</tr>
<tr>
<td>Phase 1 (UNDP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anon, 1969</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mineral Inventory</td>
<td>A - Bocas del Toro</td>
<td>3,950 km²</td>
<td>1,633</td>
<td>0.41</td>
<td>Cu, Pb, Zn, Mo, Cu, Co, Mn</td>
</tr>
<tr>
<td>Phase 2 (UNDP)</td>
<td>B - Maje</td>
<td>2,800 km²</td>
<td>1,477</td>
<td>0.49</td>
<td>some Au, Ag, As, Mn</td>
</tr>
<tr>
<td>Anon, 1972</td>
<td>C - San Blas, Darien</td>
<td>3,850 km²</td>
<td>1,807</td>
<td>0.47</td>
<td>a few Ni, Co</td>
</tr>
<tr>
<td></td>
<td>D - Pierre</td>
<td>4,800 km²</td>
<td>2,200</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>15,400 km²</td>
<td>7,203</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Mineral Inventory</td>
<td>Sona Peninsula</td>
<td>1,542 km²</td>
<td>511</td>
<td></td>
<td>Cu, Pb, Zn, Mo, Cu, Co, Mn</td>
</tr>
<tr>
<td>Phase 3 (DGRM)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metti and Recchi, 1972</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dirección General</td>
<td>Southern Belt</td>
<td>1,649 km²</td>
<td>1,678</td>
<td>1.02</td>
<td>Pb, As in seds, soils</td>
</tr>
<tr>
<td>Recursos Minerales</td>
<td>Northern Belt</td>
<td>188 km²</td>
<td>410</td>
<td>2.18</td>
<td>Zn in soils</td>
</tr>
<tr>
<td>Anon, 1981</td>
<td>Colon</td>
<td>80 km²</td>
<td>671</td>
<td>8.38</td>
<td>Cu in seds</td>
</tr>
<tr>
<td></td>
<td>Eastern Panama</td>
<td>135 km²</td>
<td>524</td>
<td>3.89</td>
<td>Au, Ag in rocks only</td>
</tr>
<tr>
<td></td>
<td>Darien</td>
<td>40 km²</td>
<td>425</td>
<td>10.63</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>2,053 km²</td>
<td>1,202</td>
<td>0.59</td>
<td>rocks: Cu, Zn, Mn, Ni, Co</td>
</tr>
<tr>
<td>Dirección General</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recursos Minerales</td>
<td>Southern Belt</td>
<td>1,649 km²</td>
<td>1,678</td>
<td>1.02</td>
<td>Pb, As in seds, soils</td>
</tr>
<tr>
<td>Anon, 1981</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wiesemann, 1981</td>
<td>Cerro Colorado</td>
<td>750 km²</td>
<td>324</td>
<td>0.43</td>
<td>Cu, Pb, Zn, Mo, Cu, As, As plus Mn</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caeeres and Sharp, 1982</td>
<td>Rio Sagui</td>
<td>25 km²</td>
<td>81</td>
<td>3.24</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dirección General</td>
<td>Rio Tabasara</td>
<td>526 km²</td>
<td>229</td>
<td>0.44</td>
<td>Au, Ag in seds, rocks</td>
</tr>
<tr>
<td>Recursos Minerales</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anon, 1982</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IAEA Radioactive</td>
<td>Veraguas Province</td>
<td>760 km²</td>
<td>88</td>
<td>0.12</td>
<td>Cu, Pb, Zn, Mo, Cu, As, Mn, U</td>
</tr>
<tr>
<td>Minerals (Gamba, 1984)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swedish Geological</td>
<td>West Area</td>
<td>7,550 km²</td>
<td>387</td>
<td>0.05</td>
<td>Cu, Pb, Zn, Co, Ni, Cr, Mn</td>
</tr>
<tr>
<td>Mineral Inventory</td>
<td>Central Area</td>
<td>6,149 km²</td>
<td>499</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>(1988-1990)</td>
<td>East Area</td>
<td>1,925 km²</td>
<td>102</td>
<td>0.05</td>
<td>Au, As</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>15,624 km²</td>
<td>988</td>
<td>0.06</td>
<td>9 major oxides</td>
</tr>
</tbody>
</table>

Table 3. Porphyry copper deposits of Southern Central America.

<table>
<thead>
<tr>
<th>Copper-gold porphyry</th>
<th>Age of intrusion in Ma</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Azuero (Quema ?)</td>
<td>64.9 ± 1.3 on hornblende</td>
<td>Kesler and others, 1977</td>
</tr>
<tr>
<td></td>
<td>52.6 ± 0.6 on feldspar</td>
<td>Kesler and others, 1977</td>
</tr>
<tr>
<td></td>
<td>69 ± 10</td>
<td>Kesler and others, 1977</td>
</tr>
<tr>
<td></td>
<td>53 ± 3 on feldspar</td>
<td>Kesler and others, 1977</td>
</tr>
<tr>
<td>Cerro Azul</td>
<td>61.6 ± 0.5 on hornblende</td>
<td>Kesler and others, 1977</td>
</tr>
<tr>
<td></td>
<td>51.1 ± 0.6 on feldspar</td>
<td>Kesler and others, 1977</td>
</tr>
<tr>
<td>Rio Pito</td>
<td>48.5 ± 0.5 on hornblende</td>
<td>Kesler and others, 1977</td>
</tr>
<tr>
<td></td>
<td>49.2 ± 0.6 on feldspar</td>
<td>Kesler and others, 1977</td>
</tr>
<tr>
<td>Petaquilla</td>
<td>32.6 ± 2.0 on hornblende</td>
<td>Kesler and others, 1977</td>
</tr>
<tr>
<td></td>
<td>36.4 ± 2.1 on hornblende</td>
<td>Kesler and others, 1977</td>
</tr>
<tr>
<td></td>
<td>29.0 ± 0.4 on feldspar</td>
<td>Kesler and others, 1977</td>
</tr>
<tr>
<td>Cerro Colorado</td>
<td>5.9 ± 0.1 on biotite</td>
<td>Clark and others, 1977</td>
</tr>
<tr>
<td></td>
<td>3.3 ± 0.1 on biotite</td>
<td>Kesler and others, 1977</td>
</tr>
<tr>
<td></td>
<td>7.2 ± 1.6 on hornblende</td>
<td>Kesler and others, 1977</td>
</tr>
</tbody>
</table>

The best surface exposure is located along a northwest-striking fault zone and contains a 250-meter section of 0.27 percent copper with a central 30-meter zone of 0.6 percent copper. The best drill intercept contains 100 meters of 0.45 percent copper. Preliminary estimates based on drill-hole data suggest the deposit may contain 5 million tonnes of 0.3 percent copper plus 6 to 8 million tonnes of 0.1 to 0.3 percent copper. MacKevett (1980) speculated that Nari may be as large as 100 million tonnes, and Alcoa put the possible size at 200 million tonnes of 0.2 to 0.3 percent copper and 100 ppm molybdenum.

Chalcopyrite with lesser bornite and molybdenite are the main ore minerals. Minor chalcocite, chrysocolla, and malachite are observed in surface exposures. Copper mineralization is strongest in the central phyllite zone but is also present in rocks that have undergone phyllic alteration.

**Sukut, Costa Rica**

The Sukut prospect is a porphyry copper-gold system hosted
Figure 2. Geologic map of Cerro Colorado, Panama. Andesitic country rocks are unshaded. Diorite pluton is shown with a dash pattern. Granodiorite plutons are shown with a cross pattern. Limit of altered and mineralized porphyries is shown as a dash-dot line. Younger trachyandesite flows are shown with a check pattern. Modified from Linn and others (1981).

by intermediate volcanic and minor volcanogenic sedimentary rocks. Alteration is zoned from a core of advanced argillic alteration (quartz-pyrite-alumite-kaolinite) outward through phyllic and propylitic envelopes to unaltered rocks. Copper Range drilled four holes in 1975 (total: 2,000 meters) into the advanced argillic core of the system. Drill intercepts were generally under 0.2 percent copper, and the property was dropped.

Gold occurs with a complex sulfide suite in the phyllic alteration zone surrounding the copper-rich core. No drill holes have targeted gold. However, gold mineralization at Sukut has been known since 1898 and was the subject of a 1959 report by Henry Juchem. Fischer-Watt resampled many of Juchem’s sites during the mid-1980s and obtained up to 7.7 ppm gold over a 10-meter interval.

Peripheral gold, copper, silver, and zinc mineralization are controlled by two northwest-striking fracture zones. These frac-
ture zones contain anastomosing veins of quartz and barite up to 50 centimeters across. Sulfide content is high (5 to 30 percent) and consists of sphalerite, galena, chalcoite, pyrite, chalcoprite, and bornite.

Cerro Colorado, Panama

Introduction. The Cerro Colorado Porphyry Copper Deposit contains 1.3 billion tonnes of 0.76 percent copper, 0.010 percent molybdenum, 5.1 ppm silver, and 0.08 ppm gold. If cutoff grade is reduced from 0.4 to 0.2 percent copper, reserves increase to 2.2 billion tonnes. Over 220 holes have been drilled on a 150-meter grid for a total of 56,000 meters.

Literally hundreds of reports have been written about Cerro Colorado. Feasibility studies include those by Canadian Javelin in 1974, Texas Gulf in 1978, Bechtel for RTZ in 1981, Fluor for RTZ in 1982, RTZ in 1984, Rio Tinto Technical Services on a dump leach operation in 1986, and Freeport on the enrichment blanket in 1989. All feasibility studies have concluded that a conventional open pit operation with or without a smelter is uneconomic even at a mining rate of 100,000 tons per day. In 1978 capital costs were estimated at one billion dollars and operating costs at 150 million dollars annually to produce 187,000 tons of blister copper with byproduct silver and molybdenum.

Geology. Cerro Colorado is located by the Rio Escopeta Granodiorite Pluton which has been dated at 5.9 million years by Clark and others (1977). This composite pluton consists of an older equigranular phase and a younger porphyritic phase. Both intrude a section of andesite flows and fossiliferous volcaniclastic sediments dated at 29.9 million years (Clark and others, 1977). A geologic map is provided in figure 2. Propylitic alteration (epidote-calcite-chlorite-pyrite) affects the andesites and to a lesser extent the granodiorite. Phyllic alteration (quartz-sericite-pyrite) in the immediate vicinity of the deposit is locally referred to as latite porphyry (weak phyllic alteration) and feldspar porphyry (strong phyllic alteration with remnant feldspar phenocrysts replaced by sericite). Raynolds (1983) has suggested that early feldspathic alteration has been destroyed by phyllic alteration. Anhydrite is present as a minor component of the phyllic assemblage at depth.

Mineralogy consists of chalcopyrite, molybdenite, and pyrite as small disseminated grains in the latite porphyry (weak phyllic assemblage) and as larger grains in the feldspar porphyry (strong phyllic assemblage). Raynolds (1983) has distinguished five episodes of veining associated with hypogene mineralization: Barren quartz veins begin the paragenesis and are followed by quartz-chalcopyrite-pyrite, quartz-sericite, quartz-sericite-sulfide, and massive sulfide veins. Homogenization temperatures range from 250 to 450°C. Two episodes of hypogene sulfate and carbonate veins postdate mineralization.

The deposit is cut by post-mineralization dikes of rhyolite and rhyodacite. Biotite from the post-mineralization dikes has been dated at 4.2 million years (Raynolds, 1983). Unaltered trachyandesite flows overlie the deposit and have been dated at 2.5 million years (Clark and others, 1977).

Supergene Reserve. Through Empresa de Cobre S.A., the government of Panama is currently promoting mining of the supergene enrichment blanket and recovery of copper using a solvent extraction-electrowinning process. Estimates of the supergene reserve include 70 million tonnes of 1.11 percent copper (Texas Gulf, 1974), 54 million tonnes of 0.85 percent copper (Galay, 1980), and 60 million tonnes of 0.88 percent copper (Burgos, 1992).

Secondary minerals in the enrichment blanket include roughly equal proportions of chalcopyrite and covellite plus minor digenite. Enrichment factors are reported to be 1.52 for copper, 1.02 for molybdenum, and 1.23 for silver. Conversion of primary sulfides is far from complete. Roughly 65 percent of the copper in the secondary blanket is present as secondary sulfides according to a report by Galay (1980); this result is in a secondary copper grade of 0.57 percent. The remaining 35 percent of the copper in the secondary blanket is present as chalcopyrite (0.31 percent primary copper grade). There is significant variability in the thickness of the secondary blanket (3 to 111 meters with an average of 35 meters) and in grade of the blanket (0.17 to 2.35 percent copper with an average of 0.88 percent).

Metallurgy. Metallurgical test work completed to date does not specifically address the supergene enrichment blanket, which accounts for less than five percent of the copper at Cerro Colorado. Solvent extraction-electrowinning recovery from hypogene ore at Cerro Colorado was the subject of a thorough study by RTZ (1987) and averages 45 percent (plus or minus 10 percent).

Some indication of the leaching characteristics of supergene mineralization can be gleaned from reports on shaker flask tests by BC Research for Bechtel Canada (1980) and RTZ (1983). Two samples of supergene copper mineralization leached over 90 percent (after grinding to minus 400 mesh). Two holes drilled outside the limits of the enrichment blanket also reported high recoveries (87 percent), but these holes were not included in the supergene reserve because no secondary copper minerals were recognized in the core. Two additional samples collected from below the enrichment blanket reported recoveries of 84 and 92 percent. High recoveries from outside the reported limits of the enrichment blanket suggest that substantial amounts of unrecorded secondary copper mineralization are present. Chalcopyrite at Cerro Colorado is unusually reactive, or that the supergene blanket at Cerro Colorado may be larger than has been reported.

The average gold grade of the Cerro Colorado Deposit is 0.08 ppm, too low to add significantly to the value of the hypogene deposit. The average gold grade increases with increasing copper cutoff grade from 0.07 ppm at a 0.2 percent copper cutoff to 0.09 ppm at a 0.6 percent copper cutoff, and bench values vary from 0.0 (no assay) to 0.32 ppm.

Property Status. Canadian Javelin (through Pavonia S.A., a wholly owned subsidiary) acquired a preliminary exploration concession at Cerro Colorado in 1970. Canadian Javelin was unable to reach an agreement with the government of Panama regarding development of the deposit and eventually sold its shares to Codemin, the Panamanian state-owned mining company. Texas Gulf began working at Cerro Colorado in 1976 and completed feasibility study in 1978. Texas Gulf transferred its interest to RTZ Corporation in 1980. RTZ wrote off its investment in Cerro Colorado in 1988.

During 1992 Empresa de Cobre, a joint venture of Codemin (51 percent) and RTZ (49 percent), was charged with privatization of Cerro Colorado. Empresa de Cobre negotiated the trans-
fer of RTZ's interest to Panama as a first step. This was concluded on May 12, 1993. Empresa de Cobre is currently active in the negotiation of terms for the development of Cerro Colorado.

Cerro Colorado Gold Halo. The Cerro Colorado porphyry system is surrounded by a ring of gold anomalies, several of which were discovered by Swedish Geological during a regional mineral evaluation completed in 1990 on behalf of the Dirección General de Recursos Minerales.

The highest grade gold anomaly in the area is located 15 kilometers south of Cerro Colorado at San Felix, where Swedish Geological reported gold values of up to 24 ppm.

San Felix is an area of propylitically altered andesite flows and fossiliferous volcaniclastic sediments. Sediments contain several percent disseminated pyrite and up to 10 percent pyrite in fine grained siliceous layers. These units dip shallowly to the east and are cut by a series of northeast-striking dikes and quartz veins. The dikes are propylitically altered and silicified; the quartz veins are sulfidic, carry gold locally, and can be traced over distances of up to 125 meters. Strong propylitic alteration and veining extends over an area of just under one square kilometer.

Cerro Chorcha, Panama

Cerro Chorcha is a gold-bearing porphyry copper prospect located in the Chiriqui Province of western Panama. The property was discovered by a regional stream sediment sampling program conducted by ASARCO. A very strong copper anomaly (over 500 ppm) in stream sediment samples defines a primary target area located two kilometers east of Cerro Chorcha.

Stream sediment samples with over 200 ppm copper have been obtained from an area of 8 to 12 square kilometers. A second and somewhat larger area in which stream sediment samples contain 200 to more than 500 ppm copper is located roughly 5 kilometers northwest of Cerro Chorcha.

Host rocks at Cerro Chorcha include a composite quartz diorite pluton and a series of northeast-striking quartz-feldspar porphyry dikes. A geologic map by MinAmerica (fig. 3) shows a zone of copper mineralization measuring 400 meters by 900 meters. ASARCO's channel samples within this zone generally contain more than 0.5 percent copper.

Copper mineralization is associated with a magnetite-bear-
ing quartz stockwork. Phyllic alteration is well developed and imparts a bluish-green tint to feldspar. Secondary potassium feldspar or biotite has not been observed.

Some drill pipe was transported to the site during the 1970s, but no holes were drilled because ASARCO was unable to reach an agreement regarding development of the property with the government of Panama. MinAmerica S.A., a Panamanian company, applied for a concession at Cerro Chorcha in 1992 and began a drill program in 1994.

**Petaquilla, Panama**

Petaquilla is a porphyry copper district in the Colon Province of Panama. It was discovered by the United Nations Development Program in 1967 and was the subject of follow-up studies in 1967, 1968, and 1969. Anomalous copper (over 200 ppm) and molybdenum have been found in the minus 80 mesh fraction of stream sediment samples at distances of up to 15 kilometers from the Petaquilla district; the highest values from 232 stream sediment samples were 2,000 ppm copper and 125 ppm molybdenum against a regional background of 95 ppm for copper and 3 ppm for molybdenum.

Soil sampling by the United Nations Development Program over a 28 square kilometer area revealed copper anomalies at Rio Medio, Botija, Botija Abajo, and Quebrada Vega. Ten core holes (1,960 meters total) plus 27 Winkie holes (839 meters total) were drilled in 1968 and 1969. The Petaquilla area is underlain by a composite stock of intermediate composition. A geologic map (fig. 4) shows stocks of granodiorite, quartz monzonite, and dacite porphyry. Kesler and others (1977) have reported an age of 36.4 million years from a hornblende separate from the Rio Botija area and an age of 29.0 million years from a feldspar separate from the same location.

Host rocks include propylitically altered flows of basalt and andesite. Dacite porphyry may be a product of hydrothermal alteration. Propylitic alteration (chlorite-epidote-calcite-pyrite) is well-developed in both the volcanic section and the intrusions. Phyllic alteration (quartz-sericite-pyrite) and minor potassic alteration (quartz-sericite-potassium feldspar-biotite) is also present.

Copper-molybdenum mineralization is confined to the phyllic and potassic zones, is sporadically distributed in surface exposures, and is mostly hypogene. Chalcopyrite, pyrite, and magnetite are accompanied by minor chalcocite, bornite, covellite, and molybdenite.

Petaquilla was drilled by a consortium of Japanese mining companies in the 1970s. Based on 50 drill holes, they reported a
combined reserve for the Petaquilla and nearby Botija Deposits of 543 million tons of 0.56 percent copper and 0.01 percent molybdenum sulfide. Adrian Resources acquired the property in 1991 and completed approximately 20,000 meters of drilling through the first quarter of 1994. In addition to Petaquilla and Botija, mineralization has been encountered at Botija Abajo, Vega, Brazo, and Palmilla. Adrian reports a geologic resource divided among the six deposits in excess of 1.2 billion tonnes at an average grade of 0.6 percent copper. In addition to copper, some of these deposits contain significant gold mineralization. Botija Abajo is reported to contain 30 million tonnes at 0.56 percent copper and 0.64 ppm gold.

Cerro Quema, Panama

Cerro Quema is located on the Azuero Peninsula. Rock units include a cyclic sequence of andesitic volcaniclastic sedimentary rocks with well-developed graded bedding and interbedded limestone and marls. This sedimentary section overlies sheared pillow basalts of presumed Cretaceous age.

Conformable with the sediments is a series of massively bedded andesite flows which grade upsection into dacite flows, tuff breccias, and tuffs. Dacites contain quartz phenocrysts with hexagonal bipyramids and large hornblende phenocrysts up to several centimeters in length. All of the volcanic units dip steeply (50 to 60°) to the south. A geologic map is provided in figure 5.

Gold-copper mineralization is hosted by the dacites. Ore is present in vent breccias composed of silicified lithic fragments in an altered tuffaceous matrix and in surrounding tuff rings. Alteration consists of silicification and advanced argillic alteration and covers an area 10 kilometers long in an east-west direction by 500 meters wide in a north-south direction. Regional propylitic alteration consists of chlorite, laumontite, carbonate, and hematite and may have involved interaction with seawater.
Cerro Quema shares vuggy silica and high pyrite content with high sulfur epithermal systems such as Paradise Peak and Pueblo Viejo. The Cerro Quema Deposit probably formed in an emerging island arc of early Tertiary age. Suggested origins of the deposit include porphyry copper, epithermal, and volcanicogenic massive sulfide.

A single point copper anomaly was generated by a regional stream sediment survey conducted by the United Nations Development Program (Anonymous, 1969). Follow-up sampling by Transworld Exploration S.A. in the 1980s returned values of up to 5.21 ppm gold in surface rock chips. In 1994 Cyprus reported a geologic resource of 10 million tonnes of 1.26 grams gold per tonne in a leached cap overlying hypogene copper mineralization (Torrey and Keenan, 1994).

**Rio Pito, Panama**

Rio Pito is located within a remote area of the Comarca San Blas, an autonomous province of Panama. Although the government of Panama reserves mineral rights within the Comarca, the area is administered by the Cuna Indians.

The Rio Pito Porphyry System was discovered during regional stream sediment sampling by the United Nations. Stream sediment samples from an area of 15 square kilometers returned...
values of up to 1,200 ppm copper, 28 ppm molybdenum, 540 ppm zinc, and 30 ppm lead. Copper-in-soil values vary from less than 300 to over 1,300 ppm over an area of at least 10 square kilometers. This was the strongest anomaly found in the Darien area and led to a three-year follow-up program of detailed rock and soil sampling and limited drilling by the United Nations Revolving Fund for Natural Resources Evaluation (UNRFNRE).

The Pi to Batholith is a composite granodiorite and quartz diorite batholith covering roughly 200 square kilometers near Panama’s border with Columbia (fig. 6). The batholith intrudes basalts and andesites of Upper Cretaceous(?) age. An embayment in the batholith hosts porphyry copper mineralization.

Kesler and others (1977) has reported dates of 48.5 million years on hornblende and 49.2 million years on feldspar collected from a quartz diorite porphyry. These rock types are in fault contact with a basaltic volcanic complex of Eocene age south of the northwest-striking San Blas Fault. Northerly-striking mineralized structures in the Rio Pito area are thought to have formed as a result of left-lateral strike slip motion in the San Blas Fault Zone.

Mineralization consists of pyrite, magnetite, chalcopyrite, and molybdenite with minor gold, silver, sphalerite, and galena as fracture fillings and veinlets. Gold and copper values in rock chips show a strong positive correlation.
The Palacios area (a gold-bearing breccia pipe) is reported to contain 297,300 tonnes at an average grade of 2.12 ppm gold and 4.04 ppm silver. This reserve estimate is based on trench sampling and analytical results from two UNRFNRE drill holes. Only one of the two core holes (total depth of 302 meters) was mineralized, and core recovery from the mineralized interval was in the neighborhood of 50 percent. The best intercept was 16 meters of 0.92 percent copper and 0.6 ppm gold. Copper-gold mineralization at Palacios is accompanied by quartz, sericite, and secondary biotite plus magnetite and pyrite. Mixed phyllic and potassic alteration grades outward into a propylitic assemblage (chlorite-epidote-calcite).

Five additional holes (total depth: 1,290 meters) were drilled in the quartz-sericite area. The best hypogene copper intercept was 49.5 meters of 0.21 percent; gold varies between 0.04 and 0.17 ppm. Secondary copper (chalocite) is present in a blanket that varies in thickness from 20 to 70 meters, but the average grade is under one percent copper. Gold in the secondary blanket varied between 0.33 and 0.67 ppm. Core from the Rio Pito drilling program has unfortunately been discarded.

Although the reserve estimate at Palacios is premature, work to date has defined a pipe-like mineralized body containing low grade (near 2 ppm) gold mineralization within a porphyry copper system which covers a minimum area of 5 square kilometers.

Cana, Panama

Cana is a bonanza gold district in the Oligocene Porphyry Belt of eastern Panama. Although abandoned since early in the Twentieth Century, it is still the largest gold deposit in Central America. High-grade gold mineralization is present in breccia pipes hosted by andesite and intruded by hornblende-feldspar porphyry dikes and stocks. There is widespread phyllic and local potassic alteration. A geologic map is provided in figure 7. In spite of occasional interruption by English pirates, the Spanish produced an estimated one million ounces of gold (30,000 kilograms) from 250,000 tonnes of ore during the period from 1665 to 1727. The English recovered an additional one million ounces from one million tonnes of ore during the period from 1887 to 1907. Attempts by the French to continue production from increasingly deep ore were unsuccessful, and the mine had passed into the hands of creditors by 1914.

The South or Espiritu Santo Breccia Pipe produced most of the gold that has been recovered from the Cana District. The pipe measures 25 meters in diameter and plunges steeply to the southwest. The English reached a depth of 270 meters and were producing an average grade of 50 ppm gold when the mine was closed by a combination of caving and flooding in 1907.

TexasGulf Sulfur drilled sixteen holes, mostly on San Jose Hill, during the 1970s. Although the TexasGulf target was a porphyry copper deposit, many of the drill holes were analyzed for gold. Freeport drilled forty core holes for gold, mostly at the North Mine and on San Jose Hill, during the mid-1980s. Freeport did not attempt to drill the Espiritu Santo Breccia Pipe, preferring to concentrate on the potential for near-surface high-grade ore at the North Mine.

Gold Fields of South Africa conducted a 1,200-hole soil augering program in 1992. Several gold-in-soil anomalies running in excess of one ppm that were defined served to tighten up soil anomalies previously identified by TexasGulf and Freeport.

An exploitation concession at Cana is held by Sociedad de Inversiones IXTAPA S.A.

CONCLUSIONS

In Costa Rica, porphyry systems of Miocene and younger age are spaced at an interval of 5 to 25 kilometers (average 15 km) along a northwest striking belt that measures 25 kilometers in width by 75 kilometers in length (fig. 1). This belt extends across the border into Panama and continues southeast through relatively unexplored country as far as the Azuero Peninsula, a distance of nearly 200 kilometers. Porphyry copper deposits in eastern Panama are hosted by intermediate plutons of Paleocene and Eocene age which were emplaced early in the evolution of an island arc.

Only a few of the porphyry systems in Panama and Costa Rica have been drill-tested. Cerro Colorado is the largest single deposit, containing 1.3 billion tonnes at 0.76 percent copper. Several porphyry deposits in the Petaquilla District may together contain over a billion tonnes of copper ore. Exploration efforts have focused on date to deposits which were discovered during the 1960s and 1970s by regional stream sediment programs. Renewed interest in copper since 1990 has led to a reexamination of these deposits. Grass roots exploration is also making a comeback as recognition spreads that new porphyry discoveries are likely to contain gold as well as copper.

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