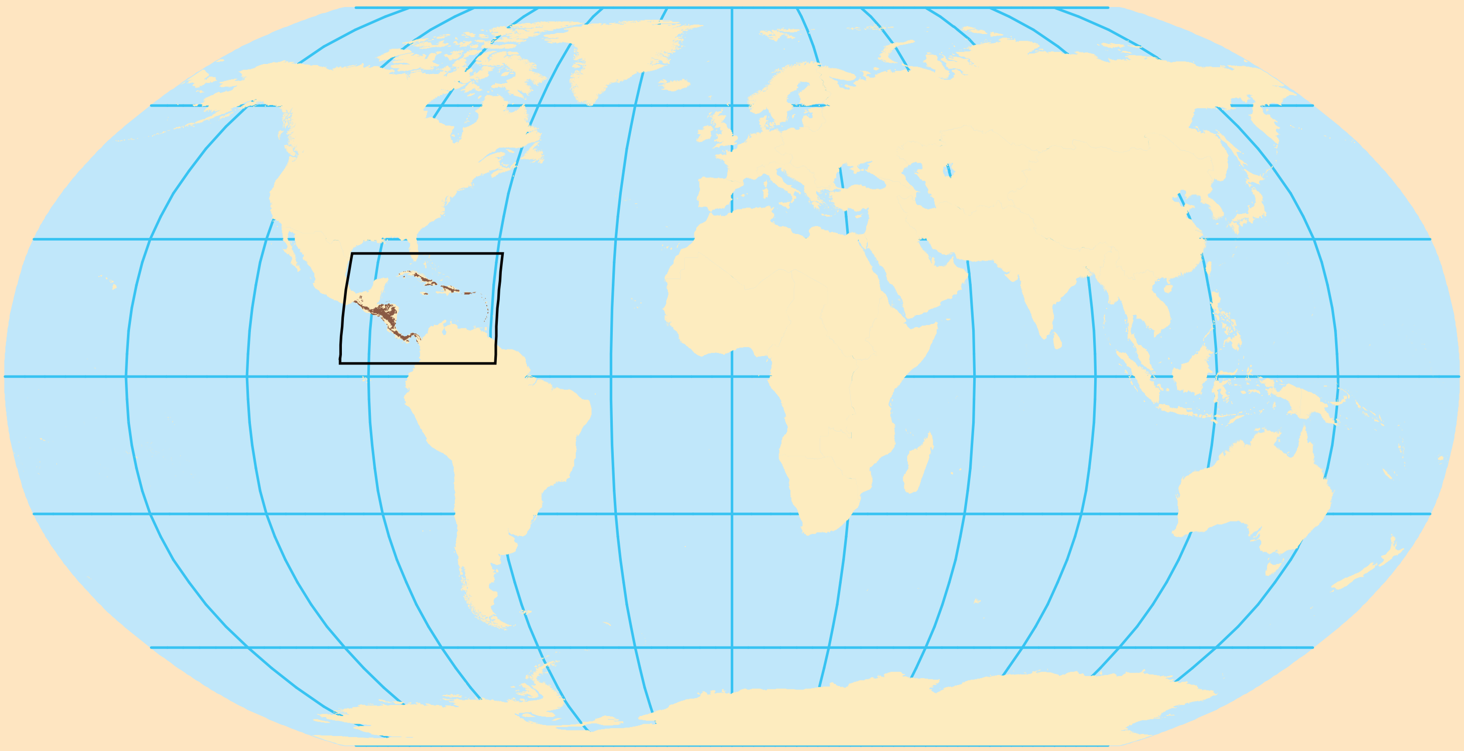
Global Mineral Resource Assessment

Porphyry Copper Assessment of Central America and the Caribbean Basin



Prepared in cooperation with the University of Arizona and Recursos del Caribe, S.A.

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Michael L. Zientek, Jane M. Hammarstrom, and Kathleen M. Johnson, editors

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By Floyd Gray, Jane M. Hammarstrom, Steve Ludington, Lukas Zürcher, Carl E. Nelson, Gilpin R. Robinson, Jr., Robert J. Miller, and Barry C. Moring

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U.S. Department of the Interior
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U.S. Geological Survey
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Acronyms and Abbreviations Used

GIS	geographic information system
g/t	grams per metric ton
kt	thousand metric tons
Ma	millions of years before present
Mt	million metric tons
t	metric ton (tonne) or megagram (Mg)
USGS	United States Geological Survey

Conversion Factors

Inch/Pound to SI	Multiply by	To obtain
Length		
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
Area		
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
Mass		
ounce, troy (troy oz)	31.103	gram (g)
ounce, troy (troy oz)	0.0000311	megagram (Mg)
ton, short (T) (2,000 lb)	0.9072	megagram (Mg)

SI to Inch/Pound	Multiply by	To obtain
Length		
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
Area		
hectare (ha)	2.471	acre
square hectometer (hm^2)	2.471	acre
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
Mass		
gram (g)	0.03215	ounce, troy (troy oz)
megagram (Mg)	1.102	ton, short (2,000 lb)
megagram (Mg)	0.9842	ton, long (2,240 lb)
Other conversions used in this report		
metric ton (t)	1	megagram (Mg)
troy ounce per short ton	34.2857	gram per metric ton (g/t)
percent	10,000	parts per million (ppm) or grams per metric ton (g/t)
percent metal	0.01 x ore tonnage, metric tons	metric tons of metal

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Porphyry Copper Assessment of Central America and the Caribbean Basin

By Floyd Gray[1], Jane M. Hammarstrom[1], Steve Ludington[1], Lukas Zürcher[2], Carl E. Nelson[3], Gilpin R. Robinson, Jr.[1], Robert J. Miller[1], and Barry C. Moring[1]

Abstract

Mineral resource assessments provide a synthesis of available information about distributions of mineral deposits in the Earth's crust. The U.S. Geological Survey prepared a probabilistic mineral resource assessment of undiscovered resources in porphyry copper deposits in Central America and the Caribbean Basin in collaboration with geoscientists from academia and the minerals industry. The purpose of the study was to (1) delineate permissive areas (tracts) for undiscovered porphyry copper deposits within 1 kilometer of the surface at a scale of 1:1,000,000; (2) provide a database of known porphyry copper deposits and significant prospects; (3) estimate numbers of undiscovered deposits within the permissive tracts; and (4) provide probabilistic estimates of amounts of copper, molybdenum, gold, and silver that could be contained in undiscovered deposits. The assessment was done using a three-part mineral resource assessment based on established mineral deposit models. Permissive tracts were delineated based primarily on distributions of mapped igneous rocks related to magmatic arcs that formed in tectonic settings associated with convergent plate margins. Five permissive tracts were delineated: the Early Cretaceous through Eocene Santiago tract, the Late Cretaceous through Oligocene Chortis tract, the Paleocene through Oligocene Darién tract, the Miocene and Pliocene Cocos tract, and the Eocene to Holocene Lesser Antilles tract. These tracts range in size from about 3,000 to about 204,000 square kilometers.

Probabilistic estimates of numbers of undiscovered deposits were made for all tracts. To estimate the number of undiscovered porphyry copper deposits, data on known mineral deposits, prospects, and occurrences were considered along with mapped alteration zones, local stream-sediment geochemistry, exploration history, descriptive deposit models, and grade and tonnage models.

Most porphyry copper exploration in Central America and the Caribbean Basin has focused on Panama and on the exposed Cretaceous to Eocene central Cordilleran arc that extends from Cuba and Jamaica through Haiti and the Dominican Republic to Puerto Rico and the Virgin Islands. Interest in gold has prompted exploration of historical precious-metal prospects and small mines, some of which may represent high-sulfidation epithermal systems or skarns overlying, or adjacent to, porphyry copper systems.

This assessment estimated a total mean of 37 undiscovered porphyry copper deposits within the assessed permissive tracts in Central America and the Caribbean Basin. This represents more than five times the seven known deposits. Predicted mean (arithmetic) resources that could be associated with these undiscovered deposits are about 130 million metric tons of copper and about 5,200 metric tons of gold, as well as byproduct molybdenum and silver. The reported identified resources for the seven known deposits total about 39 million metric tons of copper and about 930 metric tons of gold. The assessment area is estimated to contain nearly four times as much copper and six times as much gold in undiscovered porphyry copper deposits as has been identified to date.

Introduction

Minerals and mineral products have been important to commerce in Central America and the Caribbean Basin (fig. 1) since pre-Columbian times. The region contains a number of world-class mineral deposits, including at least seven porphyry copper deposits (table 1). Some areas are thought to have been a source of copper (Cu) and gold (Au) to prehistoric native populations. An example is the Pueblo Viejo epithermal gold deposit, which lies about 100 kilometers (km) northwest of Santo Domingo in the Dominican Republic (fig. 1). The gold deposit was made known to the Europeans in the 16th century and is being prepared for production today (Mueller and others, 2008). The first copper mines in the New World began operation about 1544 in Cuba and supplied metal to Spain throughout the Colonial period (Lawrence, 1910). In addition to gold and copper, the region produces nickel (Cuba) and bauxite (Jamaica; Bray, 2009). Nickel deposits in Cuba have produced 4–9 percent of world nickel annually for nearly 50 years; Cuba and the Dominican Republic contain about 8

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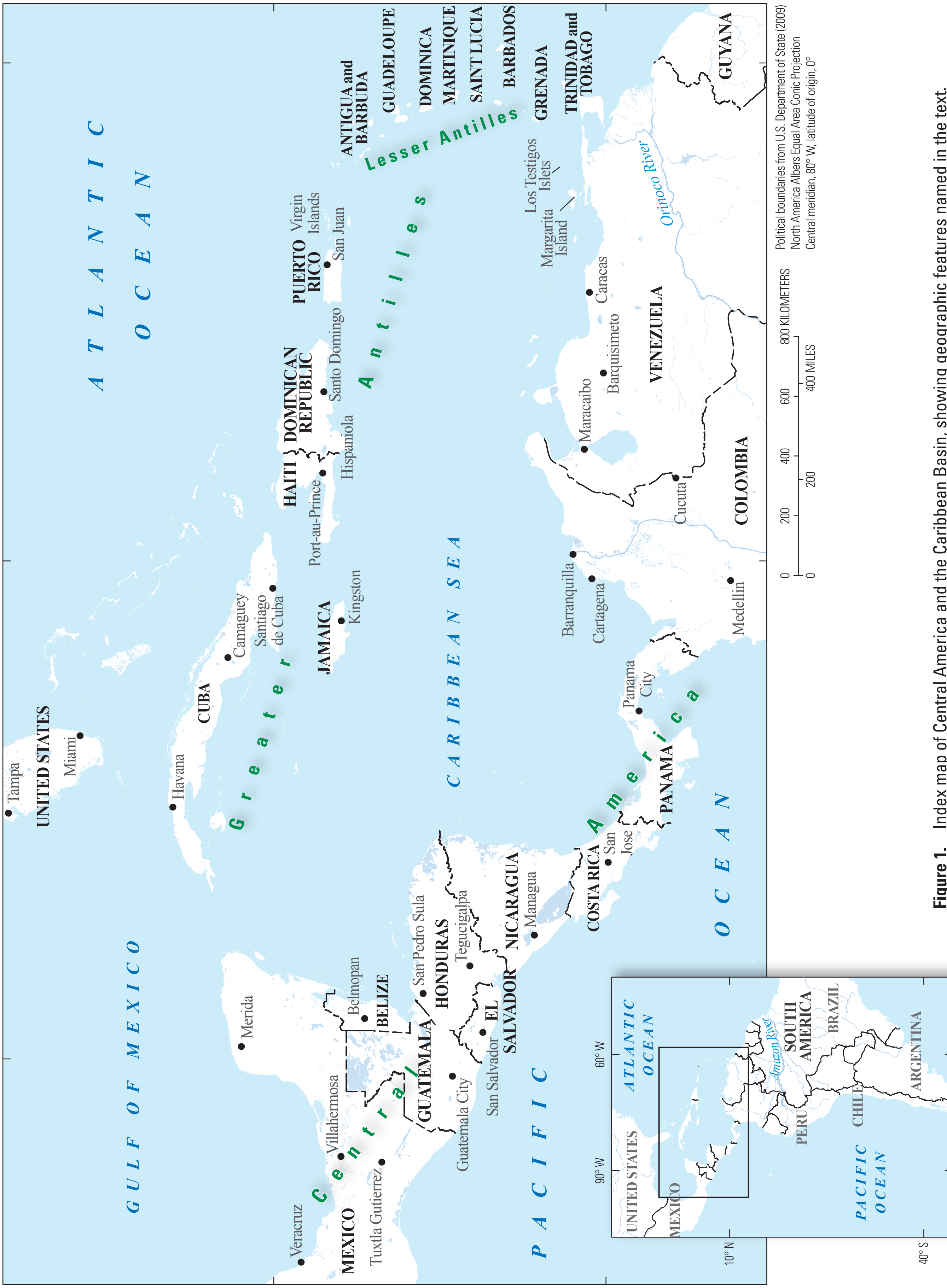

Figure 1. Index map of Central America and the Caribbean Basin, showing geographic features named in the text.

Table 1. Porphyry copper deposits in Central America and the Caribbean Basin.

[Ma, millions of years before present; Mt, million metric tons; %, percent; g/t, grams per metric ton; Cu, copper; Mo, molybdenum; Au, gold; Ag, silver; n.d., no data]

Tract	Tract name	Name	Country	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained Cu (Mt)
003pCu4001	Santiago	Arimao	Cuba	n.d.	88.8	0.27	n.d.	1	2	0.24
		Blondin-Douvray	Haiti	n.d.	327	0.44	n.d.	0.3	n.d.	1.4
		Río Viví	Puerto Rico	41	218	0.73	0.002	0.3	1	1.6
		Tanamá	Puerto Rico	42	126	0.64	0.005	0.38	1.7	0.81
003pCu4002	Darién	Cobre Panama	Panama	31.4	6,405	0.301	0.007	0.05	1.152	19.3
003pCu4004	Cocos	Cerro Chorcha	Panama	3.6	201.9	0.49	0.01	0.07	1.8	0.99
		Cerro Colorado	Panama	4.3	3,730	0.39	0.015	0.08	5.2	15

percent of world nickel reserves (Kesler, 1990; Mueller and others, 2008; Wacaster, 2008; U.S. Geological Survey, 2008; Redwood, 2009; Kuck, 2012). Jamaica provides 7–11 percent of the world's bauxite and contains about 10 percent of world reserves (U.S. Geological Survey, 2008).

Two large porphyry copper deposits are known in the region, both in Panama: Cerro Colorado, with nearly 15,000,000 metric tons (t) of copper, and Cobre Panama, with more than 19,000,000 t of copper. In addition, the region contains several smaller deposits in Cuba, Haiti, and Puerto Rico (table 1, fig. 2). These deposits remain undeveloped, although an Environmental and Social Impact Assessment for the development of Cobre Panama has been approved by the Panamanian government and development is going forward (Inmet Mining Corp., 2012).

The U.S. Geological Survey (USGS) collaborated with geologists from the University of Arizona and the minerals industry on a probabilistic mineral resource assessment of undiscovered resources in porphyry copper deposits in

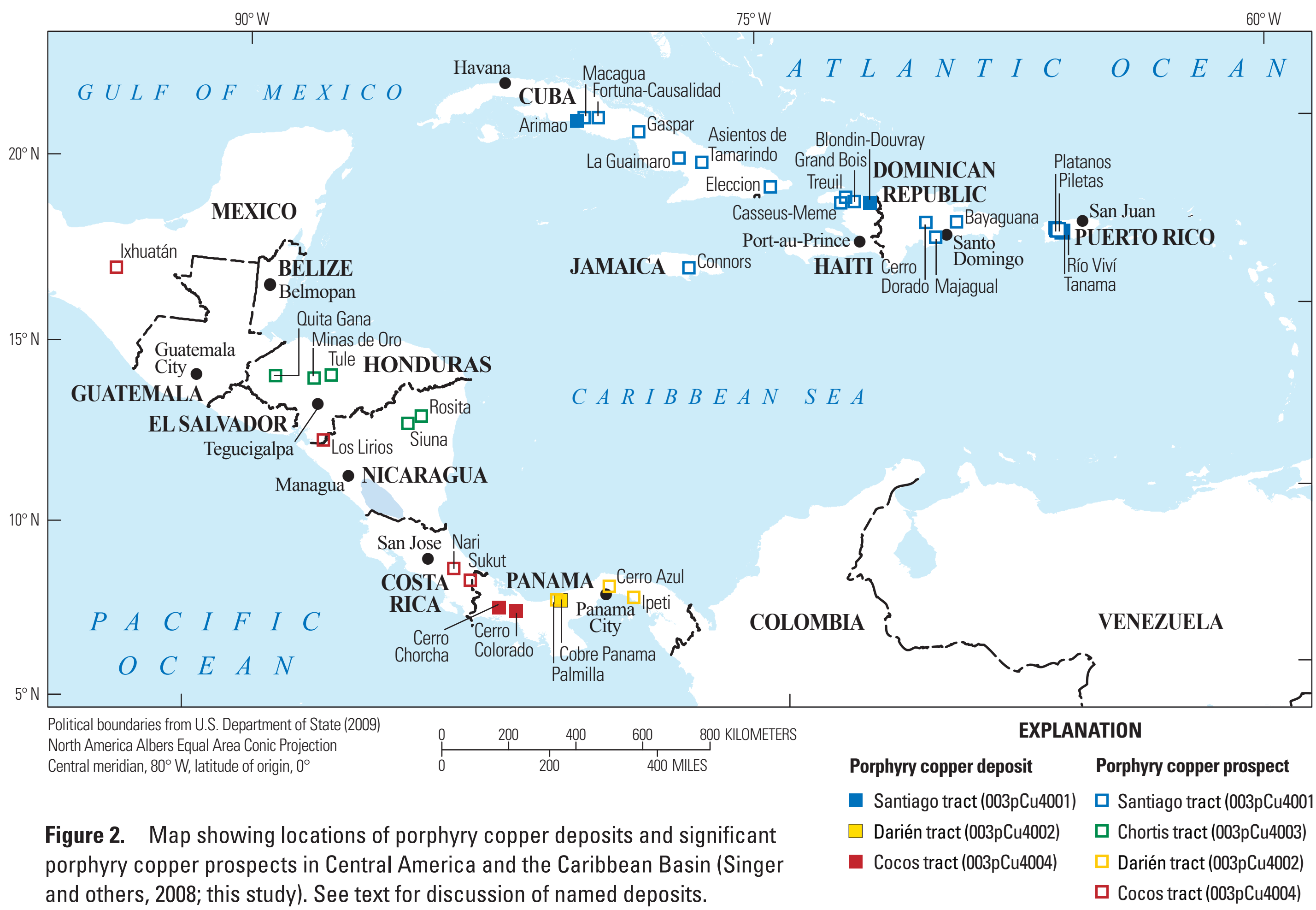

Figure 2. Map showing locations of porphyry copper deposits and significant porphyry copper prospects in Central America and the Caribbean Basin (Singer and others, 2008; this study). See text for discussion of named deposits.

Central America and the Caribbean Basin as part of a global mineral resource assessment (Briskey and others, 2001; Zientek, 2008). The purpose of the assessment was to (1) compile a database of known porphyry copper deposits and significant prospects, (2) delineate permissive areas (tracts) for undiscovered porphyry copper deposits at a scale of 1:1,000,000, (3) estimate numbers of undiscovered deposits within those permissive tracts, and (4) provide probabilistic estimates of amounts of copper (Cu), molybdenum (Mo), gold (Au), and silver (Ag) that could be contained in those undiscovered deposits.

The region is an area of active mineral exploration. This report reflects the state of exploration for base and precious metals associated with porphyry copper deposits as known to the authors in November 2011. Most recent exploration projects have focused on large concessions that were identified by gold showings associated with historical workings. Epithermal gold deposits, breccias, skarns, and (or) polymetallic veins are the initial targets of many exploration projects due to the current high price of gold, but porphyry copper systems may be associated with some precious-metal deposits and may be present in other parts of large concessions under study for precious metals.

This report includes an overview of the geology of each region, descriptions of known porphyry copper deposits, a description of the assessment process used in the study, and a summary of results, presented in tables and graphs. Appendixes A through E contain summary information for each tract including its location, the geologic feature assessed, the rationale for tract delineation, tables and descriptions of known deposits and significant prospects, exploration history, model selection, rationale for the estimates, assessment results, and references. The accompanying digital map files provide permissive tract outlines, assessment results, and data for deposits and prospects in a geographic information system (GIS) format (appendix F). Appendix G includes biographical information for the members of the assessment team.

Terminology

The terminology used in this report follows the definitions used in the 1998 USGS assessment of undiscovered deposits of gold, silver, copper, lead, and zinc in the United States (U.S. Geological Survey National Mineral Resource Assessment Team, 2000). This terminology is intended to represent standard definitions that reflect general usage by the minerals industry and the resource assessment community.

Mineral deposit—A mineral concentration of sufficient size and grade that it might, under the most favorable of circumstances, be considered to have potential for economic development.

Undiscovered mineral deposit—A mineral deposit believed to exist 1 km or less below the surface of the ground, or an incompletely explored mineral occurrence or prospect that could have sufficient size and grade to be classified as a deposit.

Mineral prospect—A mineral concentration that is being actively examined to determine whether a mineral deposit exists.

Mineral occurrence—A locality where a useful mineral or material is found.

Permissive tract—The surface projection of a volume of rock where the geology permits the existence of a mineral deposit of a specified type. The probability of deposits of the type being studied occurring outside the boundary is negligible.

Resource—A mineral concentration of sufficient size and grade, and in such form and amount, that economic extraction of a commodity from the concentration is currently or potentially feasible.

Identified resources—Resources whose location, grade, quality, and quantity are known or can be estimated from specific geologic evidence. For this report, identified resources are those in the porphyry copper deposits included in the grade and tonnage models used in the assessment. In addition, deposits that are not included in the models used for the assessment are considered to contain identified resources if they are characterized well enough by deposit type, grade, and tonnage to meet commonly used reporting guidelines, such as those established by the U.S. Securities and Exchange Commission or the Committee for Mineral Reserves International Reporting Standards (CRIRSCO)[4].

Report Format

This report begins with a discussion of the tectonic history of Central America and the Caribbean Basin, which describes the emplacement of magmatic rocks and the formation of porphyry copper deposits. The next section describes the nature and quality of the data that were gathered for the assessment, followed by a brief description of the exploration history of the area. Next, the assessment process, models, and methods used to delineate permissive tracts are described, followed by a brief description of the five permissive tracts. Finally, the probabilistic estimation process and results are discussed. More detailed descriptions and assessment results for the five permissive tracts (Santiago, Chortis, Darién, Cocos, and Lesser Antilles) evaluated in this report are presented in a standardized format in appendixes A through E of this report. The boundaries of the tracts and point locations of significant deposits and prospects are included in a GIS in Appendix F.

Considerations for Users of this Assessment

Ideally, assessments are done on a recurring basis, at a variety of scales, because available data change over time. This report represents a synthesis of information current as of November 2011. It is based on the descriptive and grade-tonnage information contained in published mineral deposit

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[4]Committee for Mineral Reserves International Reporting Standards (2006) (http://www.crirsco.com/welcome.asp).

models. Data in the grade and tonnage models represent the most reliable average grades available for each commodity of possible economic interest and are based on the total of production, reserves, and resources at the lowest cutoff grade for which data were available when the model was constructed.

The economic viability of any mineral deposit depends on a wide variety of factors, many of which vary with time, so care must be exercised when using the results of this assessment to answer questions that involve economics. Furthermore, these estimates are of numbers of deposits that are likely to exist, not necessarily those likely to be discovered (Singer, 2007b). Prospects, revealed by past or current exploration efforts, may become deposits through further drilling and characterization. These probable deposits are treated here as undiscovered deposits, albeit deposits with a high degree of certainty of existence.

The mineral industry explores for extensions of identified resources, as well as for greenfields projects in new exploration areas. Extensions of identified resources are not formally estimated in this assessment, although they are commonly a substantial part of newly discovered copper resources each year.

This assessment considers the potential for both exposed deposits and concealed deposits within 1 km of the surface. Very high-grade deposits may be exploited at greater depths; however, it is not common. Because of the expense of exploration for, and exploitation of, these deeper deposits, they may not be discovered in the near term. If they are discovered, the cost to mine deeply buried porphyry deposits may prohibit mining, depending on metal prices and technologic advancement in mining methods.

Permissive tracts are based on geology, irrespective of political boundaries. Therefore, tracts may cross country boundaries or include lands that already have been developed for other uses, or have been withdrawn from mineral development as protected areas. The tracts were constructed at a scale of 1:1,000,000 and are not intended for use at larger scales.

Tectonic Setting

Porphyry copper deposits typically form along convergent plate margins associated with subduction-related island arcs and continental arcs or less commonly in extensional back-arc or postsubduction settings (John and others, 2010; Richards, 2009). Deposits are associated with calc-alkaline to alkaline, oxidized, multiphase intrusive complexes. Many porphyry copper systems are associated with the root zones of stratovolcanoes. The Andes of South America is the classic province for continental arc magmatism (Kay and others, 1999; Richards and others, 2001). Magma associated with these deposits typically is hydrous, oxidized, rich in sulfur, and has likely undergone complex processes of differentiation and evolution at the crust-mantle boundary (Richards, 2003; John and others, 2010). Island arcs in the southwest Pacific Ocean are the archetypes of island arc magmatism (Garwin and others, 2005). Magma associated with island-arc porphyry copper deposits is similar to that associated with continental arcs, but diorite, quartz diorite, and other more mafic rocks are somewhat more abundant (Kesler and others, 1975).

The porphyry copper deposits in Central America and the Caribbean Region formed in both continental and island-arc geodynamic settings from the Cretaceous until the Late Cenozoic. The magmatic arcs that host these deposits are primarily found around the margins of the present-day Caribbean Plate and include: (1) the Cretaceous to Eocene Greater Antilles Arc; (2) Late Cretaceous to Early Tertiary Chortis magmatic zone; (3) the Paleocene to Oligocene Panamanian Arc; (4) the Oligocene to Pliocene Central American Arc; and (5) the composite Eocene to Holocene Lesser Antilles Arc (fig. 3). These arcs are made up primarily of calc-alkaline igneous rocks that formed as a result of the subduction of oceanic plates below different parts of the Caribbean Plate (Case and Holcombe, 1980; Case and others, 1984; Donnelly, 1989; Pindell, 1994). The Chortis magmatic zone is in the Chortis Block, an exotic piece of continental crust that was displaced from southwestern Mexico in the early Cenozoic and arrived at its present position through strike-slip faulting and rotation after magmatism ceased (Pindell and others, 2006).

The Caribbean Plate

The approximately 3,500,000-km^2 Caribbean Plate (fig. 3) has been influenced by interaction with the Farallon, Nazca, Cocos, and North and South American Plates since pre-Cretaceous time. The central (subsea) part of the Caribbean Plate is composed primarily of Cretaceous oceanic basalt of the Caribbean Large Igneous Province. The history of the plate is complex, and many details remain to be resolved, but there is general consensus that the plate originated in the Pacific Ocean, possibly above the Galapagos hot spot, at about 100–75 Ma and moved eastward to its present location between the North and South American Plates between the Late Cretaceous and late Eocene; a comprehensive synthesis is presented by Pindell and Kennan (2009). The Caribbean Plate is moving eastward today with respect to North and South America, and west-directed subduction beneath it is responsible for the modern Lesser Antilles Arc. Meanwhile, the Cocos Plate is moving northeastward with respect to the Caribbean Plate and its subduction below the Caribbean Plate is responsible for modern volcanism in the Central American Arc. The modern Mid-Cayman Spreading Center (fig. 3), which marks a rift in the Caribbean seafloor, is an approximately 100-km-long chain of volcanoes developed on an ultraslow (moving less than 20 millimeters (mm) per year) spreading ridge associated with faults that accommodate motion between the Caribbean and North American Plates (Thompson and others, 1980).

The deformed tectonostratigraphic terranes and corresponding magmatic arcs that surround the core of the Caribbean plate are the fundamental basis for delineation of the permissive tracts used for this assessment. The following sections describe the tectonic and geologic evolution of each of these areas.

Greater Antilles Arc

The major part of the Cretaceous through Eocene Greater Antilles Island Arc (Cuba and Hispaniola; fig. 3) was formed by west-southwest to southwest-directed oblique subduction along the northern Caribbean Plate boundary where oceanic crust was underthrusting the Caribbean Plate (Nagle, 1974; Kesler and others, 1975; Case and Holcombe, 1980; Pindell and Dewey, 1982; Sykes and others, 1982; Donnelly and others, 1990; Draper and others, 1994; Iturralde-Vinent, 1998; Mann, 1999). Parts of the eastern end of the arc may have originated as an island arc off the west coast of South America that was rafted north and east to its present position (Elston and Krushensky, 1983; Krushensky and Elston, 1983). In Eocene time, relative plate motions in the area changed; subduction and volcanism of the Greater Antilles Arc ceased along the northern margin of the Caribbean Plate and were replaced by a complex transform plate boundary (Bowin, 1975; Pindell and Dewey, 1982; Sykes and others, 1982; Mann and Burke, 1984).

Chortis Magmatic Zone

The Late Cretaceous to Tertiary igneous rocks of the Chortis Magmatic Zone are a combination of accreted island-arc rocks and continental-margin arc rocks—mainly diorite and tonalite plutons (Donnelly and others, 1990; Sundblad and others, 1991) and basaltic and andesitic volcanic rocks (McBirney and Williams, 1965; Weyl, 1980; Instituto Nicaragüense de Estudios Territoriales, 1995; Arengi and Hodgson, 2000). They formed along the southwestern coast of Mexico, in a position more than 1,000 km from their present location. The Chortis Block (fig. 4), into which these igneous rocks are emplaced, is a composite terrane that consists of Proterozoic and Paleozoic continental crust and Jurassic to Early Cretaceous intraoceanic island-arc rocks. The history of the Chortis Block has been considered fundamental to the understanding

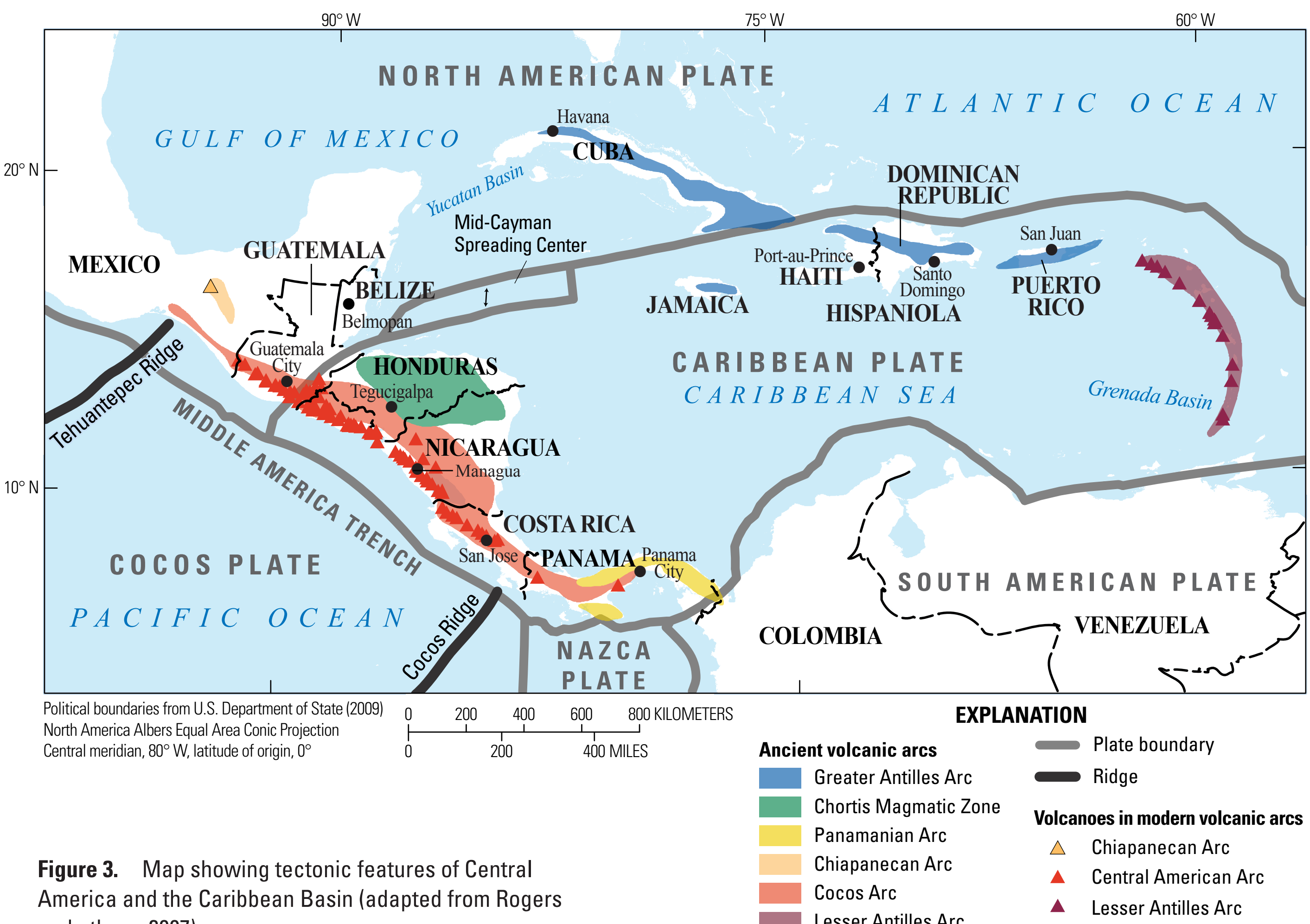

Figure 3. Map showing tectonic features of Central America and the Caribbean Basin (adapted from Rogers and others, 2007).

of Caribbean tectonics since the 1970s (Gose and Swartz, 1977; Pindell and Dewey, 1982; Dengo, 1985).

Most models proposed for the history of the Chortis Block include derivation from Mexico by large-scale strike-slip faulting (Gose and Swartz, 1977; Karig and others, 1978; Pindell and Dewey, 1982; Gose, 1985; Rosencrantz and others, 1988; Pindell and Barrett, 1990; Sedlock and others, 1993; Dickinson and Lawton, 2001; Pindell and others, 2006). Other models call for derivation from the Pacific (Keppie and Moran-Zenteno, 2005) or maintain that the block has remained in the same position relative to southern Mexico and the Caribbean since the Late Jurassic (James, 2006).

The model that best explains the tectonic history of the Chortis Block is that of Rogers and others (2007), which asserts that the Chortis Block was detached from its pre-middle Eocene position along the southwestern coast of Mexico where it was initially affected by oblique subduction of the Farallon Plate (Donnelly and others, 1990; Sundblad and others, 1991) and moved eastward by about 1,100 km of left-lateral strike-slip motion and about 30–40° of counter-clockwise rotation (fig. 4). The Motagua-Polochic fault forms the present boundary between the Chortis Block and North America.

Panamanian Arc

The Panamanian Arc (fig. 3) includes Paleocene to Miocene island arc-related calc-alkaline igneous rocks that were formed as the Nazca Plate was subducted northeastward

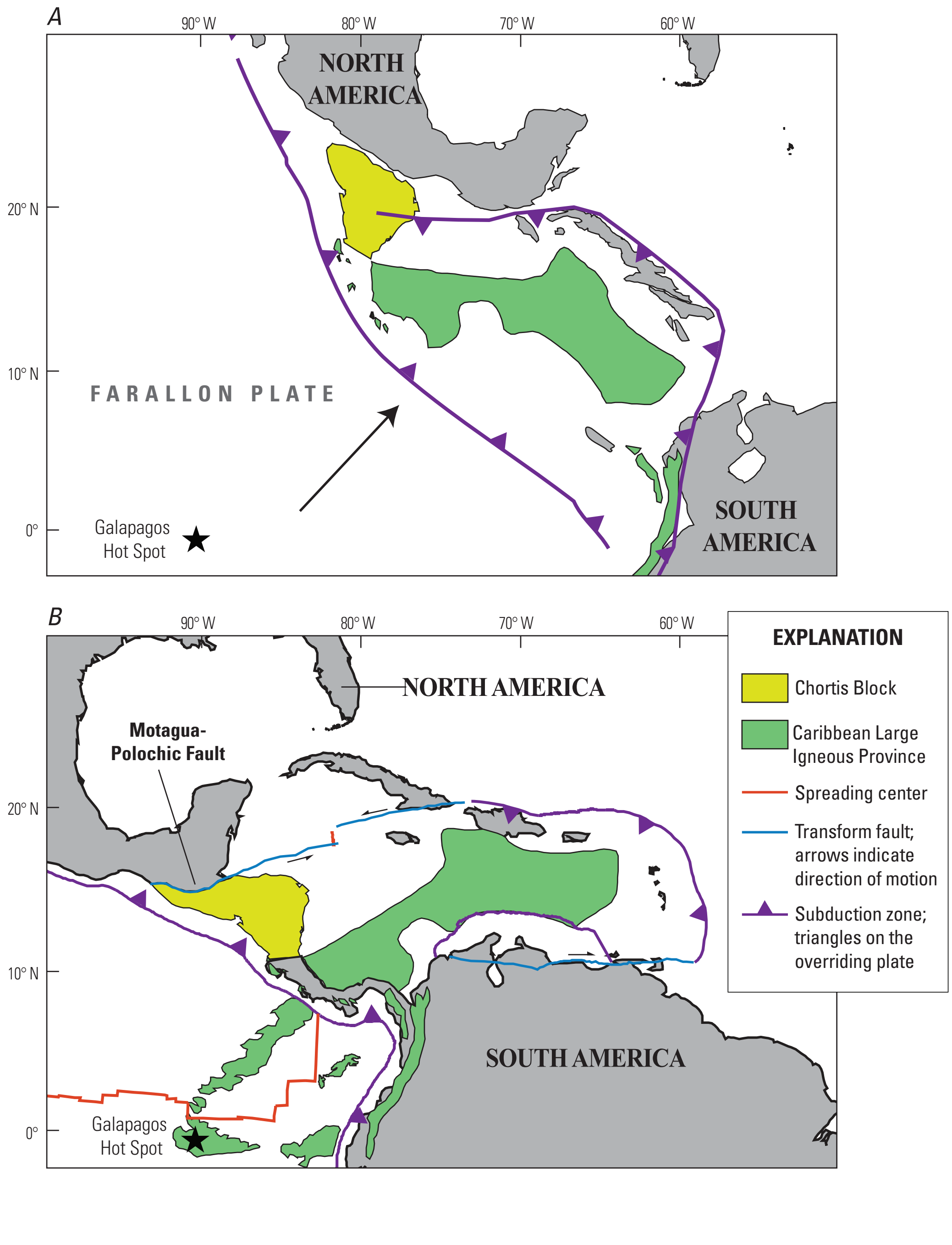

Figure 4. Location of Chortis Block *A*, in pre-middle Eocene time and *B*, today.

beneath the Caribbean Plate (Kesler and others, 1977). The rocks include a basal tholeiitic basalt suite that is overlain by andesite and dacite flows as well as dacitic ignimbrites (Williams and McBirney, 1969). The eastern part of this arc accreted to South America in northwestern Colombia near the end of Oligocene time. This effectively shut off subduction and related magmatism in eastern Panama, although to the west major volcanic activity continued through the Miocene (Wadge and Burke, 1983; Kellogg and Vega, 1995; Mann and Kolarsky, 1995; Trenkamp and others, 2002; Coates and others, 2004).

Cocos Arc

Igneous rocks of the Tertiary Cocos Arc (fig. 3) consist of calc-alkaline felsic to intermediate plutons and andesite flows that developed in response to subduction of the Cocos Plate beneath the western side of the Caribbean Plate (the Pacific coast of Central America). The northwestern limit of the Cocos Arc is marked by the Tehuantepec Ridge (fig. 3), a transpressional structure that formed about 15–20 Ma and may have created a slab window (Manea and others, 2006). Present active volcanoes in this same region are usually referred to as belonging to the Chiapanecan Arc and Central American Volcanic Arc.

Lesser Antilles Arc

The Lesser Antilles archipelago represents a composite island arc formed by west-directed subduction of Atlantic oceanic crust of the North American Plate below the Caribbean Plate (fig. 3). Magmatism in the eastern (older) portion of the arc began as early as the Eocene and ceased by mid-Oligocene time (Andreieff and others, 1988). Magmatism in the western (recent) portion of the arc began in the early Miocene and continues to the present as active stratovolcanoes. Major lava compositions in the Lesser Antilles Arc include dominantly andesitic low- and medium-potassium (K) calc-alkaline series rocks, as well as arc tholeiites and basalts (Bouysse and others, 1990).

Assessment Data

The assessment team utilized geologic maps, mineral-occurrence databases, technical reports on prospects, topical data and maps, mining company Web sites, and published geologic literature.

Geologic Maps

The USGS published a 1:2,500,000-scale map showing geology, oil and gas fields, and geologic provinces of the Caribbean region (French and Schenk, 2004). This map was useful for visualization of the magmatic rocks of the entire region, and was the only source of digital geology for the Lesser Antilles and the Virgin Islands. However, the annotation of this map with respect to age and lithology is limited, and for most of the area, the primary resource was a digital compilation of the geologic maps of the twelve large political entities that make up mainland Central America and the Greater Antilles island chain. This map, which is known as CBMap, is available for purchase at http://www.cbmap.net/.

The annotation for this map was supplemented by creating new map units that are valid across national boundaries by grouping units with similar ages and lithologies. The resulting derivative map was then used to define the magmatic arcs that form the fundamental units for tract designation.

Mineral Occurrence Databases

The global porphyry copper database of Singer and others (2008) was used as the primary data source for known deposits and for significant porphyry copper prospects in Central America and the Caribbean Basin. In addition, the combination of the USGS Mineral Resources Data System[5] and the CB Map Deposits and Prospects database (available for purchase at http://www.cbmap.net/) provided a digital database of more than 8,000 site records with information on site names, commodities present, and status. These two databases, along with information from the geologic literature, were used to identify additional porphyry copper prospects. In addition, commercially available databases (InfoMine[6], Metals Economic Group[7]), metallogenic maps, technical reports, and company Web sites were consulted. Many of the selected records were updated by checking and correcting locations, modifying descriptions, and, in some cases, updating grade and tonnage data. The spatial proximity rules described in Singer and others (2008) were applied to all the records, and a qualitative evaluation was made of the relative importance of prospects as indicators of undiscovered porphyry copper deposits. Details about the sources of information for individual deposits and prospects can be found in appendixes A through E.

Mineral Resource Assessments

Data from previous USGS mineral resource assessments of Costa Rica and Puerto Rico also were used. The USGS completed a mineral resource assessment of Costa Rica in 1986–87 in collaboration with the Dirección General de Geología, Minas e Hidrocarburos of Costa Rica and the Universidad de Costa Rica. The report includes 1:500,000-scale geologic, physiographic, and mineral occurrence maps as well as geophysical maps and topical studies. Results were released in English and Spanish in a large-format color folio (U.S. Geological Survey

[5]http://mrdata.usgs.gov.

[6]http://www.infomine.com.

[7]http://www.metalseconomics.com/default.htm.

and others, 1987). The data were subsequently released on CD and made available online (Schruben, 1996).

Several decades of geologic, geochemical, geophysical, and mineral-occurrence studies in Puerto Rico culminated in USGS reports prepared in cooperation with the Puerto Rico Department of Natural Resources and the University of Puerto Rico at Mayaguez (Cox, 1973, 1985; Bawiec and others, 1991; Bawiec, 1999).

Other Data

Stream-sediment surveys cover much of the study area; data compiled by surveys beginning in the 1960s are available for purchase at http://www.cbmap.net/stream-sediment-surveys/. Geochemical and geophysical data for selected areas are included in reports of the United National Revolving Fund for Natural Resources Evaluation (1988). Detailed geophysical data are available for selected areas, such the Chortis Block (Rogers and others, 2007), and in the aforementioned mineral resource assessments.

Exploration History

Porphyry copper exploration in Central American and the Caribbean Basin has been cyclic, driven largely by changing global metal prices, changing government policies, and local infrastructure development. Parts of the area remain underexplored. Political, social, cultural, and environmental issues as well as mining laws affect exploration in the region. Some areas have been closed to exploration for many years due to social opposition and restrictions on mining activities. In addition, steep topography, lack of infrastructure, tropical climate and vegetation, and natural hazards such as earthquakes and volcanic eruptions complicate exploration and development.

Both gold and copper were mined in the area for centuries by pre-Columbian indigenous populations and by Spanish colonists (Siegel and Severin, 1993; Lothrop, 1937; Terry, 1956; Heffernan, 2004). Modern efforts began in the 1960s, when several international mining companies began exploration. Both the USGS and the British Geological Survey completed programs during this time, and the United Nations sponsored numerous regional stream-sediment geochemical surveys. Most of the known porphyry copper deposits were discovered before 1970 (Nelson, 1995). Important factors that led to this phase of exploration and discovery in Central America and the Caribbean Basin include:

- The definition and refinement of the theory of plate tectonics (Wilson, 1963, 1965, 1966; McKenzie and Parker, 1967; Morgan, 1968; Le Pichon, 1968).
- The maturation of descriptive and exploration models for porphyry copper deposits (Titley and Hicks, 1966; Lowell and Guilbert, 1970; Rose, 1970; Sillitoe, 1972; Guilbert and Lowell, 1974; Sutherland Brown, 1976; Titley, 1975).
- The development and application of exploration geochemistry in mineral exploration in the 1950s and 1960s; this includes the development of analytical methods to study large numbers of samples.
- The passing of United Nations Article 55 providing for the United Nations to “promote higher standards of living, full employment, and conditions of economic and social progress and development.” To fulfill this charge, the United Nations Expanded Program of Technical Assistance (UNEPTA) was created in 1949, expanded with a Special Fund in 1957, culminating in foundation of the United Nations Development Programme (UNDP) in 1966.
- The Cuban revolution in 1959.
- The nationalization of the Chilean copper industry in 1969 and 1970.
- The increase in the price of copper from the end of World War II to the late 1970s (with spikes in the late 1960s and early 1970s).

Porphyry copper deposits in the Petaquilla (now Cobre Panama) and Río Pito districts in Panama and porphyry copper prospects were discovered as a consequence of the UNDP decision to do stream-sediment geochemical surveys in Costa Rica, El Salvador, Haiti and the Dominican Republic (Hispaniola), Honduras, Nicaragua, Panama, and Guatemala from 1965 to 1973. The success of the UNDP program led to funding from the United Nations Revolving Fund for Natural Resources Evaluation, the Caribbean Development Bank, the U.S. Agency for International Development, and the Canadian International Development Agency to do work in Dominica, Costa Rica, Haiti, Panama, Honduras, Jamaica, and Saint Lucia. This work, which included regional geologic mapping, was done by several international organizations (such as the British Geological Survey, the German Bundesanstalt für Geowissenschaften und Rohstoffefunding (BGR), Los Alamos National Laboratories, and the USGS) in the 1980s.

In the late 1960s and early 1970s, several major mining companies actively explored the region. In some cases, their work followed up on sites identified by the UNDP surveys, but they also discovered several deposits and prospects (such as Cerro Chorcha) that are outside the UNDP study areas. Exploration activity has continued intermittently for as long as 50 years at several sites in Panama, Haiti, and Honduras, and the mining industry continues to use the United Nations-sponsored geochemical surveys to guide exploration and identify new prospective areas. At present, Panama, Haiti, and the Dominican Republic are receiving the most attention.

The Assessment Process

The assessment team was composed of geologists from the USGS, the University of Arizona, and the minerals industry. The team had expertise in regional geology, porphyry copper deposits, mineral deposits and mineral exploration of

Central America and the Caribbean Basin, GIS, and mineral-assessment methodology (see appendix G). Published regional geologic data and proprietary geologic maps were used. The USGS hosted an assessment workshop in Tucson, Arizona, in April 2010. To prepare for the workshop, the team compiled existing data, reviewed the geology of Central America and the Caribbean Basin, and identified appropriate deposit models. At the workshop, preliminary permissive tracts were presented to the entire team, necessary modifications were made, and the probabilistic mineral resource assessment was completed with input from all team members. The assessment has since been refined in response to internal USGS review.

Three-Part Assessment

The assessment was done using a three-part form of mineral-resource assessment based on mineral deposit models of Singer (1993; 2007a, b), Singer and Menzie (2010), and Menzie (2005a, b). The three parts include: (1) delineation of permissive tracts, according to the types of mineral deposits permitted by geology, (2) estimation of the amount of metal in known deposits by the use of grade and tonnage models, and (3) estimation of the number of undiscovered deposits by subjective methods (Singer, 2007a).

A permissive tract for porphyry copper deposits was delineated as a geographic area that includes intrusive and volcanic rocks of specified ranges of composition and age that are part of a magmatic arc, generally related to a convergent plate margin. The tract generally was bounded by the outline of the magmatic arc, as depicted at the scale of the available maps, and included known porphyry copper deposits and prospects of the appropriate age range. The tract could also include areas that were covered by younger or structurally overlying materials less than 1 km thick.

Frequency distributions of tonnages and average grades of thoroughly explored deposits of a given type were used as models for grades and tonnages of undiscovered deposits (Singer, 1993). Data for the models included the average grade of each metal or commodity of possible economic interest and the associated tonnage based on the total production, reserves, and resources at the lowest possible cutoff grade, as described by Singer and others (2008).

The assessment team estimated numbers of undiscovered deposits in each tract at various probabilities (degrees of belief). Strategies for estimation included counting the number and ranking the favorability of significant prospects, and comparing the spatial density of known deposits and expected undiscovered deposits to that of known deposits in similar, well-explored regions (Singer, 2007b). Probable amounts of undiscovered resources were estimated by combining estimates of numbers of undiscovered deposits with grade and tonnage models by using a Monte Carlo simulation (Root and others, 1992; Bawiec and Spanski, 2012; Duval, 2012).

Porphyry Copper Deposit Models

Descriptive Models

Porphyry copper mineral deposit models used for the assessment included those of Cox (1986a, b), Berger and others (2008), Singer and others (2008), and John and others (2010). In addition, distinctive characteristics of porphyry copper deposits in the region were noted from a number of topical and regional studies (Kesler and others, 1975; Kesler, 1978; Nelson, 1995; Nelson and Nietzen, 2000). In Central America and the Caribbean Basin, source rocks for porphyry deposits are Early Cretaceous and younger and are mostly quartz diorite and granodiorite. The arc rocks become more potassic through time and porphyry deposits tend to be emplaced near the end of any specific subduction cycle. Most Caribbean deposits are gold-rich and molybdenum-poor, although deposits in Panama contain distinctly more molybdenum and less gold. Many deposits and prospects are spatially and temporally associated with Cu and Cu-Au skarn and replacement deposits; high-grade supergene enrichment zones are developed at some deposits (table 1, Cerro Colorado, Tanamá). Initial strontium ratios for porphyry-related intrusions in island arcs are generally less than 0.705, indicating minimal interaction with continental crust.

Grade and Tonnage Models

The grade and tonnage models for porphyry copper deposits of Singer and others (2008) were used for the simulation of undiscovered resources. Available models include a global porphyry Cu-Au-Mo model based on 422 deposits (fig. 5), a Cu-Au subtype based on 115 deposits, and a Cu-Mo subtype based on 51 deposits. If sufficient numbers of known deposits were present in a tract, grades and tonnages of deposits within the tracts were tested against global models using statistical tests (*t*-test or analysis of variance). At the 1 percent screening level adopted for this study, the global porphyry Cu-Au-Mo model was acceptable for all of the tracts (table 2). However, the Cu-Au subtype model was used for the Santiago and Lesser Antilles tracts. The selection for the Santiago tract was based on the fact that the four known deposits meet the criteria for the subtype (0.2 grams per metric ton (g/t) Au), occur in an island arc setting, and fit the Cu-Au subtype model better based on the *t*-tests. For the Lesser Antilles tract, no deposits are known but the island-arc settings and presence of epithermal gold mineralization suggest that any deposits present are likely to be gold-rich and molybdenum-poor. Five of the known deposits in Central America and the Caribbean are distributed at or below the median tonnage for the model; the two large deposits in Panama, Cerro Colorado, and Cobra Panama are among the largest 10 percent of all deposits in the model (fig. 5). Average copper grades for the deposits range from 0.27 to 0.73 percent copper; median copper grade for the model is 0.44 percent copper.

Table 2. Statistical test results for the porphyry copper assessment of Central America and the Caribbean Basin.

[Pooled *t*-test results assuming equal variances; p>0.01 indicates that the deposits in the tract are not significantly different from those in the model at the 1-percent level; N_{known}, number of known deposits in the tract; -, no test performed]

Tract	Tract name	N_{known}	Model	*p* values					Model selected	Basis for selection
				Tons	Cu	Mo	Ag	Au		
003pCu4001	Santiago	4	Cu-Au-Mo	0.64	0.61	0.06	0.55	0.12	Cu-Au	Known deposits are all of the Cu-Au subtype; deposits are all island-arc related; *t*-tests support either model.
			Cu-Au	0.78	0.67	0.84	0.34	0.75		
003pCu4003	Chortis	0	-	-	-	-	-	-	Cu-Au-Mo	No known deposits; default to general model.
003pCu4002	Darién	1	Cu-Au-Mo	0.03	0.43	0.59	0.52	0.39	Cu-Au-Mo	General model based on statistical test; also, Cobre Panama fits the general model based on Au/Mo ratio = 8.
003pCu4004	Cocos	2	Cu-Au-Mo	0.22	0.97	0.99	0.49	0.41	Cu-Au-Mo	General model based on statistical test.
003pCu4005	Lesser Antilles	0	-	-	-	-	-	-	Cu-Au	No known deposits; Cu-Au model based on island arc setting.

Related Deposit Types

Base- and precious-metal skarn, replacement, and high-sulfidation epithermal deposits form in magmatic-hydrothermal systems that may also contain porphyry copper deposits (Sillitoe, 2002); however, spatial, temporal, and genetic links with porphyry systems are not always present. In Central America and the Caribbean Basin, both skarns and limestone replacement deposits are known to be associated with some porphyry systems.

Tract Delineation

The geology-based strategy used for porphyry copper tract delineation is described here. See appendixes A through E for details on individual tracts.

The digital map compilation (CBMap; available at http://www.cbmap.net/) was created by merging digital representations of maps at different scales for 12 countries (the Dominican Republic, Haiti, Cuba, Jamaica, Puerto Rico, Guatemala, Belize, Honduras, El Salvador, Nicaragua, Costa Rica, and Panama). It contains more than 600 map units. For the Lesser Antilles tract, the digital geologic map of the Caribbean by French and Schenk (2004) was used. For the part of the Cocos tract in Mexico, the digital map used in the Mexico portion of the global mineral resource assessment (Hammarstrom and others, 2010) was used.

A derivative map was created for tract delineation by combining map units on the basis of age and lithology into units based on volcanic arcs and metallogenic episodes. Using the individual unit descriptions and lithologic information, these

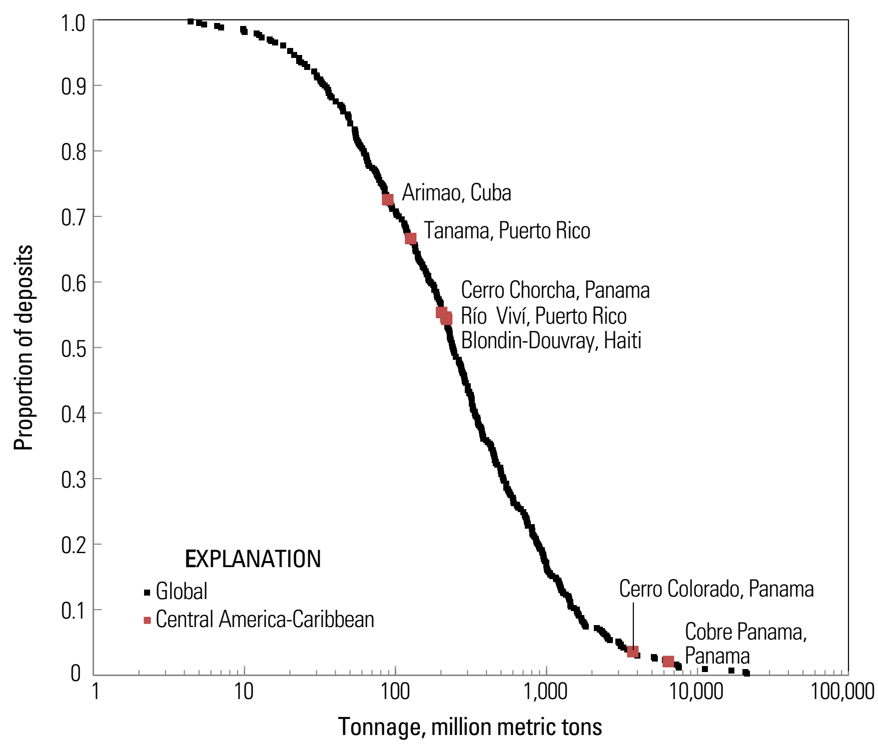

Figure 5. Plot showing global tonnage model for porphyry copper deposits (all subtypes); deposits in Central America and the Caribbean Basin (table 1) are shown as red squares. Model data from Singer and others (2008).

units were then further classified as to whether they were permissive for the occurrence of porphyry copper deposits or not.

Digital geologic data were processed in a GIS (appendix F) using ArcMap software, as follows:

- The fundamental units for tract delineation, magmatic arcs or belts of igneous rocks of a given age range, were identified using regional-scale maps and geologic literature.
- The map units used to define preliminary tracts permissive for porphyry copper deposits were then selected from the digital geologic map. Igneous map units were subdivided into age groups and classified as permissive or nonpermissive based on lithology. Permissive rocks included calc-alkaline and alkaline plutonic and volcanic rocks. Nonpermissive rocks included, for example, ultramafic assemblages, ophiolites, highly evolved granites, peraluminous granites, and pillow basalts.
- A 10-km buffer was then applied to plutonic rock polygons and a 2-km buffer to volcanic rock polygons; this generally expanded the area of the tract to include all porphyry copper deposits and significant associated prospects. The buffer accounts for uncertainties in the cartographic position of mapped boundaries, and for possible unexposed or unmapped permissive rocks.
- After buffering, available data on mineral deposits and occurrences, locations of dated igneous rock samples, and geophysical and geochemical information were examined to identify previously unrecognized evidence of unmapped permissive rocks or hydrothermal systems.
- An aggregation and smoothing routine was applied to the resulting polygons, and the tracts were edited by hand in accord with postmineral fault boundaries. In some cases, more detailed geologic maps were used to resolve tract boundary issues, or schematic map illustrations from the literature were incorporated to augment the existing digital maps.
- Areas with postmineral volcanic centers, depositional basins, and other forms of cover judged to exceed 1 km in thickness were excluded from the tracts. Intrusions younger than the designated tract age were also excluded. Volcanic rocks younger than the designated tract age, but inferred to be less than 1 km thick, were included within permissive areas.
- Resulting tract boundaries were truncated at shorelines to eliminate undersea areas using a global GIS dataset adopted for the project (U.S. Department of State, 2009).

Permissive Tracts for Porphyry Copper Deposits in Central America and the Caribbean Basin

Five permissive tracts for porphyry copper deposits were delineated in Central America and the Caribbean Basin (table 3, fig. 6). These tracts are based on the mapped extent of igneous rocks that are permissive for porphyry copper deposits. Brief summaries of the tracts are included here; the rationales for tract delineation, tables of map units included in each tract, descriptions of deposits and prospects, and other details are provided in appendixes A through E and are included in the GIS (appendix F).

Santiago Tract

The Santiago tract (003pCu4001), with an area of about 79,000 km^2, is defined by Cretaceous through Eocene igneous rocks of the Greater Antilles Arc (fig. 3) that formed along the northern margin of the Caribbean Plate during southwest-directed subduction of oceanic crust. These are calc-alkaline rocks that formed in an island arc more than 2,000 km long that extends from western Cuba through the island of Hispaniola to Puerto Rico. Intrusive rocks primarily are diorite, quartz diorite, tonalite, and granodiorite; volcanic rocks primarily are basalt, basaltic andesite, and andesite (Kesler and others, 1975).

The tract includes four porphyry copper deposits: Arimao in Cuba, Blondin-Douvray in Haiti, and Tanamá and Río Viví in Puerto Rico (table 1). Río Viví is the largest, with about 1.6 million metric tons (Mt) of contained copper. Information is available for 15 prospects (appendix A) including porphyry, copper- and (or) gold-bearing skarn, and vein deposits that are indicative of the porphyry copper environment (Nelson, 2007).

Chortis Tract

The Chortis tract (003pCu4003), with an area of about 68,000 km^2, is defined by Late Cretaceous through Oligocene igneous rocks of the Chortis magmatic zone (fig. 3) that formed partly as an island arc and partly as a continental arc along the southwestern coast of Mexico and were subsequently tectonically transported to their present position, which is primarily in Honduras (fig. 3). The intrusive rocks are mainly diorite and tonalite that intrude basalt and andesite flows. Much of this tract is partially concealed by distal volcanic rocks of the Cocos Arc to the south. There are no porphyry copper deposits in the tract and no identified porphyry copper prospects; however, there are numerous copper- and (or) gold-bearing skarn, replacement, and vein deposits that are indicative of the porphyry copper environment (Kirkham and Dunne, 2000; First Point Minerals Corp., 2004; Nelson, 2007).

Darién Tract

The Darién tract (003pCu4002), with an area of about 16,500 km^2, is defined by Paleocene through Oligocene igneous rocks of the Panamanian Arc (fig. 3) that formed along the southern margin of the Caribbean Plate during northeast-directed subduction of oceanic crust of the Cocos Plate. These calc-alkaline rocks formed in an island arc nearly 500 km long that extends from western Panama to northwestern Colombia. Volcanic rocks of the arc consist primarily of basalt flows at the base (Donnelly and others, 1990), followed by andesite and dacite flows, along with some ignimbrite sheets of dacite

Table 3. Permissive tracts for porphyry copper deposits in Central America and the Caribbean Basin.

Tract Name	Coded_Id	Tract_Id	Appendix	Countries	Geologic feature assessed
Santiago	003pCu4001	CA_CARIB- KT1	A	Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, Virgin Islands	Cretaceous-Eocene oceanic arc associated with subduction along the northern Caribbean Plate boundary, corresponding to the modern Greater Antilles Arc
Chortis	003pCu4003	CA_CARIB- KT2	B	Guatemala, Honduras, Nicaragua	Late Cretaceous through Oligocene continental arc of dioritic-tonalitic plutons that intrude Mesozoic sedimentary and older metamorphic rocks in northern Central America
Darién	003pCu4002	CA_CARIB- T1	C	Panama	Paleocene through Oligocene island arc-related calc-alkaline igneous rocks that were formed as the Nazca Plate was subducted beneath the Caribbean Plate
Cocos	003pCu4004	CA_CARIB- T2	D	Mexico, Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica, and Panama	Miocene and Pliocene continental arc formed above the northern part of the Middle America Trench in a complex zone of interaction of the North American, Caribbean, Nazca, and Cocos Plates
Lesser Antilles	003pCu4005	CA_CARIB- T3	E	**Sovereign states**: Antigua and Barbuda, Dominica, Grenada, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines. **Non-sovereign territories**: Anguilla, Guadeloupe, Martinique, Montserrat, Saba, Saint Barthélemy, Saint Estasius, Saint Martin.	Eocene through Holocene Lesser Antilles composite volcanic arc

Figure 6. Permissive tracts for porphyry copper deposits in Central America and the Caribbean Basin.

and rhyolite (Williams and McBirney, 1969). Intrusions, primarily of diorite and granodiorites, have ages of about 60–48 Ma in eastern Panama. After the suturing of eastern Panama to South America, subsequent intrusions in western Panama are mostly Oligocene.

The tract contains one large porphyry copper deposit, Cobre Panama, which is in western Panama and was originally known as Petaquilla Copper. This deposit contains nearly 20 Mt of copper and is one of the largest porphyry copper deposits in the world (table 1). It was nearing production in 2012, but is still under active exploration and additional resources can be expected. In addition, there are three porphyry copper prospects in the tract (appendix C), as well as numerous copper- and (or) gold-bearing skarn, replacement, and vein deposits that are indicative of the porphyry copper environment (Ferencĭć, 1970; Nelson, 2007).

Cocos Tract

The Cocos tract (003pCu4004), with an area of more than 200,000 km^2, is defined by mid-Tertiary and younger igneous rocks of the continental Cocos and Chiapanecan Arcs (fig. 3) that formed along the southwestern margin of the Caribbean Plate during northeast-directed subduction of the Cocos Plate. The Cocos Arc is about 2,000 km long and stretches from southern Mexico through El Salvador, Guatemala, Honduras, Nicaragua, and Costa Rica into central Panama. The Chiapanecan Arc is smaller, about 200 km long, and is in southern Mexico. In Costa Rica, the highest mountains in Central America are the result of recent rapid uplift above the subducting aseismic Cocos Ridge. Most of the rocks are calc-alkaline, felsic- to intermediate-composition plutons that intrude basalt, andesite, and dacite flows.

The tract contains two porphyry copper deposits, Cerro Colorado and Cerro Chorcha (table 1). Both are late Miocene to Pliocene in age, but Cerro Colorado is much larger and contains nearly 15 Mt of copper (Cooke and others, 2005). In addition, there are four porphyry copper prospects (Nelson and Nietzen, 2000; Nelson, 2007).

Lesser Antilles Tract

The Lesser Antilles tract (003pCu4005), with an area of about 3,000 km^2, is defined by the onshore parts of the Eocene to Holocene Lesser Antilles Arc (fig. 3). This arc is a result of the west-directed subduction of Atlantic oceanic crust beneath the eastern margin of the Caribbean Plate. The volcanic islands of the tract are made up of intermediate-composition stratovolcanoes, some of which are intruded by small plutons. No porphyry copper deposits or important prospects are known in the tract, but numerous high-sulfidation epithermal gold prospects and Cu-Au and iron (Fe)-Au skarns are associated with quartz diorite plutons. Porphyry-style hydrothermal alteration is reported on several of the islands of the Lesser Antilles (Beaufort and others, 1990; McKelvey, 1995).

Estimating Numbers of Undiscovered Deposits

Assessment team members evaluated the available data and made individual, subjective estimates of the numbers of undiscovered porphyry copper deposits using expert judgment. Estimates are expressed in terms of different levels of certainty. Estimators are asked for the least number of deposits of a given type that they believe could be present at three specified levels of certainty (90 percent, 50 percent, and 10 percent). For example, on the basis of all the available data, a team member might estimate that there was a 90-percent chance of one or more; a 50-percent chance of five or more; and a 10-percent chance of ten or more undiscovered deposits in a permissive tract. The individual estimates were discussed by the team, and a single team estimate was agreed upon for each tract.

The estimates are converted to a mean number of deposits and standard deviation using an algorithm developed by Singer and Menzie (2005). This algorithm can be described by the following general equations, which are used to calculate a mean number of deposits (λ) and a standard deviation (S_x) based on estimates of numbers of undiscovered deposits predicted at different quantile levels[8] (N_{90} = 90-percent level, N_{50} = 50-percent level, for example):

$$\lambda = 0.233\,N_{90} + 0.4\,N_{50} + 0.225\,N_{10} + 0.045\,N_{05} + 0.03\,N_{01} \quad (1)$$

$$S_x = 0.121 - 0.237\,N_{90} - 0.093\,N_{50} + 0.183\,N_{10} + 0.073\,N_{05} + 0.123\,N_{01} \quad (2)$$

For the example given above (N_{90}=1; N_{50}=5; N_{10}=10), λ=5.2 and S_x=3.2.

These equations were programmed in a spreadsheet to allow the team to quickly evaluate estimates. The spread in the number of deposits associated with the 90th percentile to the 10th percentile or 1st percentile reflects uncertainty; large differences in number suggest great uncertainty. The mean number of deposits for the permissive tract, or the numbers associated with a given probability level, reflect favorability. Another useful parameter for reporting uncertainty associated with an estimate is the coefficient of variation (C_v), defined as:

$$C_v = S_x / \lambda \quad (3)$$

The coefficient of variation is often reported as percent relative variation (100 × C_v).

The final team estimates reflect both the uncertainty in what may exist and the favorability of the tract (Singer, 1993). The estimates are combined with appropriate grade and tonnage models in a Monte Carlo simulation using the EMINERS computer program (Bawiec and Spanski, 2012; Duval, 2012) and based on the original Mark3 computer program described by Root and others (1992); results provide a probabilistic estimate of amounts of resources that could be associated with undiscovered deposits.

[8]To use the equation in cases where three nonzero quantiles (90-50-10) are estimated, use the N_{10} values for N_{05} and N_{01}; where four quantiles (90-50-10-5) are estimated, use the N_{05} value for N_{01}.

Table 4. Estimates of numbers of undiscovered porphyry copper deposits in Central America and the Caribbean Basin.

[N_{XX}, estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; *s*, standard deviation; C_v%, coefficient of variance; N_{known}, number of known deposits in the tract that are included in the grade and tonnage model; N_{total}, total of expected number of deposits plus known deposits; km², area of permissive tract in square kilometers; N_{total}/100k km², deposit density reported as the total number of deposits per 100,000 km². N_{und}, *s*, and C_v% are calculated using a regression equation (Singer and Menzie, 2005)]

Coded_Id	Tract name	Consensus undiscovered deposit estimates						Summary statistics				Tract area (km²)	Deposit density (N_{total}/100k km²)
		N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	*s*	C_v%	N_{known}	N_{total}		
003pCu4001	Santiago	4	11	22	22	22	12	6.5	54	4	16	78,780	20
003pCu4003	Chortis	2	5	12	12	12	6.1	3.7	61	0	6.1	67,570	9
003pCu4002	Darién	2	3	6	6	6	3.5	1.6	47	1	4.5	16,480	27
003pCu4004	Cocos	4	14	24	24	24	14	7	51	2	16	203,630	8
003pCu4005	Lesser Antilles	0	1	2	3	3	1.1	0.98	91	0	1.1	2,980	37

The rationales for individual tract estimates are discussed in the appendixes. In some cases, the number and features of porphyry copper prospects within a tract were the primary basis for estimates at the 90th and 50th quantiles. Particular weight was given to prospects classified as porphyry copper-related in published literature and recent exploration reports. Other important considerations included the location, number, deposit type, and relative importance of other prospects. Recent literature, company Web sites, and technical reports for exploration projects were examined for descriptions of geology, mineralogy, deposit type, rock alteration, and sampling results to evaluate the likelihood that a prospect is associated with a porphyry copper system like those in the grade and tonnage models. The level of exploration, the number of prospects with declared resources, the distribution of reported copper and gold occurrences of unknown type, and the presence of placer gold workings were also considered in making estimates. In some cases, team members provided information about prospects based on personal observations from site visits. In less well-explored areas, and in areas with poor documentation of mineral occurrences, it was not possible to use such methods; the spread in estimates and associated relatively high coefficients of variation reflect the team's uncertainty.

Final team estimates of undiscovered deposits are summarized in table 4, along with statistics that describe mean numbers of undiscovered deposits, the standard deviation and coefficient of variation associated with the estimate, the number of known deposits, and the implied deposit density for each tract. The assessment predicts a total of 37 undiscovered porphyry copper deposits in all tracts, which represents about 5 times the number of known deposits (table 1).

Summary of Probabilistic Assessment Results

Simulation results for mean and median estimates of contained copper and gold in undiscovered deposits are reported in table 5 along with total identified resources in known deposits in each tract. Identified resources in the table refer to metal contained in porphyry copper deposits only; the known resource data are based on total production, if any, along with published data for resources. Thus, identified resources may include substantial amounts of metal that have already been produced.

Simulation results are reported for selected quantiles, along with the mean amount of metal, the probability of the mean, and the probability of no metal. For each metal, the probability of at least the mean amount of metal expected is reported for selected quantiles. The quantile estimates represent ranked data from the 4,999 Monte Carlo simulations and are linked to each tract simulation; therefore, they should not be summed across tracts. Mean estimates, however, can be combined across tracts to obtain total amounts of metal and mineralized rock. These totals can be compared between tracts and regions.

Discussion

This assessment indicates that the study area may contain 37 undiscovered deposits with a mean (arithmetic) of about 130,000,000 t of copper (tables 4, 5). Seven known porphyry copper deposits in the area contain identified resources of about 39,000,000 t of copper (table 1). Approximately 80 percent of the estimated mean undiscovered copper resource is associated with the three permissive tracts (Santiago, Darién, and Cocos) that contain known deposits (fig. 7). In addition to copper, the simulation predicts mean undiscovered byproduct resources of about 2,700,000 t of molybdenum, 43,000 t of silver, and 5,200 t of gold. Median amounts of metals predicted by the simulations are substantially lower than mean estimates.

The Santiago tract (003pCu4001) is estimated to contain about ten times more undiscovered copper than presently identified. The tract is being actively explored only in Haiti and the Dominican Republic. Deposits within the Cocos tract (003pCu4004) contain a significant portion of the identified copper resources due to the large Cerro Colorado deposit; predicted undiscovered copper in that deposit is about 3.5 times the amount of identified copper. In contrast, the Darién tract

Table 5. Summary of simulations of undiscovered resources in porphyry copper deposits and comparison with identifed copper and gold resources in porphyry copper deposits of Central America and the Caribbean Basin.

[t, metric tons; Mt, million metric tons, NA, not applicable (only means are additive)]

Tract	Tract name	Known copper resources (t)	Mean estimate of undiscovered copper resources (t)	Median estimate of undiscovered copper resources (t)	Known gold resources (t)	Median estimate of undiscovered gold resources (t)	Mean estimate of: Undiscovered gold resources (t)	Mean estimate of: Undiscovered molybdenum resources (t)	Mean estimate of: Undiscovered silver resources (t)	Mean estimate of: Rock (Mt)
003pCu4001	Santiago	4,100,000	36,000,000	27,000,000	300	2,100	2,700	210,000	12,000	7,400
003pCu4003	Chortis	0	23,000,000	13,000,000	0	300	570	640,000	7,300	4,600
003pCu4002	Darién	19,000,000	14,000,000	6,900,000	320	150	340	400,000	4,400	2,900
003pCu4004	Cocos	16,000,000	53,000,000	39,000,000	310	970	1,300	1,400,000	18,000	11,000
003pCu4005	Lesser Antilles	0	3,300,000	670,000	0	64	240	19,000	1,100	680
Total		39,000,000	130,000,000	NA	930	NA	5,200	2,700,000	43,000	27,000

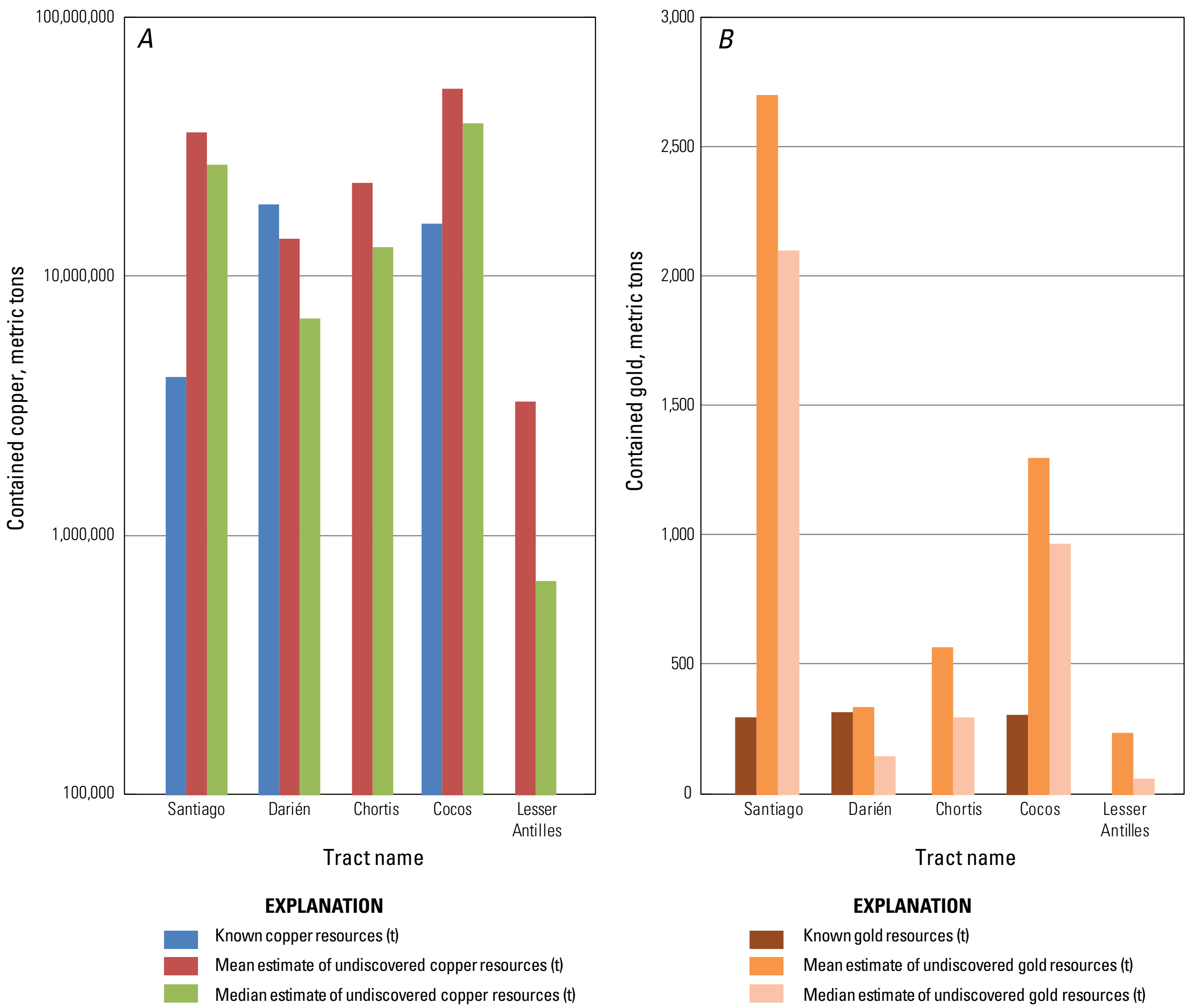

Figure 7. Bar charts comparing identified resources to estimates, by tract. *A*, Known copper compared with mean and median estimates. *B*, Known gold compared with mean and median estimates. Data are from table 5.

(003pCu4002) contains the highest percentage of identified resources due to the large Cobre Panama deposit (nearly 20 Mt of copper); in this tract, the quantity of predicted undiscovered copper is only about 0.7 times the amount of known copper.

Although these results indicate that Central America and the Caribbean Basin will continue to be an important source of copper, a significant part of these resources, if present, may be inaccessible or uneconomic. Results should be interpreted with due caution, as no economic filters have been applied to these results to evaluate what portion of the estimated undiscovered resources might be economic under various conditions.

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Appendixes A–G

Appendix A. Porphyry Copper Assessment for Tract 003pCu4001 (CA_CARIB-KT1), Santiago Region—Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, and the Virgin Islands

By Floyd Gray[1], Lukas Zürcher[2], Steve Ludington[1], Jane M. Hammarstrom[1], Gilpin R. Robinson, Jr.[1], Carl E. Nelson[3], and Barry C. Moring[1]

Deposit Type Assessed: Porphyry Copper, Copper-Gold Subtype

Descriptive model: Porphyry copper (Cox, 1986; Berger and others, 2008; John and others, 2010)
Grade and tonnage model: Porphyry copper, Cu-Au subtype (Singer and others, 2008)

Table A1 summarizes selected assessment results.

Table A1. Summary of selected resource assessment results for tract 003pCu4001 (CA_CARIB-KT1), Santiago region—Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, and the Virgin Islands.

[km, kilometers; km^2, square kilometers; t, metric tons]

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (t)	Mean estimate of undiscovered copper resources (t)	Median estimate of undiscovered copper resources (t)
April 2010	1	78,780	4,100,000	36,000,000	27,000,000

Location

The tract consists of the Greater Antilles island chain that stretches from western Cuba eastward to the Virgin Islands (fig. A1).

Geologic Feature Assessed

Cretaceous-Eocene oceanic arc associated with subduction along the northern Caribbean Plate boundary, corresponding to the modern Greater Antilles Arc.

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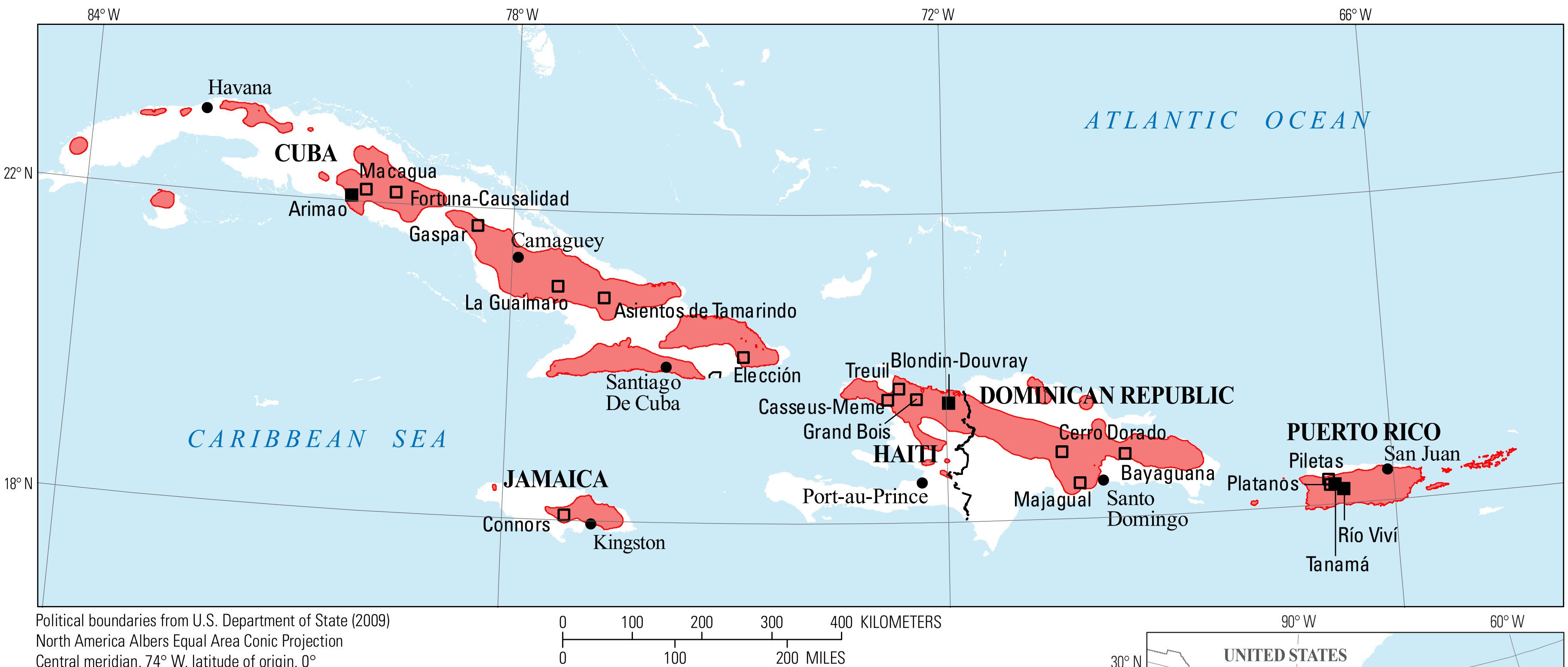
[2]University of Arizona; now at U.S. Geological Survey.

[3]Recursos del Caribe, S.A.



Political boundaries from U.S. Department of State (2009)
North America Albers Equal Area Conic Projection
Central meridian, 74° W, latitude of origin, 0°

EXPLANATION

- Assessed porphyry copper tract 003pCu4001
- Porphyry copper deposit
- Porphyry copper prospect

Figure A1. Map showing the location of tract 003pCu4001 (CA_CARIB-KT1), known deposits, and significant prospects and occurrences, Santiago Region—Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, and the Virgin Islands.

Delineation of the Permissive Tract

Tectonic Setting

The tract corresponds to the Greater Antilles Island Arc, which was active from Early Cretaceous to Eocene time. The island arc extends over a distance of more than 2,000 km through parts of the Greater Antilles (fig. A1). From central Cuba, the tract extends to the southeastern tip of the island maintaining a width of approximately 70 km. The tract continues across to the northern peninsula of Haiti into the central Cordillera of the Dominican Republic to the eastern tip of the island (Hispaniola). The tract also includes part of the Jamaican Blue Mountains and most of central Puerto Rico, extending eastward to the Virgin Islands.

It is generally accepted that the Atlantic Plate was underthrusting the Caribbean Plate during Late Cretaceous to Eocene time (Nagle, 1974; Kesler and others, 1975; Kesler, 1978; Case and Holcombe, 1980; Pindell and Dewey, 1982; Sykes and others, 1982). During the Eocene, relative plate motions changed, volcanism ceased along the northern boundary of the Caribbean Plate, and a complex transform plate boundary zone developed (Jakeš and Gill, 1970; Bowin, 1975; Gill, 1981; Pindell and Dewey, 1982; Sykes and others, 1982; Mann and Burke, 1984; Donnelly and others, 1990). The tract includes younger plutonic and volcanic rocks formed near the time of cessation of subduction of the Greater Antilles Arc.

The Greater Antilles Arc is associated with back-arc basins in the Yucatan Basin (fig. 3) adjacent to Cuba (Rosencrantz, 1990) and the Grenada Basin (fig. 3) adjacent to the Lesser Antilles Arc (Bouysse, 1988). Both back-arc basins appear to have opened in earliest Cenozoic time and may have formed a single, continuous basin prior to disruption by Eocene to Holocene strike-slip faults of the North America-Caribbean Plate boundary (Mann and others, 1991).

Geologic Criteria

Tract 003pCu4001 (fig. A1) was constructed using the 1:500,000 digital geologic map of the Caribbean Basin (available for purchase at http://www.cbmap.net/) to identify areas of permissive rock. Geologic information found in map-attribute tables allowed the assessment team to identify map units that represent lithologic assemblages of the appropriate age and composition to be included in the permissive tract. Lithologic assemblages that were not considered permissive by reason of age or composition were excluded. For example, Late Cretaceous to Paleocene early arc-related tholeiitic suites were not considered to be permissive.

Intrusive and volcanic map units assigned to this permissive tract are shown in figure A2 and listed in table A2. From each map unit listed, only those sets of polygons that represent lithologic assemblages containing permissive rock types were selected for tract delineation. The permissive tract for Late Cretaceous to Eocene porphyry copper deposits was extended under shallow cover (less than 1 km thick) beyond mapped contacts using GIS tools to create a 10-km buffer around the mapped intrusive units of appropriate age and composition; a 2-km buffer was used around appropriate volcanic rocks. Larger-scale (1:250,000) geologic maps and literature were used to check map unit boundaries, ages, and structures (Helsley, 1971; Cox and Briggs, 1973; Bowin, 1975; Cox, 1985; Pushcharovskiy and Mossakovskiy, 1986; Bawiec, 1999). Tract boundaries were clipped along borders and coastlines using the accepted international boundaries for the project (U.S. Department of State, 2009).

In the western part of the tract in Cuba and Hispaniola, arc-related rocks include intrusive tonalite, trondhjemite, granodiorite, quartz monzonite, alkaline quartz diorite, quartz diorite, quartz monzodiorite, and granite. To the south, in Jamaica, the tract includes granodiorite, quartz monzodiorite, and tonalite.

Arc-related intrusive rocks in central Puerto Rico include quartz diorite, tonalite, quartz monzodiorite, granodiorite, and granite. In the eastern end of the island, tonalite, quartz monzodiorite, and granodiorite occur (Bawiec, 1999). Porphyry copper deposits at Tanamá and Río Viví, Puerto Rico, are associated with small hornblende, quartz diorite porphyry stocks, biotite quartz diorite, and hornblende quartz diorite. Volcanic rocks (lapilli tuff, vitric tuff, trachytic fragments of andesite and dacite, and basalt) are intruded by Eocene tonalite, granodiorite, and quartz diorite at the Sapo Alegre porphyry copper prospect.

The Eocene Virgin Islands batholith and Upper Cretaceous to lower Tertiary volcanic rocks crop out on many of the Virgin Islands (Rankin, 2002; Schrecengost and others, 2008). Intrusive rocks include diorite, tonalite, hornblende granodiorite, trondhjemite, dikes and small plugs of quartz-andesine porphyry, and andesine-hornblende porphyry and volcanic rocks. The batholith (greater than 250 km^2) is composed of a heterogeneous series of plutons emplaced over a 13-million-year period starting at 43.5 Ma; trends in geochronology and geochemistry in the batholith support a southwestward migration of magmatism during a transition in the region from subduction to transtension (Schrecengost and others, 2008, 2009). Hydrothermal alteration locally associated with small intrusions is widespread along the southern shores of both St. Thomas and St. John and on many of the smaller islands (fig. A2).

Known Deposits

Four calc-alkaline porphyry Cu-Au deposits occur in tract 003pCu4001 (table A3, fig. A1). The two deposits in central Puerto Rico, Tanamá and Río Viví, both occur along the southwestern margins of the Cretaceous Utuado batholith (fig. A3).

Arimao, Cuba

The Arimao deposit, also known as Santa Clara, Los Pasos, and Brenas, is located in Cienfuegos Province (fig. A2). The deposit is hosted in volcanic rocks that are intruded by granite and gabbro. A number of oxidized areas within the volcanic rocks, and in proximity to the intrusive rocks, have been mapped and sampled (CaribGold Resources Inc., 1995). Trenching by Joutel Resources, Ltd. and Cuban partner Geominera S.A. reportedly outlined a gold zone extending for 200 m through the center of a 60 Mt porphyry copper deposit averaging 0.31 percent copper (Joutel Resources, Ltd., 1995, 1996, 1998; The Northern Miner, 1996). More recent data suggest the deposit size is approximately 89 Mt, averaging 0.27 percent copper with minor gold (Singer and others, 2008). Samples collected from trenches yielded gold assays of 0.32 g/t across 30 m and 0.41 g/t across 43.3 m. Drilling (three holes) beneath the trenches intersected a 40-m zone of quartz stockwork containing pyrite and chalcopyrite (Joutel Resources, Ltd., 1996, 1998).

Tanamá, Puerto Rico

The Tanamá deposit (including Helecho) is located on the west side of the Río Tanamá in western Puerto Rico (fig. A1). The deposit consists of two ore bodies, separated by about 100 m of weakly mineralized rock, and has a resource of about 810,000 t of copper (table A3). Three tonalite porphyry bodies, enclosed in metavolcanic rock of the Cretaceous basaltic sequence and felsic volcanic and sedimentary rocks of early Eocene age, are hydrothermally altered and mineralized (Cox, 1985). The tonalite porphyry intrusions and dacitic flows and breccias formed as a late stage, terminal igneous event during a long period of subduction-related volcanism and plutonism. Sericitic alteration largely overprints feldspar-stable assemblages in which quartz, chlorite, biotite, amphibole, epidote, alkali feldspar, magnetite, chalcopyrite, and bornite are dominant (Cox and others, 1975). The North Tanamá ore body has a copper-bearing biotite-chlorite shell enclosing a low-grade core characterized by amphibole and magnetite, the latter present in quantities up to 10 volume percent in veinlets with quartz and as disseminations (Cox and others, 1975; Cox, 1985). The South Tanamá ore body has a secondary enrichment blanket containing chalcocite and other copper sulfide minerals (Cox, 1985). Copper generally is confined to the tonalite porphyry; chalcopyrite is disseminated rather than vein-controlled, and is associated with magnetite in feldspar-stable alteration and with pyrite in feldspar-destructive alteration. Potassium-silicate alteration is displayed by trace amounts of potassium feldspar, biotite, and anhydrite.

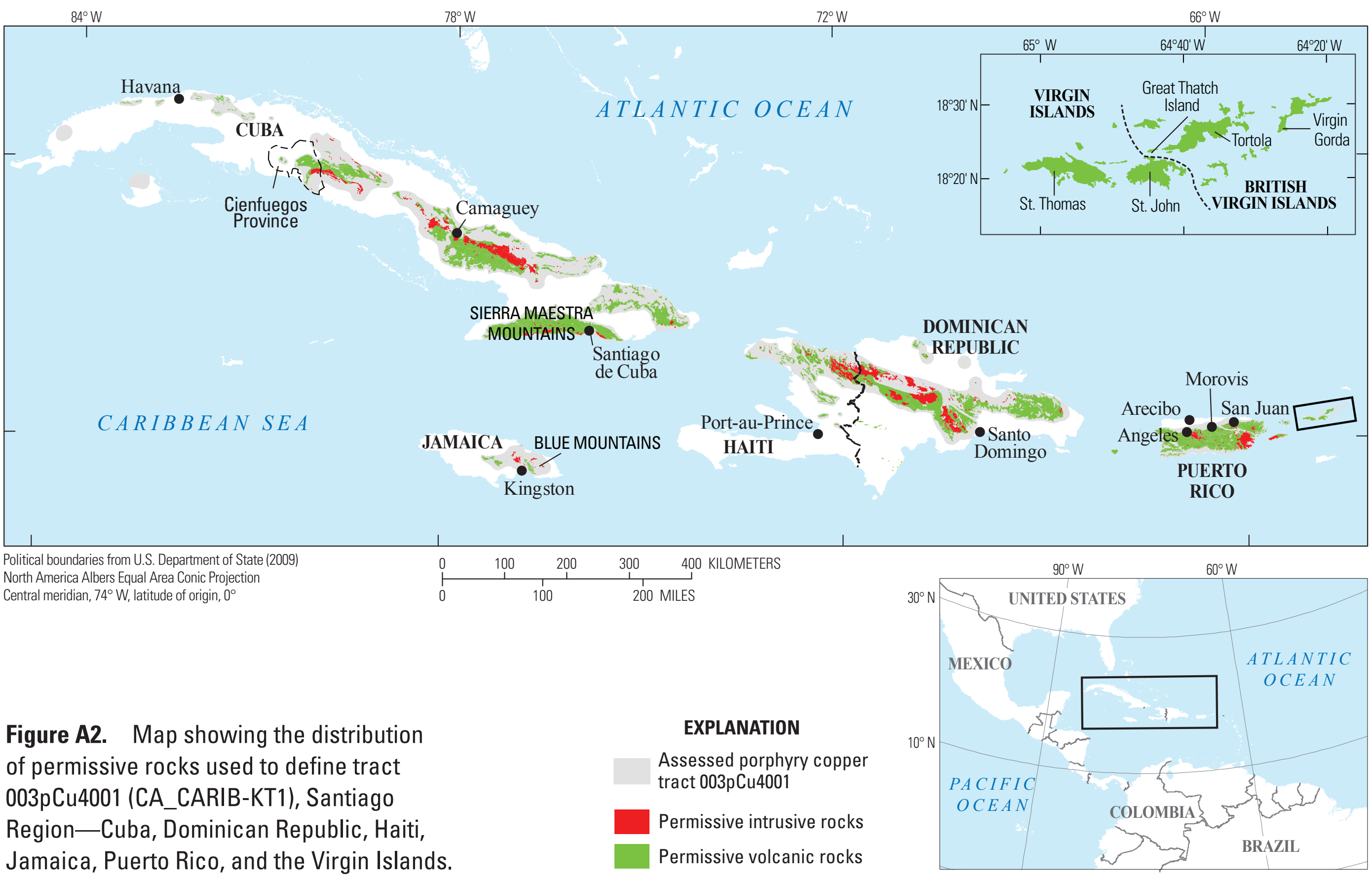


Figure A2. Map showing the distribution of permissive rocks used to define tract 003pCu4001 (CA_CARIB-KT1), Santiago Region—Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, and the Virgin Islands.

Table A2. Map units that define tract 003pCu4001 (CA_CARIB- KT1), Santiago Region—Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, and the Virgin Islands.

[Map unit, age range, and principal lithologies are based on a 1:500,000-scale digital geologic map of the Caribbean Basin (available for purchase at http://www.cbmap.net/)]

Map unit	Country	Age range	Lithology
			Intrusive rocks
KT-qsp	Puerto Rico	Late Cretaceous-Eocene	Hydrothermally altered rocks (chiefly quartz-sericite-pyrite)
Ti(Eo)	Cuba	Eocene	Plagiogranite, tonalite
Ki	Cuba	Late Cretaceous	Diorite, quartz diorite, tonalite, granodiorite, granosyenite, quartz syenite, syenite, gabbro-syenite, plagiogranite, granite, gabbro, gabbro-dolerite, dolerite
Ti(Eo)	Cuba	Eocene	Quartz diorite, diorite, porphyritic granodiorite, rhyodacite
unk-i	Dominican Republic	Unknown	Diorite
KTi	Dominican Republic	Late Cretaceous-Paleocene	Tonalite, granite
unk-i	Haiti	Unknown	Intrusive
Ki	Haiti	Late Cretaceous	Granodiorite and tonalite, Late Cretaceous du Massif du Nord
Ki	Jamaica	Late Cretaceous	Granodiorite
KTi	Puerto Rico	Cretaceous-Tertiary	Plutonic rocks. Mostly granodiorite batholiths and stocks; quartz diorite, quartz diorite porphyry, diorite and gabbro in smaller plutons
			Volcanic rocks
Tv(Pal-Eo)	Cuba	Paleocene-Eocene	Andesitic basalt, basalt, dolerite
Tv(Pal-Eo)	Cuba	Paleocene-Eocene	Andesite, porphyritic diorite
Kv	Cuba	Late Cretaceous	Basalt, andesitic basalt, andesite, dacitic andesite, rhyolite; associated tuff and tuffaceous sediment; abundant intercalated volcaniclastic sediment; minor trachyandesite; rare porphyritic granodiorite and granite; basal unit in some areas may consist of volcaniclastic conglomerate, calcareous shale, and limestone
Tv(Pal-Eo)	Cuba	Paleocene-Eocene	Rhyolite, tuff, agglomeritic tuff, andesite, dacitic andesite, dacite, porphyritic granodiorite; intercalated tuff, volcaniclastic sediment and limestone
Tv(Eo-Oli)	Cuba	Eocene	Ash-flow tuff, tuff, rhyolite, rhyodacite, dacite, minor andesite; calcareous tuff, tuffaceous limestone; calcareous sediment; trachybasalt
Kv	Dominican Republic	Cretaceous	Basalt
Kv	Dominican Republic	Cretaceous	Magmatic, volcanic, and sedimentary rocks of island arc affinities (Tipo Tireo, Duarte); includes minor basalt; in Cordillera Central occurs as contact metamorphism around intrusives (for example, tonalites)
KTv	Dominican Republic	Late Cretaceous	Rhyodacite to rhyolite
Tv(Eo-Oli)	Dominican Republic	Eocene	Volcano-sedimentary rocks (Cordillera Oriental y Peninsula de Semana; Tipo Loma Caballero in northern border of Cordillera Central)
Kv	Haiti	Cretaceous-Late Cretaceous	Basic volcanics and tuffs of Massif du Nord (Upper Cretaceous); lavas and volcano-sedimentary complexes (calc-alkaline) of Lower Cretaceous (first cycle?) and especially Upper Cretaceous andesite and basalts; basalts, cherts, and radiolarites from the Southern Peninsula and the Black Mountains; minor nepheline basalts of Morne La Vigie and de L'Est de la Chaine des Matheux, accompanied by ash and scoria
Tv(Eo-Oli)	Jamaica	Eocene	Volcanics
Kv	Jamaica	Cretaceous	Andesitic volcanics
KTv	Puerto Rico	Cretaceous-Tertiary	Undivided rocks of the central volcanic-plutonic subprovince: mostly volcanic breccia, tuffaceous sandstone and chert, tuff, marine lava (more than 20%), middle and lower limestone, middle and upper conglomerate more than 17,000 m thick, no base observed. Some hypabyssal rocks present
			Undivided rocks of the northeastern volcanic-plutonic subprovince. Mostly tuff, volcanic rock, tuffaceous sandstone and shale (marine). More than 15% lava in lower and some middle sections; limestone occurs in upper more than 10,000 m, not in base. Some hypabyssal rocks present
			Undivided rocks of the southwestern volcanic-plutonic subprovince. Mostly volcanic rocks, tuff, mudstone, impure limestone, marine lava more than 25% throughout. Limestone throughout more than 5,000 m thick. Some hypabyssal rocks present
KTv	Virgin Islands	Cretaceous-Tertiary	Hornblende-dacite-rhyodacite lava flows, sandstone-siltstone, and tuff

Río Viví, Puerto Rico

The Río Viví deposit, located about 10 km southeast of Tanamá (fig. A3), has a resource of about 1.6 Mt of copper (table A3). The deposit is located within Eocene tonalite stocks that intrude Cretaceous metabasalts (Barabas, 1971, 1977) and may represent faulted segments of a single deposit (Lutjen, 1971). Ore bodies at Río Viví include the 450 m by 250 m Piedra Hueca ore body (33 Mt at 0.82 percent copper), the 1,200 m by 200 m Calá Abajo ore body (72 Mt at 0.82 percent copper), and the small, gold-rich Sapo Alegre ore body (Cox and others, 1975; Bradley, 1971).

Blondin-Douvray, Haiti

Located in northeastern Haiti, the Blondin-Douvray area has been known to contain copper and gold resources since the 1970s, when the United Nations Development Program (UNDP) conducted a stream-sediment geochemical sampling program (United Nations, 1978). The source for the material presented below, unless otherwise noted, is a technical report prepared for Majescor Resources Inc., which is currently exploring the property (Barrie, 2009).

There are two ore bodies on the property, Blondin to the north and Douvray to the south; they are separated by less than two kilometers of less intensely mineralized rock. Each has been partially

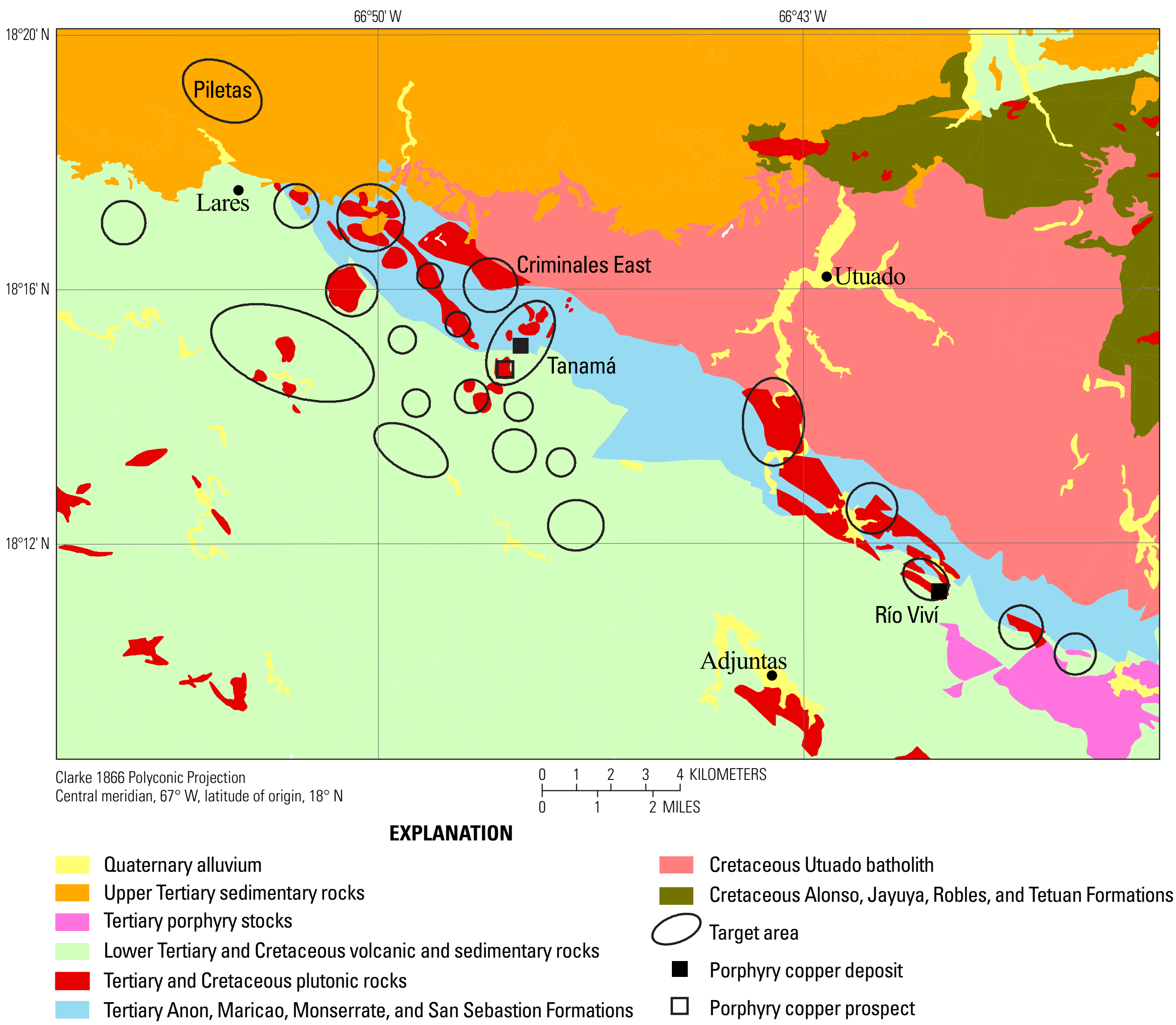


Figure A3. Mapped distribution of Tertiary intrusions and porphyry copper prospects and occurrences in the Lares-Adjuntas area along the south flank of the Cretaceous Utuado batholith, Puerto Rico (adapted from Bawiec, 1999).

Table A3. Identified porphyry copper resources in tract 003pCu4001 (CA_CARIB- KT1), Santiago region—Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, and the Virgin Islands.

[Ma, millions of years before present; Mt, million metric tons; %, percent; g/t, grams per metric ton; n.d., no data. Contained Cu in metric tons is computed as tonnage: (Mt × 1,000,000) × Cu grade (percent) × 0.01]

Name	Latitude	Longitude	Country	Subtype	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained Cu (t)	Reference
Arimao (includes Santa Clara area, Los Pasos; Brenas)	22.066	-80.290	Cuba	Cu-Au	n.d.	88.8	0.27	n.d.	1	2	240,000	Joutel Resources, Ltd. (1996)
Blondin-Douvray (includes Dos Rada-Faille B)	19.555	-71.960	Haiti	Cu-Au	n.d.	327	0.44	n.d.	0.3	n.d.	1,400,000	Kesler (1968), Singer and others (2008)
Tanamá	18.257	-66.791	Puerto Rico	Cu-Au	42	126	0.64	0.005	0.38	1.7	810,000	Barabas (1982), Barabas and Quinn (1980), Cox (1973, 1985), Cox and others (1973), Singer and others (2008)
Río Víví (includes Cala Abajo, Piedra Hueca, Sapo Alegre)	18.188	-66.680	Puerto Rico	Cu-Au	41	218	0.73	0.002	0.3	1	1,600,000	Cox (1973, 1985), Cox and others (1975), Plaza Toledo (2005), Singer and others (2008)

delineated. Blondin was explored by the UNDP via eight diamond drill holes in 1975–76. At Douvray, the UNDP completed 14 holes at that time and the BRG drilled another 24 in 1977–80. In 1997, St. Genevieve Resources drilled a further 24 holes at Douvray, but did not prepare an updated resource estimate. The area is under active exploration by Majescor Resources at present (Majescor Resources, Inc., 2011).

The combined resource for the two ore bodies is about 1.4 Mt of copper (table A3). Historical drilling that produced this resource estimate was reconnaissance in nature; samples were not analyzed for gold. Both ore bodies are undergoing exploration and are open to further discovery, especially to the northwest and southeast, toward the nearby Dos Rada (Nicole) prospect area (Majescor Resources, Inc., 2011). Nevertheless, because of historical precedent, Blondin-Douvray is considered to be a known porphyry copper deposit for the purposes of this assessment.

The deposit is hosted by a suite of tuffs, flows, and agglomerates. These rocks are generally altered to a mixture of chlorite, sericite, epidote, and quartz. Outcrops of tonalite and granodiorite are nearby, but geologic logs of the historic drilling are not available and the subsurface geology is not well known. Hypogene ore minerals include chalcopyrite, bornite, enargite, chalcocite, molybdenite, covellite, tennantite, electrum, and pyrite. Malachite, azurite, chrysocolla, and brochantite are observed at the surface. No studies of hydrothermal alteration are available.

Prospects, Mineral Occurrences, and Related Deposit Types

Table A4 lists 15 prospects (fig. A1) that have characteristics of porphyry copper or related deposit types; prospects are listed in alphabetical order. Two of these prospects, Asientos de Tamarindo in Cuba and Casseus-Meme in Haiti primarily are skarns that could be associated with porphyry copper systems. Characteristics of the eight most significant prospects are described below, listed by country, from west to east across the tract area.

Connors, Jamaica

The Connors prospect (also known as Bellas Gate, Camel Hill) is located 64 km northwest of Kingston, Jamaica (fig. A1). Copper occurrences in this region were identified as early as the late 1800s; subsequent recognition of the Connors-Ginger Ridge porphyry prospect put the surrounding vein deposits within the framework of a single hydrothermal system (Zanes, 1951; Hughes, 1973; Fenton, 1982). Stream-sediment and island-wide low density soil surveys for gold further delineated the mineralized areas (Garrett and Gedes, 1991; Garrett and others, 2004). Drilling in 1997 defined an 800 m by 300 m Cu-Au anomaly, elongated in a north-northwesterly direction (Orogrande Resources Ltd., 1997).

Connors, Camel Hill, and other prospects along this trend are part of Carube Resources Inc.'s 2012 Bellas Gate exploration project. An historical resource of 3.5 Mt at 0.5 percent copper was calculated for the Connors prospect. A 43–101 compliant inferred resource of 13.2 Mt at 0.35 percent copper and 0.17 g/t gold is reported (Carube Resources Inc., 2012). Both porphyry targets are open at depth and along strike.

Elección, Cuba

The Elección prospect (also known as Purial or Jobito), Cuba, is reported to have 10.8 Mt at 1.07 percent copper, and the adjacent Jobito property has 0.48 Mt at 2.05 percent copper and 2.91 g/t gold (combined as 11.28 Mt copper at 1.12 percent

Table A4. Significant prospects and occurrences in tract 003pCu4001 (CA_CARIB- KT1), Santiago region—Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, and the Virgin Islands.

[%, percent; g/t, grams per metric ton; Mt, million metric tons; Ma, millions of years before present; n.d., no data; significant prospect names are shown in boldface]

Name	Latitude	Longitude	Country	Age (Ma)	Comments	Reference
Asientos de Tamarindo	20.902	-76.706	Cuba	n.d.	Primarily a skarn deposit	Lavandero and others (1988)
Bayaguana	18.820	-69.593	Dominican Republic	n.d.	Doña Loretta is in production; partial resource of 8.2 Mt at 0.5% Cu; could be porphyry Cu at depth. Doña Amanda has a partial resource of 127.8 Mt at 0.31% Cu	Chénard (2006)
Casseus-Meme	19.606	-72.793	Haiti	66	Known mineralization is primarily skarn; historic production of more than 1 Mt at 2–3% Cu. Two partial resource estimates: 7 Mt at 0.757% Cu and 1.5 Mt at 2% Cu and 2 g/t Au	Eurasian Minerals, Inc. (2010a, b) Harnish and Brown (1986) Kesler (1968), Majescor Resources, Inc. (2009)
Cerro Dorado	18.879	-70.447	Dominican Republic	n.d.	Quartz stockwork zone in diorite intrusion; many soil samples greater than 0.1 g/t Au	Goldquest (2012)
Connors (Bellas Gate, Camel Hill)	18.072	-77.165	Jamaica	n.d.	Discovered through stream-sediment geochemistry; numerous drill intercepts of more than 0.3% Cu	Fenton (1982), Orogrande Resources, Ltd. (1997); Carube Resources Inc., (2012)
Elección	20.160	-74.770	Cuba	n.d.	State-owned mining company Geominera estimated resource of 11.3 Mt at 1.12 % Cu, 0.124 g/t Au, 28.7 g/t Ag; 88 reverse circulation drill holes	Lavandero and others (1988) PR Newswire (1997)
Fortuna-Causalidad	22.146	-79.671	Cuba	n.d.	Limited information	Lavandero and others (1988)
Gaspar	21.771	-78.502	Cuba	n.d.	Preliminary drilling in 1996 suggested an epithermal Au deposit, possibly underlain by a deep porphyry system; anomalous Au and Cu	Lavandero and others (1988) KWG Resources Inc., (1996)
Grand Bois	19.610	-72.407	Haiti	n.d.	Seventeen drill holes with numerous intercepts more than 0.2% Cu and more than 0.5 g/t Au; large Cu anomaly in soil	Eurasian Minerals, Inc. (2010a,b)
La Guaimaro	21.035	-77.348	Cuba	n.d.	Limited information	Lavandero and others (1988)
Macagua	22.153	-80.091	Cuba	n.d.	Limited information	Lavandero and others (1988)
Majagual	18.467	-70.217	Dominican Republic	n.d.	Stockwork zone near quartz-feldspar porphyries; large zone of rock and soil samples enriched in copper and gold	Energold Mining, Ltd. (2010a,b)
Piletas	18.324	-66.872	Puerto Rico	n.d.	Based on aeromagnetic anomalies. No plutonic rocks exposed	Cox (1973)
Platanos	18.253	-66.855	Puerto Rico	n.d.	Chalcopyrite in small veins in an area of phyllic alteration; stream-sediment samples contain up to 1,000 ppm Cu	Cox (1973)
Treuil	19.747	-72.644	Haiti	n.d.	Numerous grab samples grading more than 1% Cu, 0.5 g/t Au, 30 g/t Ag; mostly high-grade NNW-trending veins	Eurasian Minerals, Inc. (2010a,b)

copper, 0.124 g/t gold; KWG Resources, Inc., 2002). Republic Goldfields' plans called for a drilling program to confirm the continuity of the mineralization, which was unknown due to previous poor drill recoveries. Gold sampling and assaying at the Elección and Jobita prospects was also planned to evaluate the concession's potential to host a bulk tonnage, low-grade porphyry Cu-Au operation. In 1995, KWG Resources acquired the interest from Republic Goldfields and in early 1996 and completed a very low frequency (VLF) electromagnetic (EM) geophysical survey following the cutting of a survey grid.

Casseus-Meme, Haiti

Mineralization at the Casseus Cu-Au deposit (Meme district), Haiti, is localized at the contact between the 66 Ma Terre-Neuve quartz monzonite, syenodiorite and granodiorite pluton and a large block of Upper Cretaceous limestone. Both the igneous rock and limestone were replaced by skarn containing garnet, diopside, hedenbergite, epidote, wollastonite, idocrase, scapolite, tremolite, and calcite. Metallization followed skarn formation and included deposition of hematite, magnetite, pyrite, molybdenite, chalcopyrite, bornite, chalcocite, and digenite in that paragenetic order. Copper and gold mineralization is associated with three small intrusions that are present within a northwest trending structural zone, with the Meme mine located at the southeast end of this trend. Majescor Resources, Inc. (2009) reports a partial resource of 7 Mt, with 0.757 percent copper. The mine was primarily active during the 1960s and produced ore from five working levels accessed by a series of adits (Kesler, 1966, 1968). Louca's (1989) United Nations summary report indicates that the Meme mine hosts a resource of 1.5 Mt grading 2.0 percent copper and 2.0 g/t gold. Gold and copper mineralization is present at the Casseus prospect, located 2 km to the northwest of Meme mine.

Treuil, Haiti

The Treuil area, located in northwest Haiti, encompasses a zone of oxide copper occurrences discovered and explored by UNDP during the 1978–83 timeframe. The UNDP work included regional stream-sediment sampling programs (1980–81), followed by soil sampling, trenching, and ground geophysical surveys (1983–84). No drilling has occurred on the property. The geology of the Treuil area consists of a north-south trending zone of quartz-diorite porphyry intrusions that are hosted in Cretaceous andesitic volcanics and calcareous siltstones and mudstones. Two porphyry-type mineralized systems have been identified. The Coupe Conte porphyry is located in the northern sector, and is 600 m north-south by 150 m east-west as currently defined. The Dacilia porphyry is located 2.2 km to the south, and has dimensions of 400 m north-south by 150 m east-west. The intrusive and volcanic rock units at Coupe Conte and Dacilia have undergone intense structural deformation.

Grand Bois, Haiti

The Grand Bois area in northern Haiti (fig. A1) principally is exploited for gold; however, soil anomalies and a series of drillhole intercepts identify copper mineralization adjacent to, and below, a known oxide gold resource (Eurasian Minerals, Inc., 2010a, b). A copper-in-soil anomaly area approximately 1.8 km by 1.1 km was delineated by 183 soil samples. Eighty two percent of the samples contained greater than 250 parts per million (ppm) copper, 36 percent contained greater than 500 ppm; a high-grade core area defined by 11 percent of the samples assayed greater than 1,000 ppm (0.1 percent) copper. Reportedly, drillholes consistently intersected chalcocite, covellite, and chalcopyrite in a sulfide copper zone below the oxide gold horizon. Many drill holes showed numerous intercepts with more than 0.2 percent copper and more than 0.5 g/t gold (Eurasian Minerals, 2010a).

Majagual, Dominican Republic

Exploration at Majagual, Dominican Republic, by Energold Mining Ltd. has yielded quantitative results including a copper anomaly with values ranging from above 500 ppm to greater than 1 percent over an area of 500 m by 800 m, accompanied by gold values greater than 90 parts per billion (ppb) and locally greater than 1 g/t. Molybdenum values are up to 250 ppm (Energold Mining, Ltd., 1997a, b). The anomaly is associated with a zone of magnetic highs which ring a central magnetic low, consistent with the alteration associated with a porphyry system. A highly conductive unit detected by an induced polarization (IP) survey indicates the presence of a sulfide zone at depth. The area is underlain by andesitic volcanic rocks and associated epiclastic sediments intruded by quartz-feldspar porphyry, dikes, plugs, and breccia pipes. A central zone of potassic alteration and an outer phyllic zone are overprinted by propylitic alteration. Copper occurs as chalcopyrite in coarse- to fine-grained disseminations, as fracture fillings, and in a vein stockwork developed within and near the quartz-feldspar porphyries. Sulfide-rich float samples with extensive secondary chalcocite occur in a creek that cuts through the center of the mineralized zone, indicating the possibility of a supergene enrichment zone.

Bayaguana, Dominican Republic

The Bayaguana prospect, Bayaguana district, Dominican Republic, which includes the Doña Amanda, Doña Loretta, and Cerro Kiosco target areas, was identified as a large-scale copper porphyry system. The prospect has an estimated inferred resource of 8.2 Mt at 0.5 percent copper (GlobeStar Mining Corp., 2010). The mineralization consists mainly of chalcopyrite and chalcocite in breccia pipes within quartz-feldspar porphyry. The mineralization appears to be confined to the breccia pipe and the porphyry between breccia pipe, with limited dissemination into the surrounding porphyry systems. The system is open in all directions and at depth. Copper-gold mineralization is mainly associated with the argillic alteration zones. Previously unknown zones of silicification and sulfide alteration have been recognized in sedimentary and volcaniclastic sequences along near-vertical northwest-trending fractures. The geology of the Bayaguana district is dominated by the Los Ranchos Formation which includes basalt flows, dacitic domes, and mixed volcaniclastic and sedimentary sequences. The Los Ranchos Formation is defined by a series of volcanic centers and coeval sedimentary basins. Dacite dome complexes are surrounded by pyroclastic aprons of coarsely fragmented heterolithic tuff breccias and interbedded finer-grained tuffs. In some areas, these volcanic and volcaniclastic sequences grade into carbonate-rich sedimentary sequences.

Piletas, Puerto Rico

The Piletas prospect (fig. A1) and other porphyry target areas (fig. A3) were identified in a 1:200,000-scale mineral assessment of Puerto Rico done by the USGS (Bawiec, 1999). The Piletas prospect underlies approximately 300 m of Oligocene sedimentary rocks (fig. A3). Aeromagnetic anomalies that are similar in form to highs associated with known porphyry copper deposits occur in the area and are on strike with deposits at Río Viví and Tanamá. At Criminales East (fig. A3), a breccia body contains pervasive quartz-sericite-pyrite altered rock, with outcrop values of up to 0.34 percent copper, and stream sediment values of 0.006–0.01 ppm gold. Criminales East is part of the Tanamá deposit, as defined by the rules adopted for defining deposits as geologic entities for assessment (Singer and others, 2008).

Copper Occurrences in the Virgin Islands

Hydrothermal alteration is widespread along the southern shores of both St. Thomas and St. John, U.S. Virgin Islands, and on many of the smaller islands (fig. A2). No porphyry copper prospects are known in the Virgin Islands. However, scattered skarn mineralization and possible porphyry-style alteration have been observed on St. John and also on Tortola and other islands immediately to the north and northeast in the British Virgin Islands group (Tucker and others, 1985). Geochemical studies on the U.S. Virgin Islands showed that the mineralized areas are related to major faults and transect all rock types (Alminas and others, 1994). Closely spaced quartz-potassium feldspar-chalcopyrite-pyrite-molybdenite veins cut porphyritic quartz diorite plutons of the Virgin Islands batholith (Longshore, 1965; Longshore and Donnelly, 1968; Helsley, 1960, 1971; Ratté, 1970; Kesler and others, 1975). Historical copper mining occurred along a hydrothermally altered north-striking fault zone at Copper Mine Point on the southern tip of Virgin Gorda in the British Virgin Islands (fig. A2). The mine site is now a tourist destination in a national park; the island of St. John (fig. A2) in the U.S. Virgin Islands is also a national park.

Exploration History

In the early 1970s the tract area underwent extensive regional- and prospect-scale exploration, initially as regional stream-sediment surveys by the UNDP. Several national survey efforts were undertaken to establish critical base information. Modern exploration for precious metals and porphyry copper deposits in the Santiago tract is quite variable and sporadic depending on the political and socio-economic context of the underlying country or territory; nevertheless, this tract contains some of the best-explored areas in the Caribbean Basin.

Cuba

In the western part of the tract, Cuban and Soviet geologists produced geologic and mineral resources maps of Cuba that showed the results of pre-1958 investigations and indicated the primary areas of future exploration (Institute of Geology and Paleontology, 1962, 1963). New 1:500,000- and 1:1,000,000-scale national geologic maps were published in 1985 and 1986 (USSR Ministry of Geology and the Cuban Ministry of Basic Industry, 1985; Mezhelovskiy, 1986; Pushcharovskiy and Mossakovskiy, 1986; Tikhomirov and others, 1987). A followup 1:500,000-scale mineral deposits map was published by Lavandero and others (1988). The current focus of exploration in the tract, as typified by exploration in the central and southern portions of the tract area, is directed toward Late Cretaceous to early Tertiary precious and polymetallic vein deposits, epigenetic skarn, and underlying or structurally uplifted porphyry copper deposits. To this end, in 1995, Joutel Resources and CaribGold announced plans for extensive airborne geophysics, ground surveys, and diamond drilling near Santa Clara, Camaguey, Purial, and the Sierra Maestra areas. Economically important epithermal precious metal deposits such as Pedro Barba, La Vega, Carlota, Regidor, Guadalupe, and La Zona Barita were identified and drilled (CaribGold Resources Inc., 1995; Joutel Resources Ltd., 1995). However, by 1999 options were dropped on many of the projects in these areas and no new information has been made available.

Jamaica

Two geochemical surveys, one using stream sediments in selected regions of Jamaica considered as having somewhat elevated mineral potential, and the other an island-wide low-density soil survey, were undertaken in 1986 and 1988, respectively (Canadian International Development Agency 1988a, 1988b, 1992, 1993). The stream-sediment survey (1 site per 1 km^2) led to the discovery of three new gold occurrences, one of which became a producing mine in 2001. The low-density soil survey (1 site per 64 km^2) identified the host rocks of three of these auriferous districts as having gold potential, including those of the producing mine, demonstrating its value as a broad-scale regional mineral reconnaissance tool (Garret and Geddes, 1991; Garret and others, 2004). In 1992, Golden Ring Resources began drilling on the Connors prospect and followed on Camel Hill. A detailed geological evaluation continued on several other targets and a second diamond drill rig was brought to the property early in the year. Golden Ring Resources dropped its option in the third quarter of 1992, after a second phase of drilling indicated a limited potential for increased tonnages. BHP briefly picked up a portion of the property but also ended with similar results. Modern exploration continued on the site by Orogrande Resources, Ltd. (Orogrande Resources, Ltd., 1997).

Hispaniola (Haiti and Dominican Republic)

The UNDP carried out regional stream-sediment surveys between 1973 and 1979 throughout northern Haiti, followed by soil sampling for targeted areas. These surveys outlined significant copper anomalies as well as a gold prospect near Grand Bassin, Haiti (Georges and others, 1978). The UNDP program found a soil copper anomaly of greater than 200 ppm copper centered on the Douvray and Blondin deposits (Valls, 2004). The UNDP program drilled five areas and located copper, copper-gold, and gold mineralization in northeast Haiti, and the Blondin-Douvray deposit proved to be the most significant of the findings. The UNDP also located a vein gold prospect (at Faille B), and demonstrated that anomalous gold was present for a strike length of 2 km. Following the UNDP work, BGR, in collaboration with the UN, tested the Douvray prospect with 24 drill holes from 1977 to 1980 and carried out a resource estimate. Much of the current exploration by Majescor Resources in the Blondin and Douvray copper-gold prospects is focused on evaluating porphyry copper mineralization in extensions of known skarn systems using mapping, geophysical techniques to estimate extensions of shallow buried intrusions, and targeted geochemistry to locate surface mineralization (Majescor Resources, Inc., 2009). Similar occurrences are being explored in Santo Domino, Dominican Republic, where Unigold is exploring targets with mineralization ranging from Cu-Au porphyry systems such as El Corozo and high-sulfidation epithermal gold at the Los Candelones deposit. GlobeStar Mining, exploring the Bayaguana district, located a large area of intense alteration associated with the Managua volcanic center, recognized as the largest hydrothermal alteration complex in Dominican Republic outside the Pueblo Viejo system, 70 km to the northwest.

Puerto Rico

Stream-sediment anomalies in the Río Viví area led to the discovery of mineralized porphyry in the walls of the river canyon. In 1960, a geochemical soil survey was conducted by Ponce Mining Company, which included drilling in the area (Lutjen, 1971). Other porphyry copper occurrences were discovered in the Río Tanamá watershed to the northwest. At least eight porphyry copper systems and their settings were delineated by USGS and exploration company investigations in the Lares-Adjuntas area (fig. A3) on the southwest flank of the Utuado batholith (Nelson and Tobish, 1968; Mattson, 1968; Cox, 1973; Cox and Briggs, 1973; Learned and Boissen, 1973; Cox and Learned, 1977; Barabas, 1982; Cox, 1985). The 1990 USGS resource assessment of the island focused on the undiscovered resources in porphyry copper, epithermal gold, lateritic nickel, and other deposits. A more detailed quantitative mineral resource assessment of undiscovered porphyry Cu-Au deposits was based on 1:50,000-scale geological and aeromagnetic maps from Kennecott Exploration Inc. and geochemical maps (Bawiec and others, 1991; Bawiec, 1999).

In June 1995, the Puerto Rican government amended Law Number 9 of August 18, 1933, to prohibit open pit mining, strip mining, or any other method to extract metallic minerals that could significantly alter the natural background of the mining area (Plaza Toledo, 2005). Subsequently, most of the prospective region became a protected forest. A geochemical background study (water, stream sediments, and vegetation) in the undeveloped mine area watershed was done to provide information on premining geochemical signatures that could be used as an analog for background characterization and establishing realistic reclamation goals for porphyry copper deposits in tropical climates (Plaza Toledo, 2005).

Sources of Information

Principal sources of information used by the assessment team for delineation of the Santiago tract are listed in table A5.

Grade and Tonnage Model Selection

The four known deposits (see table A3 and fig. A1) are all of the Cu-Au subtype and the deposits are all island-arc related. In the Cu-Au subtype, deposits have Au/Mo ratios greater than 30 or average Au grades greater than 0.2 g/t (Singer and others, 2008). Statistical tests (table 2) showed that the known deposits are not significantly different from either the global Cu-Au-Mo general model or the Cu-Au subtype model at the 1-percent level. Based on geologic rationale and a slightly better statistical fit of the available gold and molybdenum data, the Cu-Au subtype model was selected.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Based on the presence of intrusive and volcanic igneous rocks of appropriate age and composition, mapped alteration characteristic of porphyry copper deposits, and the occurrence of 4 known deposits and 9 prospect areas, the team arrived at a consensus estimate of 4 undiscovered deposits at a 90-percent confidence level, 11 undiscovered deposits at a 50-percent confidence level, and 22 undiscovered deposits at a 10-percent confidence level, which represents a mean of 12 undiscovered deposits (table A6). These estimates reflect the number of current exploration targets in play (some of which have partial delineated resources), copper skarn occurrences not associated with deposits, and the extent of geochemical anomalies and altered areas in the tract.

The portion of the tract underlain by the Commonwealth of Puerto Rico was previously assessed (Bawiec, 1999). In that

Table A5. Principal sources of information used for tract 003pCu4001 (CA_CARIB-KT1), Santiago region—Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, and the Virgin Islands.

[NA, not applicable]

Theme	Name or title	Scale	Citation
Geology	CBMap—Digital geologic map of the Caribbean Basin	1:500,000	Available for purchase from http://www.cbmap.net/
	Geologic map of Cuba	1:1,000,000	Pushcharovskiy and Mossakovskiy (1986)
		1:500,000	USSR Ministry of Geology and the Cuban Ministry of Basic Industry (1985)
Mineral occurrences	Porphyry copper deposits of the world—Database, map, and grade and tonnage models	NA	Singer and others (2008)
	Geology, geochemistry, geophysics, mineral occurrences and mineral resource assessment for the Commonwealth of Puerto Rico	1:200,000	Bawiec (1999)
	CBMap—Digital geologic map of the Caribbean Basin	1:500,000	Available for purchase from http://www.cbmap.net/
	U.S. Geological Survey Mineral Resources Data System	NA	U.S. Geological Survey (2005)
	Commercial databases	NA	http://www.metalseconomics.com/default.htm
Geochemistry	United Nations Development Program	NA	UNDP (1969)
	Geochemistry of stream-sediment samples, Puerto Rico	NA	Marsh (1992), Learned and others (1973)
Exploration	Company Web sites	NA	See table A4 and Prospects, Mineral Occurrences, and Related Deposit Types section of text

Table A6. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 003pCu4001 (CA_CARIB- KT1), Santiago Region—Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, and the Virgin Islands.

[N_{xx}, estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; s, standard deviation; C_v%, coefficient of variation; N_{known}, number of known deposits in the tract that are included in the grade and tonnage model; N_{total}, total of expected number of deposits plus known deposits; km², square kilometers; N_{total}/100k km², deposit density reported as the total number of deposits per 100,000 km². N_{und}, s, and C_v% are calculated using a regression equation (Singer and Menzie, 2005)]

Consensus undiscovered deposit estimates					Summary statistics					Tract area (km²)	Deposit density (N_{total}/100k km²)
N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	s	C_v%	N_{known}	N_{total}		
4	11	22	22	22	12	6.5	54	4	16	78,780	20

study, a permissive tract was outlined for undiscovered porphyry copper deposits at a scale of 1:200,000 (Bawiec, 1999). The authors defined a favorable area for the porphyry Cu-Au subtype within a larger permissive tract. The Puerto Rico assessment utilized 1:500,000- or larger-scale geologic maps, aeromagnetic maps provided by Kennecott Exploration Inc., and geochemical maps. They estimated two undiscovered deposits in Puerto Rico at a 90-percent confidence level, three undiscovered deposits at a 50-percent confidence level, and five undiscovered deposits at a 10-percent confidence level. This estimate was done at a much larger scale with more detailed geophysics and geochemistry than the present study, but is compatible with our broader estimate of the redefined Santiago tract.

The team also noted that Hispaniola has a number of prospects in play. The tract includes a mature oceanic arc with a long period of magmatic activity (Cretaceous-Eocene), four known deposits, and a number of significant prospects. Some areas of the tract may be underexplored.

Probabilistic Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered porphyry deposits with the porphyry copper, Cu-Au subtype of Singer and others (2008) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, 2012; and Duval 2012). Selected simulation results are reported in table A7. Results of the Monte Carlo simulation are presented as a cumulative frequency plot (fig. A4). The cumulative frequency plot shows the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

Table A7. Results of Monte Carlo simulations of undiscovered resources for tract 003pCu4001 (CA_CARIB- KT1), Santiago Region—Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, and the Virgin Islands.

[Cu, copper; Mo, molybdenum; Au, gold; and Ag, silver; in metric tons; Rock, in million metric tons]

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	1,500,000	4,100,000	27,000,000	82,000,000	100,000,000	36,000,000	0.39	0.02
Mo (t)	0	3,200	100,000	590,000	820,000	210,000	0.31	0.08
Au (t)	140	370	2,100	5,600	7,000	2,700	0.41	0.02
Ag (t)	0	520	5,800	32,000	48,000	12,000	0.29	0.05
Rock (Mt)	360	920	5,700	16,000	20,000	7,400	0.4	0.02

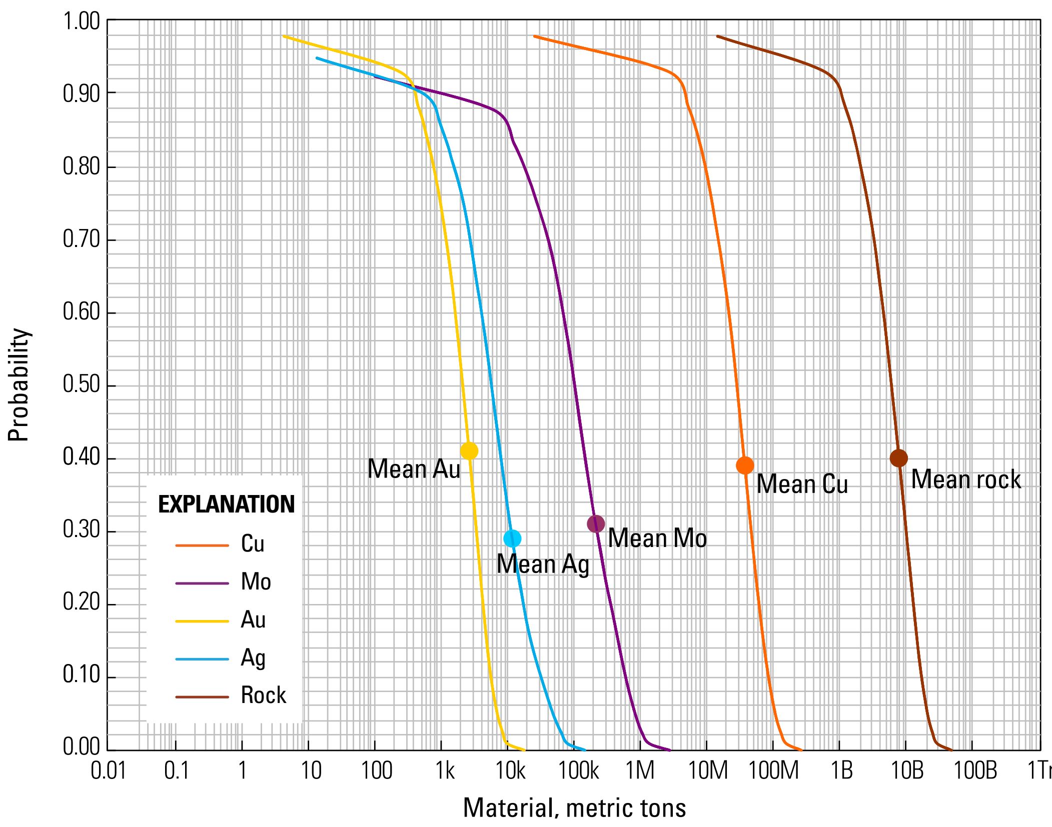


Figure A4. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in tract 003pCu4001(CA_CARIB-KT1), Santiago region—Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, and the Virgin Islands. k, thousands; M, millions; B, billions; Tr, trillions.

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Appendix B. Porphyry Copper Assessment for Tract 003pCu4003 (CA_CARIB-KT2), Chortis Region—El Salvador, Guatemala, Honduras, and Nicaragua

By Lukas Zürcher[1], Floyd Gray[2], Steve Ludington[2], Gilpin R. Robinson, Jr.[2], Jane M. Hammarstrom[2], Carl E. Nelson[3], and Barry C. Moring[2]

Deposit Type Assessed: Porphyry Copper

Descriptive model: Porphyry copper (Cox, 1986; Berger and others, 2008; John and others, 2010)
Grade and tonnage model: Global Cu-Au-Mo porphyry copper model (Singer and others, 2008).
Table B1 summarizes selected assessment results.

Table B1. Summary of selected resource assessment results for tract 003pCu4003 (CA_CARIB-KT2), Chortis region—El Salvador, Guatemala, Honduras, and Nicaragua.

[km, kilometers; km^2, square kilometers; t, metric tons]

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (t)	Mean estimate of undiscovered copper resources (t)	Median estimate of undiscovered copper resources (t)
April 2010	1	67,570	0	23,000,000	13,000,000

Location

The tract is centered on Honduras, extending southward into Nicaragua, with minor extensions into Guatemala and El Salvador (fig. B1).

Geologic Feature Assessed

Late Cretaceous through Oligocene continental arc of dioritic-tonalitic plutons that intrude Mesozoic sedimentary and older metamorphic rocks in northern Central America.

[1]University of Arizona, now at U.S. Geological Survey
[2]U.S. Geological Survey.
[3]Recursos del Caribe, S.A.

Delineation of the Permissive Tract

Tectonic Setting

Tract 003pCu4003 occupies most of the Chortis Block (fig. 4), a terrane that forms the nucleus of modern Central America. This block underlies portions of Guatemala, El Salvador, Honduras, and northern Nicaragua. This complex block of accreted crustal elements of diverse origin has long been recognized as a key to the origin and evolution of the Caribbean Plate (Gose and Swartz, 1977; Pindell and Dewey, 1982; Case and others, 1984; Dengo, 1985; Pindell and others, 2006). The Chortis Block includes Gondwana-derived Grenville and Paleozoic continental crust, proto-Caribbean Jurassic terranes, Late Jurassic-Early Cretaceous subduction complexes and sutures, and Late Jurassic-Early Cretaceous paleo-Pacific intraoceanic island arc complexes (Rogers and others, 2007).

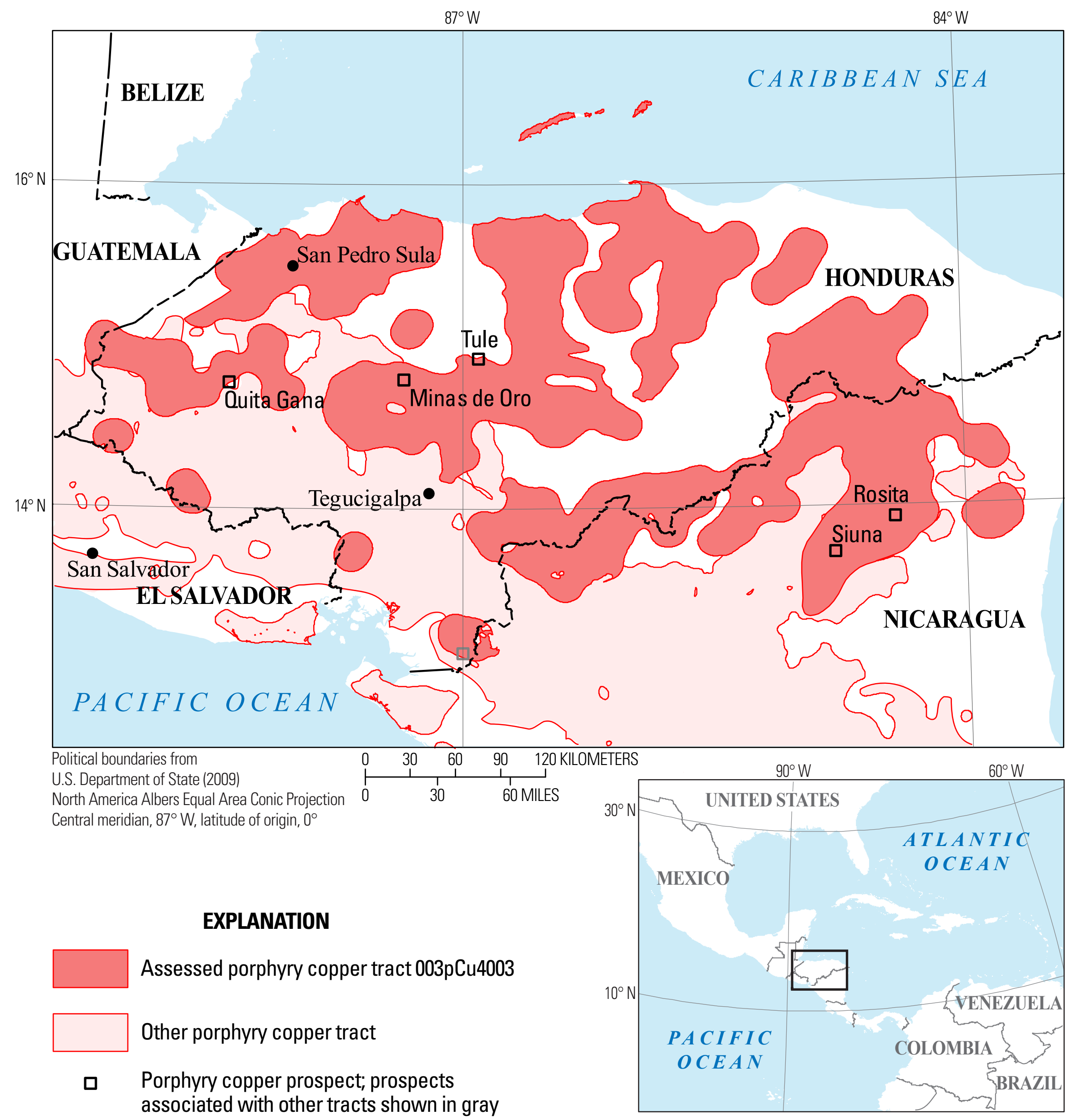

Figure B1. Map showing the tract location and significant prospects in tract 003pCu4003 (CA_CARIB-KT2), Chortis region—El Salvador, Guatemala, Honduras, and Nicaragua.

Table B2. Map units that define tract 003pCu4003 (CA_CARIB-KT2), Chortis region—El Salvador, Guatemala, Honduras, and Nicaragua.

[Geologic map units representing lithologic assemblages containing calc-alkaline volcanic rocks of Late Cretaceous to Early Tertiary age. Map unit, age range, and principal lithologies are based on a 1:500,000 digital geologic map of the Caribbean Basin (available for purchase at http://www.cbmap.net/)]

Map unit	Country	Age range	Lithology
			Intrusive rocks
Ki	Honduras	Cretaceous	Granites, granodiorites, diorites, and tonalites
KTi	Honduras	Cretaceous-Tertiary	Granites, granodiorites, diorites, and tonalites
Ti	Honduras	Tertiary	Granites, granodiorites, diorites, and tonalites
Ki	Nicaragua	Cretaceous	Granite, granodiorite
Ti	Nicaragua	Paleocene	Granodiorite, syenite
			Volcanic rocks
Tv	Honduras	Tertiary	Undifferentiated volcanic rocks of uncertain age; generally tuffs, andesites, and pyroclastic rocks

The currently accepted model that explains the tectonic history of the Chortis Block calls for large-scale strike-slip motion on the northern edge of the block (fig. 4). In this scenario, the Chortis Block was detached from its pre-middle Eocene position along the southwestern coast of Mexico and moved eastward by approximately 1,100 km of left-lateral strike-slip motion and about 30–40° of large-scale, counterclockwise rotation (Campa and Coney, 1983; Gose, 1985; Pindell and Barrett, 1990; Sedlock and others, 1993;Venable, 1994; Mann, 1999; Dickinson and Lawton, 2001; Keppie, 2004; Keppie and Moran-Zenteno, 2005; James, 2006; Pindell and others, 2006; Rogers and others, 2007).

For the purposes of the porphyry copper mineral resource assessment, the various terranes of the Chortis Block and the accreted Siuna terrane were evaluated as a composite area including all Cretaceous through Oligocene arc-related magmatism. Basement rocks in the Chortis Block include pre-Mesozoic metamorphic rocks, pre-Jurassic greenschist facies rocks, Mesozoic sedimentary strata, and tectonic slices of Cretaceous collisional and ophiolite complexes along the northern margin of the area. These rocks are unconformably overlain by unmetamorphosed Early Jurassic to Jurassic marine to lacustrine strata that grade upward to Late Cretaceous-Tertiary volcaniclastic rocks. These sequences are intruded by predominantly Late Cretaceous to early Eocene calc-alkaline mainly dioritic-tonalitic plutons related to the oblique subduction of the Farallon Plate (Donnelly and others, 1990; Sundblad and others, 1991). Associated Paleocene volcanic rocks cap the region and are composed mainly of calc-alkaline basaltic and andesitic volcanic rocks (Matagalpa Formation), which in many areas have been affected by hydrothermal alteration (McBirney and Williams, 1965; Weyl, 1980; INETER, 1995; Arengi and Hodgson, 2000).

The Farallon Plate gave way to the Cocos and Nazca Plates (fig. 3) about 26 Ma, generating a subduction zone that produced the younger magmatic arc (Cocos) along the Pacific coast. Miocene, dominantly calc-alkaline, ignimbrite sequences and upper Miocene-Quaternary basalts, including the Pleistocene-Holocene stratovolcanoes, form the youngest volcanic cover along the Pacific margin.

Geologic Criteria

Tract 003pCu4003 was constructed using a 1:500,000-scale digital geologic map of the Caribbean Basin (available for purchase at http://www.cbmap.net/) in ArcGIS to identify areas of permissive rock types. Geologic information found in attribute tables associated with those maps allowed the team to identify polygons representing lithologic assemblages that include permissive igneous rocks. Polygons representing lithologic assemblages not considered permissive by reason of age or composition were excluded.

Intrusive and volcanic rock map units selected from the digital geologic map to initially define the permissive tract are listed in table B2 and shown on figure B2. Areas of rocks that are potentially permissive for Late Cretaceous to early Tertiary porphyry copper deposits under shallow cover (less than 1 km thick) were included in the tract by using GIS tools to create a 10-km buffer around appropriate intrusive rocks and a 2-km buffer around appropriate volcanic rocks. The tracts defined by the buffer criteria were extended in some cases to include additional areas that are suggestive of shallowly buried plutonic rocks based on aeromagnetic data (Rogers and others, 2007). Larger-scale (1:250,000) geologic maps and literature were consulted and used to check map unit boundaries, ages, and structures (see Pindell and Barrett, 1990; Sedlock and others, 1993; Rogers and others, 2007).

Table B3. Significant prospects and occurrences in tract 003pCu4003 (CA_CARIB-KT2), Chortis region—El Salvador, Guatemala, Honduras, and Nicaragua.

[%, percent; g/t, grams per metric ton; Mt, million metric tons; ppm, parts per million; t, metric tons; oz, ounces; n.d., no data. All five prospects are considered to be significant]

Name	Latitude	Longitude	Country	Age	Comments	Reference
Quita Gana	14.727	-88.337	Honduras	n.d.	Skarn and replacement deposits; partial resource of 1.52 Mt at 2.17% Cu, 2.46 % Zn, 55 ppm Ag	UN Revolving Fund for Natural Resources Evaluation (1988), Nelson and Nietzen (2000)
Minas de Oro	14.801	-87.355	Honduras	Paleocene(?)	Skarn. Tetanacho reserves: 6.2 Mt at 0.76% Cu, 0.7 g/t Au; Montecielo-Iran reserves: 3.3 Mt at 0.9% Cu, 0.9 g/t; Minas Viejas (North Zone) 2.4 Mt at 0.82% Cu, 0.8 g/t Au. Stockwork zone present	Drobe and Cann (2000)
Tule	14.929	-86.906	Honduras	n.d.	Significant gold and copper values are associated with pervasive sericite, chlorite, iron oxide alteration and quartz veins and are hosted in the intrusions	First Point Minerals Corp. (2010)
Siuna (La Luz)	13.718	-84.781	Nicaragua	n.d.	Skarn deposit with past production; historical resource estimate of 10,600,000 t containing 816,958 oz Au	Plecash and Hopper (1963), Arengi and others (2003), Calibre Mining Corp. (2009)
Rosita	13.928	-84.424	Nicaragua	n.d.	Production: 5,374,688 tons at 2.57% Cu, 0.03 g/t Au, 15.22 g/t Ag.	Arengi and others (2003)

Tract boundaries were clipped along coastlines using the accepted international boundaries for the project (U.S. Department of State, 2009).

Known Deposits

No porphyry copper deposits are known within the tract.

Prospects, Mineral Occurrences, and Related Deposit Types

Table B3 lists significant prospects with characteristics of porphyry copper deposits in the Chortis tract. Three of these prospects primarily are skarn rather than porphyry copper prospects, but could be associated with porphyry copper systems.

Quita Gana, Honduras

The Quita Gana skarn prospect has been explored via regional geological mapping, geochemical and geophysical surveys, and follow-up diamond drilling. It is estimated to contain approximately 1.5 Mt grading about 2 percent copper, 2.5 percent zinc, and 55 g/t silver (United Nations Revolving Fund for Natural Resources Evaluation, 1988).

Minas de Oro, Honduras

The Minas de Oro Cu-Au skarn and replacement prospect (fig. B1) formed in Cretaceous volcano-sedimentary rocks along the margins of the early Paleocene Minas de Oro Granodiorite, a granodiorite to dacite intrusive complex. Nine skarn zones that include 30 or more skarn bodies are recognized within a 7 by 3 km area (Drobe and Cann, 2000). Multiple prospects are located within a radius of 2 km; these are grouped as the Minas de Oro prospect (table B3). Weak porphyry Cu-Mo mineralization is associated with quartz-feldspar porphyry near the Iran skarn (Drobe and Cann, 2000). The project encompassing the Minas de Oro prospect covered 10,000 hectares (ha) as of the end of 2008 (Tombstone Exploration, 1995; Rusoro Mining, Ltd., 2008).

Skarns include (1) massive brown-green andradite and lesser magnetite and pyroxene, (2) magnetite and hematite with less than 50 percent garnet, and (3) more than 50 percent pyrrhotite and chalcopyrite with interstitial garnet or pyroxene. Gold and copper are present in potentially economic concentrations in all skarn types; silver, lead, zinc, and molybdenum are locally abundant. The highly variable distribution and nature of these skarn deposits is controlled by intrusive activity, composition of host rocks, faulting and fracturing, and the attitude of host carbonates. Low-temperature replacement mineralization containing gold, copper, and arsenic occurs in calcareous sandstone and conglomerate about 2 km away from the skarns and is composed of masses of copper sulfides hosted within a zone of brecciation and quartz flooding. Garnet and (or) magnetite skarn are absent in these distal copper occurrences.

In the northern part of the central zone of the district, the Tatanacho area is the most well-explored skarn body (58 drill holes). This 1.5-km-by-1-km zone was the focus of 1970s-era exploration and early attempts to mine gold and copper from magnetite-garnet skarn with copper carbonate and oxide (Drobe and Cann, 2000). Numerous faults intersect in the area and feldspar-hornblende porphyry dikes are common. Tatanacho consists of a massive garnet skarn and sulfides that are preserved at depth. The skarn is bounded to the west by Honduras Group sediments and to the east by marble and quartz-feldspar porphyry. The mineralization is not confined to the skarn body and is open in all directions.

Tule, Honduras

Intrusion-hosted gold and porphyry Cu-Au mineralization at the Tule property, a recent discovery by First Point Minerals Corp. (2010), is located 100 km northeast of Tegucigalpa in central Honduras. Massive Mesozoic platform limestones and associated sediments are intruded by Tertiary diorite and granodiorite. Gold and copper values in the intrusions are associated with pervasive sericite, chlorite, iron oxide alteration, and quartz veins. A gold and copper soil anomaly on the eastern end of the soil grid measures 1,500 m by 600 m and is open on all sides except to the west. The two significant mineralized and anomalous areas correlate with intrusion-hosted gold mineralization in the western margin of the grid and porphyry Cu-Au mineralization in the eastern end of the grid (First Point Minerals Corp., 2010).

Siuna, Nicaragua

The Siuna (La Luz) prospect hosts gold skarn mineralization and associated porphyry mineralization. Past production at the site yielded 17 Mt of ore containing more than 2 million ounces (oz) of gold and almost 700,000 oz of silver. The mining camp covers 9,500 ha of concessions and

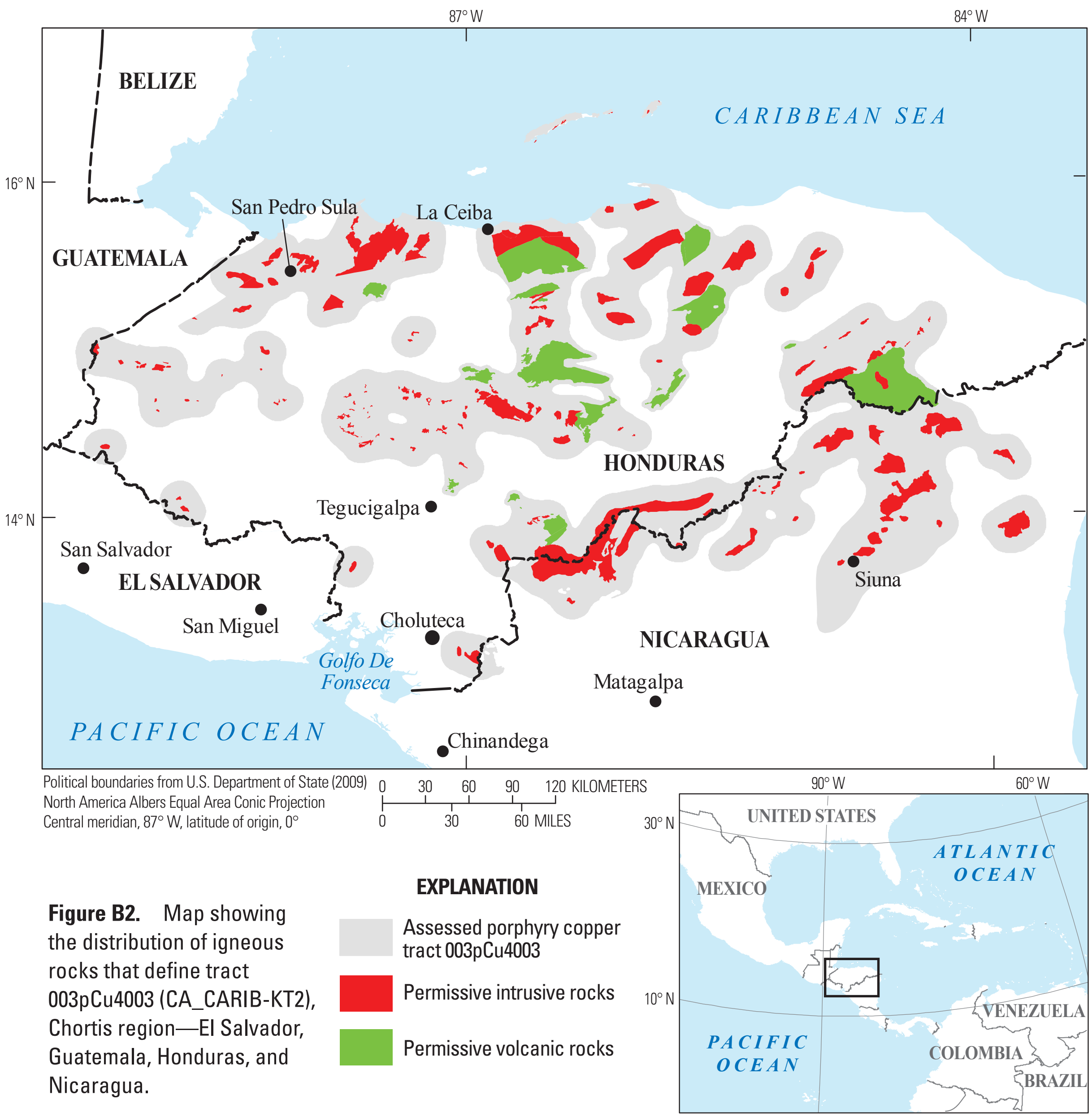

Figure B2. Map showing the distribution of igneous rocks that define tract 003pCu4003 (CA_CARIB-KT2), Chortis region—El Salvador, Guatemala, Honduras, and Nicaragua.

Table B4. Principal sources of information used for tract 003pCu4003 (CA_CARIB-KT2), Chortis region—El Salvador, Guatemala, Honduras, and Nicaragua.

[NA, not applicable]

Theme	Name or title	Scale	Citation
Geology	CBMap—Digital geologic map of the Caribbean Basin	1:500,000	Available for purchase at http://www.cbmap.net/
	Geologic map of Guatemala	1:500,000	Bonis and others (1970)
	Preliminary geologic map of Nicaragua	1:1,000,000	Maximiliano and Martínez (1974)
Mineral occurrences	Porphyry copper deposits of the world—Database, map, and grade and tonnage model	NA	Singer and others (2008)
	Honduras mineral resources	1:1,000,000	AID Resources Inventories Center (1965)
	CBMap—Digital geologic map of the Caribbean Basin	1:500,000	Available for purchase at http://www.cbmap.net/
	Nicaragua mineral inventory	1:500,000	Catastro e Inventario de Recursos Naturales and El Departmento de Desarrollo Regional [1977?]
	Mineral resources in Nicaragua	NA	Darce (1993)
	U.S. Geological Survey Mineral Resources Data System	NA	U.S. Geological Survey (2005)
	Metals Economic Group database	NA	http://www.metalseconomics.com/default.htm
Geochemistry	United Nations Development Program	NA	UN Revolving Fund for Natural Resources Evaluation (1988)
Exploration	Company Web sites	NA	See references in table C3
Geophysics	Tectonic terranes of the Chortis Block based on integration of regional aeromagnetic and geologic data	1:500,000	Rogers and others (2007)

includes the past-producing Siuna gold skarn. The Siuna Camp consists of a 12 km long by 1–2 km wide, north-northeast oriented arcuate belt of limestone and calcareous sediments in contact and interbedded with andesitic volcanics. Subvolcanic intermediate to mafic dikes and sills intrude this sequence and are related to the Au-Cu skarn deposits at Siuna. The extensive exposures of sediments suggest fairly shallow levels of erosion in this camp, making it more prospective for additional skarn and porphyry-style mineralization, rather than epithermal mineralization (Arengi and others, 2003).

Rosita, Nicaragua

Exploration at the Rosita Camp covers 20,500 ha of concessions, including the past-producing Santa Rita mine that produced copper and gold from skarn. The Santa Rita copper mine was in production from the mid-1960s to the early 1980s and had a low-grade resource remaining at the time it was shut down; at closure, the Santa Rita total resource was listed as 15.3 Mt, containing 149 t copper and 9 t gold (Bevan, 1973). Past production is reported as about 5.4 Mt of rock that produced more than 138,000 t copper, about 5 t gold, and about 74 t silver (Arengi and others, 2003). The northern part of the Rosita camp is characterized by Matagalpa Group andesitic volcanic and minor pyroclastic rocks and associated intermediate to felsic intrusions. The Cu-Au skarn deposits at the historic Santa Rita mine are spatially related to these intrusions. There are also significant exposures of limestone and calcareous sediments in the southeastern part of the camp. Low sulfidation style epithermal veins are reported in proximity to some skarn prospects (Arengi and others, 2003).

Exploration History

Exploration was conducted in Honduras in the 1980s by the United Nations Development Program (United Nations Revolving Fund for Natural Resources Evaluation, 1988). Small-scale gold mining occurred in the Minas de Oro district, Honduras in the 1880s and early 1900s. Modern exploration in the Minas de Oro skarn district occurred from 1965 to 1975, and started again in the 1990s (Drobe and Cann, 2000), continuing until the early 2000s when the mining law in Honduras was put on hold. Exploration activity in much of the tract is, as of 2010, suspended.

Sources of Information

Principal sources of information used by the assessment team for delineation of 003pCu4003 are listed in table B4.

Grade and Tonnage Model Selection

The porphyry Cu-Au-Mo model of Singer and others (2008) was selected for the assessment as a default based on geologic characteristics of the tract and insufficient information to do statistical tests.

Table B5. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 003pCu4003 (CA_CARIB-KT2), Chortis region—El Salvador, Guatemala, Honduras, and Nicaragua.

[N_{xx}, estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; *s*, standard deviation; C_v%, coefficient of variance; N_{known}, number of known deposits in the tract that are included in the grade and tonnage model; N_{total}, total of expected number of deposits plus known deposits; km², square kilometers; N_{total}/100k km², deposit density reported as the total number of deposits per 100,000 km². N_{und}, *s*, and C_v% are calculated using a regression equation (Singer and Menzie, 2005)]

Consensus undiscovered deposit estimates					Summary statistics					Tract area (km²)	Deposit density (N_{total}/100k km²)
N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	s	C_v%	N_{known}	N_{total}		
2	5	12	12	12	6.1	3.7	61	0	6.1	67,570	9

Table B6. Results of Monte Carlo simulations of undiscovered resources for tract 003pCu4003 (CA_CARIB-KT2), Chortis region—El Salvador, Guatemala, Honduras, and Nicaragua.

[Cu, copper; Mo, molybdenum; Au, gold; and Ag, silver; t, metric tons; Mt, million metric tons]

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	330,000	1,400,000	13,000,000	54,000,000	82,000,000	23,000,000	0.32	0.04
Mo (t)	0	1,000	230,000	1,600,000	2,600,000	640,000	0.26	0.1
Au (t)	0	10	300	1,400	2,000	570	0.31	0.08
Ag (t)	0	0	2,600	19,000	30,000	7,300	0.27	0.15
Rock (Mt)	76	330	2,800	11,000	17,000	4,600	0.33	0.04

Estimate of the Number of Undiscovered Deposits

The tract is a large, underexplored area in a remote setting. The team interpreted the area as a possible fragment of the Guerrero terrane, a Paleocene to Miocene continental arc that was delineated as tract 003pCu3011 (MX-T3) in southwestern Mexico (Hammarstrom and others, 2010). The Mexican tract includes known porphyry copper deposits and prospects, similar gold and iron skarns, and intrusive rocks of late Laramide to Tertiary age. The skarns in the Chortis tract have indications of associated porphyry-style stockwork mineralization. The team considered these porphyry-type and related prospects to be important; these prospects might be associated with deposits like those included in the selected grade-tonnage model (Einaudi, 1982; Cox, 1986; Singer and others, 2008). Several prospects were undergoing exploration and development at the time of the assessment (Minas de Oro, Siuna, Rosita, and Tule). In addition to the significant porphyry copper prospects listed in table B3, more than 10 additional veins, as well as skarn prospects in the tract, are considered to be indicators of porphyry copper deposits. The tract also contains many small intrusive bodies surrounded by coeval volcanics, and the distribution of skarn and epithermal deposits indicates that much of the tract has been eroded to a depth that is prospective for porphyry copper mineralizaion (Arengi and Hodgson, 2000). Based on these considerations, the assessment team concluded that there is a 90-percent chance of 2 deposits or more, a 50-percent chance of 5 deposits or more, and a 10-percent chance of 12 or more porphyry copper deposits with grade-tonnage characteristics consistent with the porphyry Cu-Au-Mo model (table B5). No deposits are known within the tract; six or more undiscovered deposits are expected based on the estimates (table B5).

Probabilistic Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining team estimates for numbers of undiscovered porphyry deposits with the general porphyry copper model of Singer and others (2008) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, 2012; Duval, 2012). Selected simulation results are reported in table B6. Results of the Monte Carlo simulation are presented as a cumulative frequency plot (fig. B3). The cumulative frequency plot shows the estimated resource amounts associated with cumulative probabilities of occurrence as well as the mean for each commodity and for total mineralized rock.

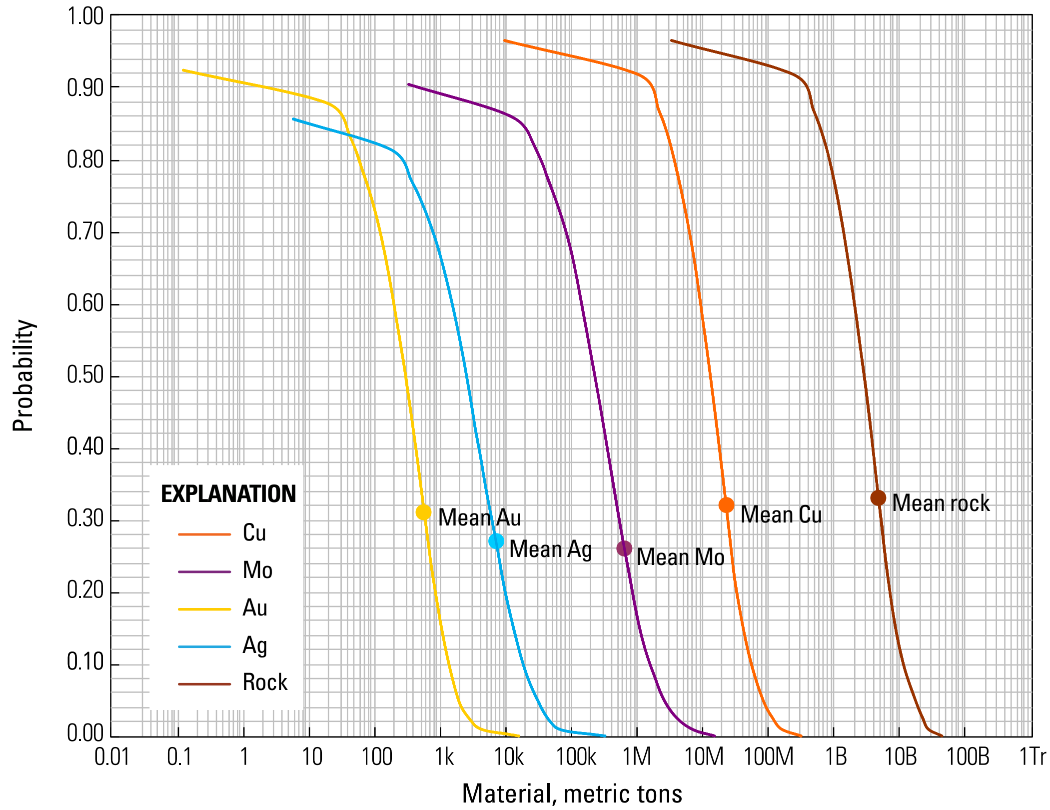

Figure B3. Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in tract 003pCu4003 (CA_CARIB-KT2), Chortis region—El Salvador, Guatemala, Honduras, and Nicaragua. k, thousands; M, millions; B, billions; Tr, trillions.

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Appendix C. Porphyry Copper Assessment for Tract 003pCu4002 (CA_CARIB-T1), Darién Region—Panama

By Floyd Gray[1], Lukas Zürcher[2], Steve Ludington[1], Jane M. Hammarstrom[1], Gilpin R. Robinson, Jr.[1], Carl E. Nelson[3], and Barry C. Moring[1]

Deposit Type Assessed: Porphyry Copper

Descriptive model: Porphyry copper (Berger and others, 2008; John and others, 2010)
Grade and tonnage model: Global Cu-Au-Mo porphyry copper model (Singer and others, 2008).
Table C1 summarizes selected assessment results.

Table C1. Summary of selected resource assessment results for tract 003pCu4002 (CA_CARIB-T1), Darién region—Panama.

[km, kilometers; km², square kilometers; t, metric tons]

Date of assessment	Assessment depth (km)	Tract area (km²)	Known copper resources (t)	Mean estimate of undiscovered copper resources (t)	Median estimate of undiscovered copper resources (t)
April 2010	1	16,480	19,000,000	14,000,000	6,900,000

Location

The Darién tract is located in eastern Panama (fig. C1) and is continuous with the Acandi tract (005pCu1001) in Colombia (Cunningham and others, 2008).

Geologic Feature Assessed

Paleocene through Oligocene island arc-related calc-alkaline igneous rocks that were formed as the Nazca Plate was subducted beneath the Caribbean Plate.

[1]U.S. Geological Survey.
[2]University of Arizona; now at U.S. Geological Survey.
[3]Recursos del Caribe, S.A.

Delineation of the Permissive Tract

Tectonic Setting

The Darién tract includes Paleocene through Oligocene island arc-related calc-alkaline igneous rocks of the Panama Arc that were formed as the Nazca Plate was subducted beneath the Caribbean Plate (fig. 3). The arc was built on oceanic crust of early Campanian age (Kesler and others, 1977; del Guidice and Recchi, 1969; Ferencić, 1970, 1971; Bandy and Casey, 1973; Case, 1974). The eastern portion of the arc is sutured with South America in northwestern Colombia to create the Isthmus of Panama; this late Oligocene to mid-Miocene accretion effectively shut off subduction and subduction-related magmatic activity in eastern Panama. The subduction and subduction-related magmatic activity shifted to the west through Miocene time (Wadge and Burke, 1983; Kellogg and Vega, 1995; Mann and Kolarsky, 1995; Trenkamp and others, 2002; Coates and others, 2004).

Geologic Criteria

The 16,480-km^2 tract consists of calc-alkaline intermediate and minor felsic igneous centers with coeval volcanic rocks that intrude and overlie a widespread early arc-related tholeiitic volcanic suite (Donnelly and others, 1990). The overlying volcanic rocks include andesitic and dacitic flows and associated agglomerates that are interlayered with and overlain by extensive rhyolitic and dacitic ignimbrite sheets (Williams and McBirney, 1969). Intrusive activity began in Paleocene to Eocene time in eastern Panama. Intrusions in the Cerro Azul and Río Pito prospect areas (fig C1) yielded radiometric ages on hornblende of 61.53±0.70 and 48.45±0.55 Ma, respectively. Intrusions of roughly equivalent age and composition occur further to the east in northwestern Colombia and form the remnants of a subduction zone positioned off northern South America in Eocene time (Tschanz and others, 1974; Kesler and others, 1977; von Huene and others, 1995; Coates and others, 2004). Magmatic activity shifted westward during the Oligocene, principally around the Cobre Panama deposit in western Colón province. Miocene volcanism occurred in western Panama as well as in adjacent Costa Rica; however, few intrusive rocks and no

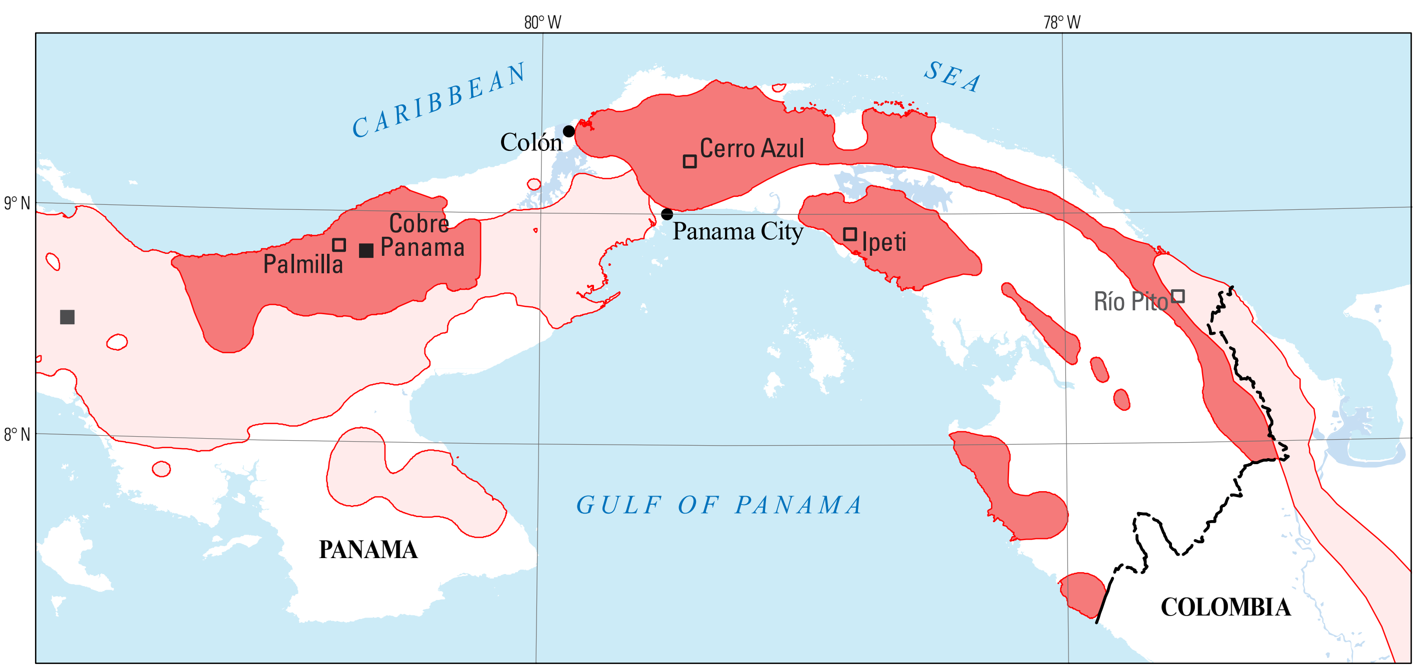

Figure C1. Map showing the location of tract 003pCu4002 (CA_CARIB- T1), Darién region—Panama.

related porphyry occurrences of Miocene age are recognized, reflecting a period of stagnation along the ridge that separates the Cocos and Nazca Plates (fig. 3).

Calc-alkaline intrusive rocks in the Panama Arc have been divided into a quartz diorite group and a granodiorite group, named for the most common rock type found within each group (Kesler and others, 1977). The quartz diorite group, which consists of hornblende-quartz diorite and hornblende olivine gabbro to granodiorite, includes rocks from the Cerro Azul plutonic complex (fig. C2) and from the Río Pito prospect area (fig. C1). Diorite and quartz diorite at Cerro Azul were dated as Paleocene and included in discussions of island-arc rocks associated with porphyry copper mineralization by Kesler and others (1977) and Nelson (2007). In the Río Pito area, quartz porphyry plugs are found along the southern margin of the quartz diorite-granodiorite batholith of the Darién Massif that runs along the northeast coast of Panama. The granodiorite group includes rocks from the Cobre Panama area in western Panama and the Río Guayabo area from eastern Panama (fig. C2). Rocks from this group are dominantly quartz diorite to quartz monzonite. Porphyritic rocks, including a biotite-hornblende-plagioclase porphyry unit, are relatively common throughout the area and are well developed at Río Guayabo.

Tract 003pCu4002 was constructed using the 1:500,000 digital geologic map of the Caribbean Basin (available for purchase at http://www.cbmap.net/) in ArcGIS to identify areas of permissive rock types. Geologic information found in attribute tables associated with the map allowed us to identify polygons representing lithologic assemblages containing rocks of the appropriate age and composition to be included in this permissive tract.

Intrusive and volcanic rocks selected from the digital geologic-map units to define the permissive tract are listed in table C2 and shown on figure C2. From each map unit listed, we selected only those sets of polygons that represent lithologic assemblages containing permissive rock types. Potentially permissive areas for Paleocene through Oligocene porphyry copper deposits under shallow cover (less than 1 km thick) were defined by using GIS tools to create a 10-km buffer around the appropriate age and composition igneous rocks and a 2-km buffer around appropriate volcanic rocks. The tracts defined by the buffer criteria were extended in some cases to include additional areas that are suggestive of shallowly buried plutonic rocks based on aeromagnetic data.

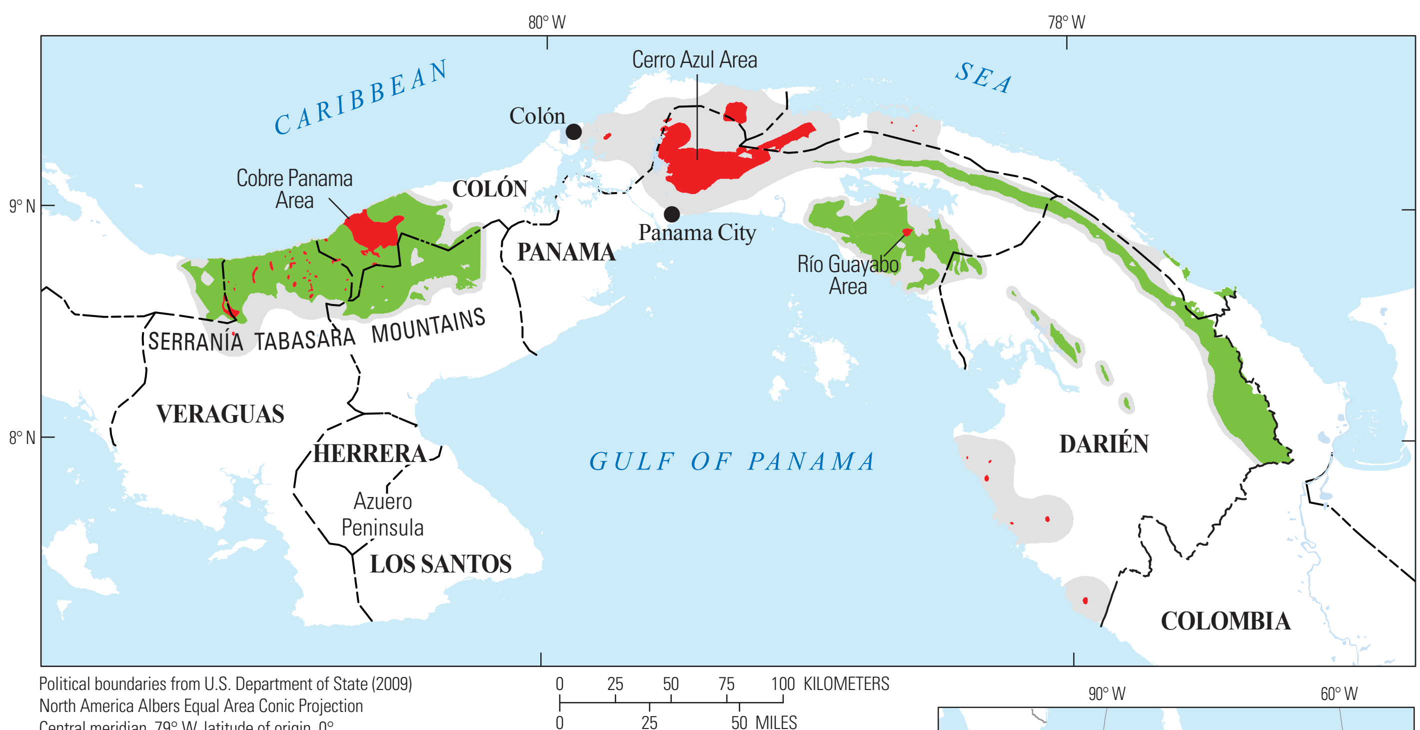

Figure C2. Map showing permissive rocks used to define tract 003pCu4002 (CA_CARIB-T1), Darién region—Panama.

Table C2. Map units that define tract 003pCu4002 (CA_CARIB-T1), Darién region—Panama.

[Geologic map units representing lithologic assemblages containing calc-alkaline volcanic rocks of Late Cretaceous to Oligocene ages. Map unit, age range, and principal lithologies are based on a 1:500,000 digital geologic map of the Caribbean Basin (available for purchase at http://www.cbmap.net/)]

Map unit	Age range	Lithology
		Intrusive rocks
Ti(Olig)	Oligocene	Granodiorite, quartz monzonite, gabbrodiorite, diorite, and dacite
Ti(Eoc)	Eocene	Granodiorite
Ti(Pal)	Paleocene	Quartz diorite, granodiorite
Ki	Cretaceous	Quartz diorite, granodiorite, diorites, gabbros, monzonite, and ultrabasic rocks
		Volcanic rocks
Ti	Oligocene	Principally dactite; includes minor granodiorite
Tv	Oligocene	Andesites/basalts, pyroclastics, and boulders; lavas and tuffs
KTv	Cretaceous-Tertiary	Volcanic agglomerates, breccias, conglomerates, interstratified fine-grained tuffs

Table C3. Identified porphyry copper resources in tract 003pCu4002 (CA_CARIB- T1), Darién region—Panama.

[Ma, millions of years before present; Mt, million metric tons; %, percent; g/t, grams per metric ton; t, metric ton. Contained Cu in metric tons is computed as tonnage (Mt × 1,000,000) × Cu grade (percent) × 0.01]

Name	Latitude	Longitude	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained Cu (t)	Reference
Cobre Panama	8.830	-80.664	31.4	6,405	0.301	0.0065	0.05	1.152	19,300,000	Ferencĭć (1970), Kesler and others (1977), Nelson (1995), Speidel and others (2001), Inmet Mining Corp. (2010), Rose and others (2010)

Larger scale (1:250,000) geologic maps and literature were consulted and used to check map unit boundaries, ages, and structures (Nelson, 2007; Inmet Mining Corp., 2010). Tract boundaries were clipped along coastlines using the accepted international boundaries for the project (U.S. Department of State, 2009).

Known Deposits

Cobre Panama, located in Colón province, Panama, approximately 120 km west of Panama City, is the only known porphyry copper deposit in the tract (fig. C1, table C3). The deposit area, formerly known as Petaquilla Copper, consists of a cluster of calc-alkaline porphyry Cu ± Mo ± Au mineralized systems with well-defined identified reserves occupying an area of approximately 13,600 ha (Inmet Mining Corp., 2009, 2010). Estimated reserves for the developing deposit are 6,406 Mt averaging 0.301 percent copper, 0.05 g/t gold, 0.007 percent molybdenum, and 1.152 g/t silver (Inmet Mining Corp., 2010). This porphyry system fits descriptive models for porphyry copper deposits by Cox (1986) and Singer and others (2008).

The deposit area initially was discovered based on copper anomalies in stream-sediment surveys done by the United Nations Development Program (United Nations Development Program, 1969). Mineralization in the western portion of the deposit consists of a multiphase intrusive complex that includes diorite to granodiorite, quartz monzonite, and dacite porphyry that is stock-like in its center but displays abundant subhorizontal interfingerings with hornfelsed andesite on its margins (Speidel and others, 2001). Mineralization is associated with an east-southeasterly trending, shallow, north-dipping, 2.5 km by 1 km feldspar-quartz-hornblende porphyry sill-and-dike complex that intrudes granodiorite and andesitic volcanic rocks. Kesler and others (1977) reported an age of 31.4 Ma from secondary biotite in this area of the deposit, which is thought to represent the age of porphyry-style mineralization. To the south, mineralization occurs in an elliptical zone approximately 2 km by 1 km in size, with a southeast elongation, and is associated with a southeast-trending feldspar-quartz-hornblende porphyry lopolith bounded to the north and south by andesitic volcanic rocks and minor granodioritic dikes. The overall area has a funnel shape with mineralization occurring in the contact zone between granodioritic intrusive rocks and the host andesite hornfels. Interfingering of andesite and intrusive rock is common along the intrusive contact (Speidel and others, 2001).

In the eastern part of the deposit, mineralization occurs as an elongate (east-southeast), thick sheet that thickens to the west, with a depressed central portion partly underlying an andesitic roof pendant (Speidel and others, 2001). Locally, a number of north-dipping feldspar-quartz-hornblende porphyry dikes cut granodiorite. Several structural domains are bounded by wide (tens of meters) and continuous east-west and northeasterly striking normal faults that show strong phyllic or phyllic-argillic alteration and control stockwork development.

To the southeast, the host rocks are dominantly feldspar-quartz or feldspar-quartz-hornblende porphyries. Pervasive sericite, clay, and pyrite are associated with well-developed quartz stockworks in the mineralized area. Hypogene sulfides occur as disseminations, microveinlets, fracture fillings, and

Table C4. Significant prospects and occurrences in tract 003pCu4002 (CA_CARIB-T1), Darién region—Panama.

[%, percent; g/t, grams per metric ton; Mt, million metric tons; Ma, millions of years before present; n.d., no data; ppm, parts per million]

Name	Latitude	Longitude	Age (Ma)	Comments	Reference
Palmilla	8.852	-80.767	31.4	Partial resource of 13 Mt at 0.3% Cu, 1.029 g/t Au; drilled in late 1990s	Speidel and others (2001); Inmet Mining Corp. (2010)
Ipeti	8.917	-78.817	n.d.	Geologic mapping, soil surveys, and a mag/VLF-EM survey identified a geochemical and geophysical anomaly; grab samples up to 0.39% Cu and 0.29 g/t Au	International CanAlaska Resources Ltd. (1997)
Cerro Azul	9.230	-79.430	57	Porphyry copper prospect? Limited information	Nelson (1995); Kesler and others (1977)
Río Pito*	8.66	-77.55	48.5	Stream sediment anomalies over large area yielded values of up to 1,200 ppm Cu, 28 ppm Mo, 540 ppm zinc, and 30 ppm Pb. Estimated resource of 180 Mt at 0.6% Cu	Nelson (1995); Kesler and others (1977)

*shown for reference only; included in Acandi tract 005pCu1001 (SA01PC) of Cunningham and others (2008)

quartz-sulfide stockworks. Chalcopyrite is the dominant copper mineral, with lesser bornite. Traces of molybdenite are common in quartz veinlets. There is no significant zone of supergene enrichment at Cobre Panama. Locally, however, supergene mineralization consisting of chalcocite-coated pyrite and rare native copper is found to a depth of at least 150 m.

Prospects, Mineral Occurrences, and Related Deposit Types

Three prospect areas with characteristics of porphyry copper deposits are recognized within the tract (fig. C1); comments and references are listed in table C4, arranged from west to east. The Río Pito prospect in the adjacent Acandi tract is mentioned to show that porphyry copper prospects are present near the eastern part of the Darién tract.

Palmilla

The Palmilla prospect, located west of Cobre Panama, was drilled in the late 1990s. The area is underlain by andesitic and basaltic volcanic rock and lesser amounts of sedimentary rock intruded by an Oligocene calc-alkaline batholith and related intrusive rocks. The area initially was explored based on copper and gold soil-geochemical anomalies with maximum values of 3,800 ppm copper and 2.85 g/t gold. Partial reserves are estimated at 13 Mt averaging 0.3 percent copper and 1.029 g/t gold (Inmet Mining Corp., 2010).

Ipeti

During a January 1996 exploration program, International CanAlaska Resources, Ltd. partially delineated a Cu-Au porphyry system at Ipeti (International CanAlaska Resources, Ltd., 1997). The 41-km^2 Ipeti concession, 90 km east of Panama City, overlies the eastern part of the Tertiary-age Guayabo quartz-diorite porphyry stock. Concentric zones of alteration have been mapped within the system, with anomalous copper values occupying a central zone approximately 1,000 by 1,200 m. Gold values of up to 1.8 g/t are associated with copper values of 0.05–0.15 percent copper. Float boulders assay as high as 0.39 percent copper and 0.29 g/t gold (International CanAlaska Resources, Ltd., 1997).

Cerro Azul

Nelson (2007) included Cerro Azul as a Cu-Au porphyry prospect. Kesler and others (1977) dated hornblende (61.58±0.70 Ma) and feldspar (51.11±0.58 Ma) from Cerro Azul and noted that the Cerro Azul intrusions have tholeiitic geochemistry and are compositionally distinct from younger calc-alkalic Eocene-Pliocene intrusions. Intrusions in the Cerro Azul area are larger and less porphyritic than those in the Río Pito area where porphyry copper prospects are well-developed in porphyritic quartz diorite (Kesler and others, 1977).

Río Pito

Río Pito was included in the Acandi tract (005pCu1001) of Colombia, Ecuador, and Panama as delineated by Cunningham and others (2008). Río Pito, discovered in the 1970s, has an estimated resource of 180 Mt at 0.6 percent copper. The prospect is located on an indigenous land reserve and has never been developed.

Exploration History

Within the defined tract area in Panama, regional- and prospect-scale exploration, principally by stream-sediment surveys, was conducted by the United Nations Development Program (1969). Subsequent surveys were done by Swedish Geological Survey International. Roughly two-thirds of the country was sampled during this effort. Porphyry copper mineralization in Panama was first discovered at Cobre Panama (Petaquilla Copper; fig. C1) during a joint Panama-United Nations survey that followed the regional stream-sediment surveys (Ferencĭć, 1970). Subsequent efforts by this group located several small prospects in eastern Panama. Drill programs have been conducted by United Nations Develoment

Table C5. Principal sources of information used for tract 003pCu4002 (CA_CARIB- T1), Darién region—Panama.

[NA, not applicable]

Theme	Name or title	Scale	Citation
Geology	CBMap—Digital geologic map of the Caribbean Basin	1:500,000	Available for purchase at http://www.cbmap.net/
Mineral occurrences	Porphyry copper deposits of the world—Database, map, and grade and tonnage models	NA	Singer and others (2008)
	CBMap—Digital geologic map of the Caribbean Basin	1:500,000	Available for purchase at http://www.cbmap.net/
	U.S. Geological Survey Mineral Resources Data System	NA	U.S. Geological Survey (2005)
	Commercial database (Metals Economic Group)	NA	http://www.metalseconomics.com/default.htm
Geochemistry	United Nations Development Program	NA	United Nations Development Program (1969)
Exploration	CBMap—Digital geologic map of the Caribbean Basin	1:500,000	Available for purchase at http://www.cbmap.net/

Program in 1968–1969, Panamá Mineral Resources Development Company, a Japanese consortium, in 1970–1980, Inmet-Adrian Resources-Teck in 1990–1997, Petaquilla Copper in 2006–2008, and Minera Panama in 2007–2009 (Lilljequist and Burgos, 1995; Doan, 1999; Teck Cominco Limited and others, 2007). A total of 1,275 diamond drill holes (230,555 m total drill length) have been completed (Minera Panama, 2010).

Sources of Information

Principal sources of information used by the assessment team for delineation of the Darién tract are listed in table C5.

Grade and Tonnage Model Selection

The global porphyry Cu-Au-Mo model of Singer and others (2008) was selected for the assessment based on geologic and grade-tonnage characteristics of Cobre Panama (table C2).

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Parts of the tract are thoroughly explored dating from the United Nations surveys to recent exploration activity by private and government-owned mining companies. The western half of the tract area is well explored on district, regional, and deposit scales and currently continues as a focus area for exploration. In the eastern part of the tract, exploration peaked and then all but terminated in the mid to late 1990s. The Cobre Panama area and the Río Pito prospect in the adjacent Acandi tract were discovered in the early 1970s. Prospects near the Cobre Panama area have been analyzed using rock samples, stream-sediment surveys, gridded soil sampling, magnetic surveys, and drilling (Speidal and others, 2001; Nelson, 1995; Inmet Mining Corp., 2010).

The eastern segment of the tract, in eastern Panama near the Colombian border, is dominated by large plutons and large areas of volcanic rock; the region consists of older (and less prospective) arc rocks than the western segment. The team also considered the number of porphyry copper occurrences clustered from discrete mineralized areas, such as the large-tonnage Cobre Panama area, that were combined into one large grade and tonnage deposit.

The assessment team estimated the number of undiscovered porphyry copper deposits in the Darién tract at the 90-, 50-, and 10-percent probability levels as two, three, and six or more deposits, respectively, for a total of about four expected deposits (table C6). These estimates reflect the number of current exploration targets in play (some of which have partially reported resources), the copper (and gold) occurrences not associated with deposits, and the extent of geochemical anomalies and altered areas in the tract. The estimate was based on the extensive exploration already undertaken and the possibility that the western portion of the tract might contain additional deposits. Some of these areas, although initially identified as potential targets, may lack modern exploration followup due to decisions regarding the country's mining policy on indigenous lands, mining law, and (or) long-term environmental concerns.

Probabilistic Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered porphyry copper deposits with the general porphyry copper model of Singer and others (2008) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, 2012; Duval, 2012). Selected output parameters are reported in table C7. Results of the Monte Carlo simulation are presented as a cumulative frequency plot (fig. C3). The cumulative frequency plot shows the estimated amounts of resources associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

Table C6. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 003pCu4002 (CA_CARIB-T1), Darién region—Panama.

[N_{xx}, estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; *s*, standard deviation; $C_v\%$, coefficient of variance; N_{known}, number of known deposits in the tract that are included in the grade and tonnage model; N_{total}, total of expected number of deposits plus known deposits; km², square kilometers; N_{total}/100k km², deposit density reported as the total number of deposits per 100,000 km². N_{und}, *s*, and $C_v\%$ are calculated using a regression equation (Singer and Menzie, 2005)]

Consensus undiscovered deposit estimates					Summary statistics					Tract area (km²)	Deposit density (N_{total}/100k km²)
N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	s	$C_v\%$	N_{known}	N_{total}		
2	3	6	6	6	3.5	1.6	47	1	4.5	16,480	27

Table C7. Results of Monte Carlo simulations of undiscovered resources for tract 003pCu4002 (CA_CARIB-T1), Darién region—Panama.

[t, metric tons; Mt, million metric tons]

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	250,000	940,000	6,900,000	31,000,000	53,000,000	14,000,000	0.27	0.04
Mo (t)	0	0	110,000	920,000	1,700,000	400,000	0.22	0.14
Au (t)	0	0	150	820	1,200	340	0.28	0.11
Ag (t)	0	0	1,200	11,000	19,000	4,400	0.24	0.23
Rock (Mt)	56	230	1,500	6,500	11,000	2,900	0.28	0.04

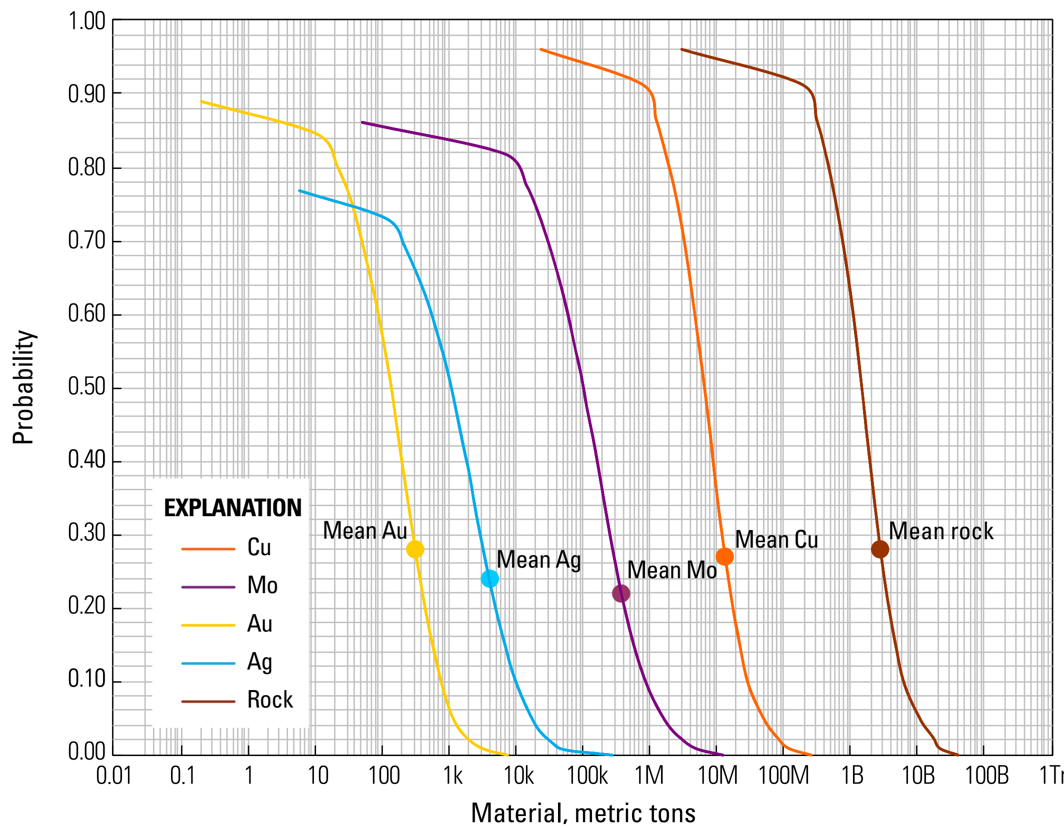

Figure C3. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in tract 003pCu4002(CA_CARIB-T1), Darién region—Panama. k, thousands; M, millions; B, billions; Tr, trillions.

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Appendix D. Porphyry Copper Assessment for Tract 003pCu4004 (CA_CARIB-T2), Cocos Region—Chiapas and Southern Oaxaca, Mexico; Guatemala; Honduras; El Salvador; Nicaragua; Costa Rica; and Western Panama

By Floyd Gray[1], Lukas Zürcher[2], Steve Ludington[1], Gilpin R. Robinson, Jr.[1], Jane M. Hammarstrom[1], Carl E. Nelson[3], and Barry C. Moring [1]

Deposit Type Assessed: Porphyry Copper

Descriptive model: Porphyry copper (Cox, 1986; Berger and others, 2008; John and others, 2010)
Grade and tonnage model: Global Cu-Au-Mo porphyry copper model (Singer and others, 2008).
Table D1 summarizes selected assessment results.

Table D1. Summary of selected resource assessment results for tract 003pCu4004 (CA_CARIB- T2), Cocos region—Chiapas and southern Oaxaca, Mexico; Guatemala; Honduras; El Salvador; Nicaragua; Costa Rica; and western Panama.

[km, kilometers; km^2, square kilometers; t, metric tons]

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (t)	Mean estimate of undiscovered copper resources (t)	Median estimate of undiscovered copper resources (t)
April 2010	1	203,630	16,000,000	53,000,000	39,000,000

Location

This tract corresponds to the central cordillera of Central America and extends from southern Mexico through Guatemala, Honduras, El Salvador, Nicaragua, and Costa Rica to western Panama (fig. D1).

Geologic Feature Assessed

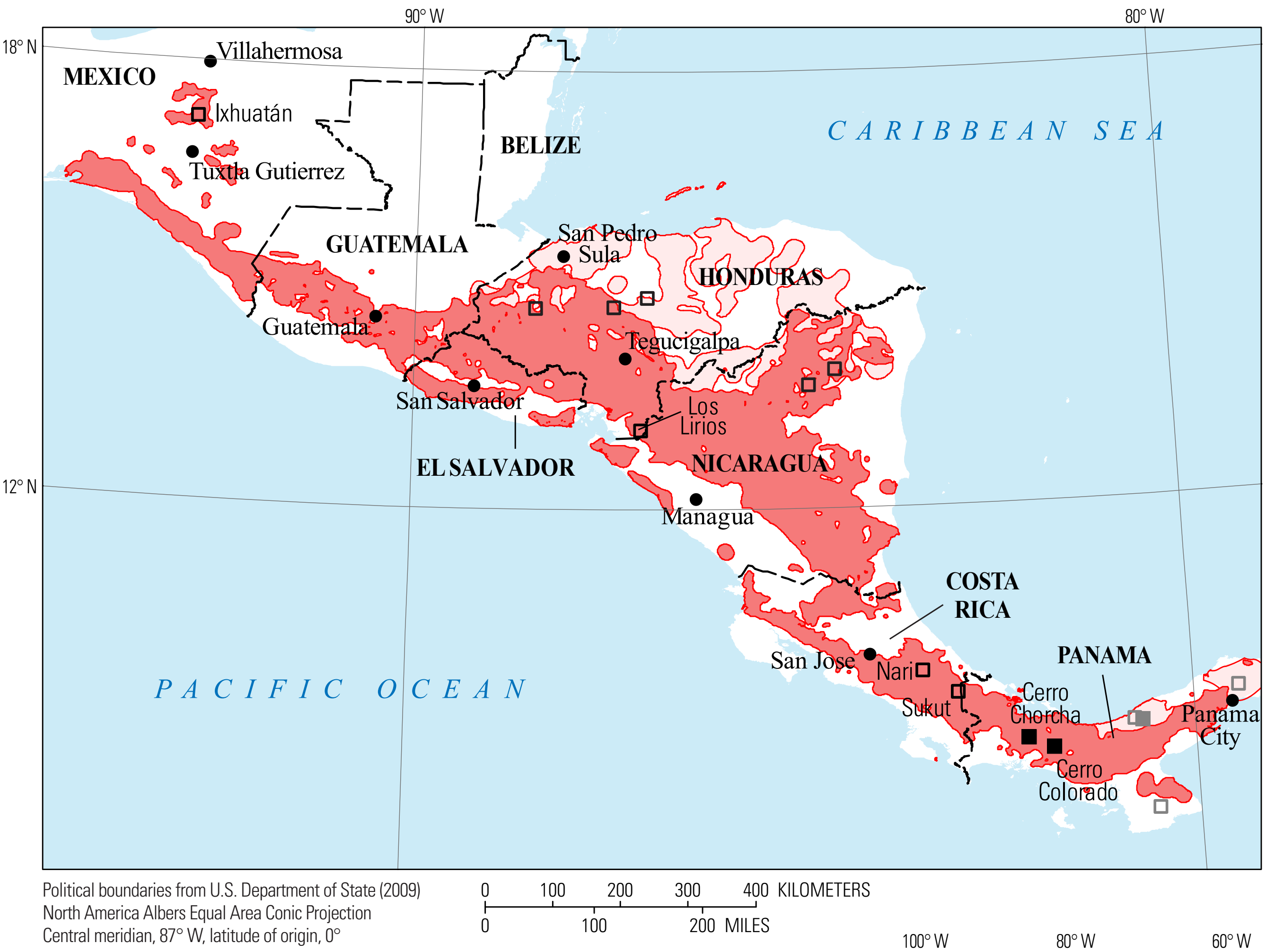
Miocene and Pliocene continental arc formed above the northern part of the Middle America Trench in a complex zone of interaction of the North American, Caribbean, Nazca, and Cocos Plates.

[1]U.S. Geological Survey.
[2]University of Arizona; now at U.S. Geological Survey.
[3]Recursos del Caribe, S.A.

Delineation of the Permissive Tract

Tectonic Setting

The Cocos tract includes Miocene and Pliocene granitic to intermediate plutons and associated andesitic volcanic rocks in a continental arc that developed above the northern part of the Middle America Trench in response to subduction of the Cocos Plate (fig. 3). The northwestern limit of the Cocos tract is defined by the gap in arc magmatism located where the subduction trench is intersected by the Tehuantepec Ridge (fig. 3). The Tehuantepec Ridge, formed 15–20 m.y. ago (Manea and others, 2006), may have created a slab window in the subduction zone giving rise to the gap in arc magmatism. The igneous rocks that crop out within the tract include numerous small bodies of granodiorite and granite. Uplift and rapid exhumation of the volcanic complexes in response to transpression have exposed porphyry-style mineralization as young as 3 Ma in this area.



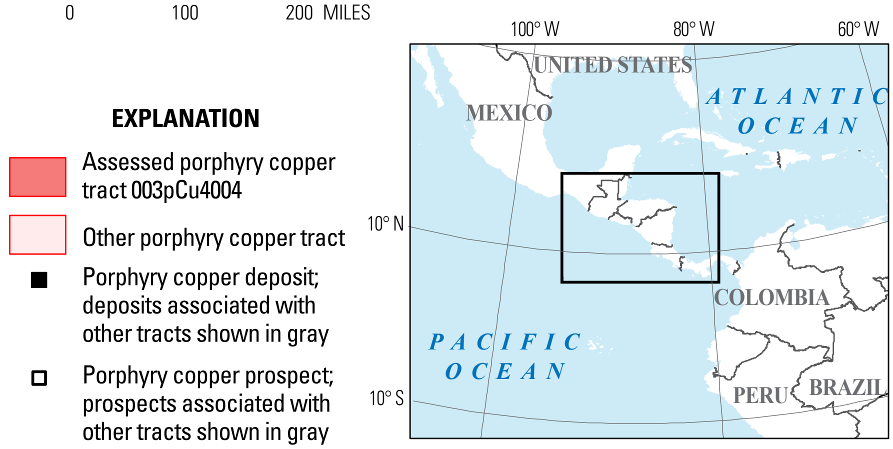


Figure D1. Map showing the location of tract 003pCu4004 (CA_CARIB-T2), Cocos region—Chiapas and southern Oaxaca, Mexico; Guatemala; Honduras; El Salvador; Nicaragua; Costa Rica; and western Panama.

Geologic Criteria

The tract was constructed using the 1:500,000 digital geologic map of the Caribbean Basin (available for purchase at http://www.cbmap.net/) in ArcGIS to identify areas of permissive rock types. Geologic information found in attribute tables associated with those maps allowed us to identify polygons representing lithologic assemblages containing rocks of the appropriate age and composition. Polygons representing lithologic assemblages not considered permissive by reason of age or composition were excluded.

Intrusive and volcanic rocks in geologic-map units selected from the digital map to define the tract are listed in table D2 and plotted in figure D2. Areas of rocks potentially permissive for middle to late Tertiary porphyry copper deposits under shallow cover (less than 1 km thick) were defined by creating a 10-km buffer around the appropriate age and composition igneous rocks and a 2-km buffer around appropriate volcanic rocks. The tracts defined by the buffer criteria were extended in some cases to include additional areas that are suggestive of shallowly buried plutonic rocks based on aeromagnetic data. Additional similar or larger-scale (1:250,000) geologic maps and literature were consulted and used to check map unit boundaries, ages, and structures (Schruben, 1996; Nelson, 2007; Brigus Gold Corp., 2010b). Tract boundaries were clipped along coastlines using the accepted international boundaries for the project (U.S. Department of State, 2009).

Figure D2. Map showing the distribution of permissive rocks used to define tract 003pCu4004 (CA_CARIB-T2), Cocos region—Chiapas and southern Oaxaca, Mexico; Guatemala; Honduras; El Salvador; Nicaragua; Costa Rica; and western Panama.

Table D2. Map units that define tract 003pCu4004 (CA_CARIB-T2), Cocos region—Chiapas and southern Oaxaca, Mexico; Guatemala; Honduras; El Salvador; Nicaragua; Costa Rica; and western Panama.

[Map unit, age range, and principal lithologies are based on a 1:500,000 digital geologic map of the Caribbean Basin (available for purchase at http://www.cbmap.net/)]

Map unit	Country	Age range	Lithology
			Intrusive rocks
Ti(Plio)	Costa Rica	Pliocene	Alkaline intrusive rocks
Ti(PlioMi)	Costa Rica	Miocene-Pliocene	Calc-alkaline magmatism, diorites and quartz monzonites and minor amount of granites and gabbros
Ti	Costa Rica	Neogene-Quaternary	Calc-alkaline plagiogranites
Ti(Mio)	El Salvador	Miocene	Intrusive acid to intermediate rocks
Ti(Mio)	Nicaragua	Miocene	Diorite, granodiorite
Ti(Plio)	Panama	Pliocene	Granodiorites and mangerite
Ti(Mio-Pl)	Panama	Miocene-Pliocene	Granodiorite and monzonite, dikes
TplGd-D	Mexico	Pliocene	Granodiorite, diorite
TmGd	Mexico	Miocene	Granodiorite
TmGd-Gr	Mexico	Miocene	Granodiorite, granite
TomGr-Gd	Mexico	Oligocene-Miocene	Granite to granodiorite intrusives
			Volcanic rocks
Tv(Plio)	Costa Rica	Pliocene-Quaternary	Alkaline magmatism of Plio-Quaternary age; basaltic volcanism of Pliocene age
QTv	Costa Rica	Pliocene-Quaternary	Alkaline magmatism of Plio-Quaternary age; potassic basalts
Tv(PlioMi)	Costa Rica	Miocene-Pliocene	Calc-alkaline magmatism; andesitic and dacitic breccias; ignimbrites and acidic tuffs
Tv(Eo-Mio)	Costa Rica	Eocene-Miocene	Volcanism (indefinite, unassigned)
Tv(Ol-Mio)	El Salvador	Oligocene-Miocene	Effusive acids and ignimbrites, local pyroclastics
Tv(Mio)	El Salvador	Miocene	Epiclastic and pyroclastics volcanics, basic local effusives, intermediate intercalated effusives
Tv(Ol-Mio)	El Salvador	Oligocene-Miocene	Intermediate effusives to intermediate acids, subordinate pyroclastics (regional alteration due to hydrothermal influence)
Tv(Mio)	El Salvador	Miocene	Intermediate pyroclastics to intermediate acids, epiclastic volcanics, subordinate effusives
Tv(Oligo)	El Salvador	Oligocene	Pyroclastic acids to intermediates; in the basal part, intermediate local effusives to intermediate acids
Tv(Mio)	El Salvador	Miocene	Pyroclastic acids, ignimbrites, epiclastic volcanics, local intercalated effusive acids
Tv	Guatemala	Tertiary (mainly Mio-Pliocene)	Undivided volcanic rocks. Includes tuffs, lava flows, laharic deposits, and volcanic sediments
Tv(Ol-Mio)	Honduras	Tertiary	Dominant flows of basalt and andesite and associated pyroclastic rocks
Tv	Honduras	Tertiary	Volcanic rocks consisting of pyroclastic rocks of the rhyolitic and andesitic suite; sedimentary rocks are derived from the volcanic rocks and flows of rhyolite, andesite, and basalt
Tv(PlioMi)	Nicaragua	Miocene-Pliocene	Andesite and basaltic andesite lavas, dacitic andesite, rhyodacite, rhyolite and dacitic tuffs and tuffaceous breccias, agglomerate
Tv(PlioMi)	Nicaragua	Miocene-Pliocene	Basaltic and basaltic-andesite lavas, andesitic dacite, ignimbrites, tuffs, tuffaceous breccias, rhyodacites, agglomoerates
Qv	Nicaragua	Quaternary	Ignimbrites, dacitic tuffs and breccias, basaltic and andesite lava flows
Tv(Mio)	Nicaragua	Miocene	Ignimbrites, lavas, tuffs, rhyolite and dacite tuffaceous breccias, basaltic andesite, tuffaceous sandstones, conglomerates

Table D2. Map units that define tract 003pCu4004 (CA_CARIB-T2), Cocos region—Chiapas and southern Oaxaca, Mexico; Guatemala; Honduras; El Salvador; Nicaragua; Costa Rica; and western Panama.—Continued

Map unit	Country	Age range	Lithology
			Volcanic rocks
Tv(Ol-Mio)	Nicaragua	Oligocene-Miocene	Rhyodacite and rhyolite tuffs, lavas, andesitic flow breccia, basalt, tuffaceous andesitic dacite, agglomerates, tuffaceous sandstone, clayey sandy breccias, ignimbrites
Tv(Mio)	Panama	Miocene	Andesite, tuffs, bentonitic clay, tuffaceous sandstones
Tv(Mio)	Panama	Miocene	Andesite/basalt, lavas, breccias, tuffs, and plugs
Tv(Mio)	Panama	Miocene	Andesite/basalt, lavas, breccias, tuffs, boulders, subintrusives, dikes, volcaniclastic sediments
Tv(Mio)	Panama	Miocene	Andesite/basalt, sand, mudstone, shale, epiclastic sediments, silicified wood, conglomerates, and breccias
Tv(Mio)	Panama	Miocene	Lavas and tuffs, agglomerates
Tv(PlioMi)	Panama	Miocene-Pliocene	Dacite, breccias, plugs, ignimbritic flows, pumice, fine tuffs. Andesite/basalt, tuffs and fine granite subintrusives
Tv(Mio)	Panama	Miocene	Dacites, rhyodacites, ignimbrite, subintrusives, tuffs and lavas
TmPA	Mexico	Miocene	Porphyritic andesite
TmTA-TR	Mexico	Miocene	Rhyolitic to andesitic tuffs, breccias
TnTA-Tda	Mexico	Neogene	Andesite tuff, dacite tuff
TplBvA-A	Mexico	Pliocene	Andesite, andesitic brecccia
TpILh-TA	Mexico	Pliocene	Lahars, andesite, and andesite tuff
TplQptLh	Mexico	Pliocene-Pleistocene	Lahars

Known Deposits

There are two porphyry copper deposits in this tract—Cerro Colorado and Cerro Chorca—both in Panama (fig. D1, table D3).

Cerro Colorado, Panama

Cerro Colorado is one of the largest undeveloped porphyry deposits in the region (Cooke and others, 2005; Nelson, 2007; Singer and others, 2008). The contained copper resource is about 15 Mt. The Cerro Colorado deposit is hosted by the Río Escopeta Granodiorite, which was dated at 5.9 Ma 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 Ma (Clark and others, 1977). 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). Anhydrite is present as a minor component at depth. The mineralogy consists of chalcopyrite, molybdenite, and pyrite as small disseminated grains in the latite porphyry and as larger grains in the feldspar porphyry. Raynolds (1983) distinguished five episodes of veining associated with hypogene mineralization—barren quartz veins, succeeded by quartz-chalcopyrite-pyrite, quartz-sericite, quartz-sericite-sulfide, and massive sulfide veins. Two episodes of hypogene sulfate and carbonate veining postdate mineralization. The deposit is cut by postmineralization rhyolite and rhyodacite dikes. Biotite from the postmineralization dikes was dated at 4.2 Ma (Raynolds, 1983). Unaltered trachyandesite flows dated at 2.5 Ma overlie the deposit (Clark and others, 1977). Estimates of the supergene resource include 70 Mt of 1.11 percent copper (Nelson, 1995). Mineralization in the enrichment blanket includes roughly equal proportions of chalcocite and covellite and 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 incomplete. Roughly 65 percent of the copper in the secondary blanket is present as secondary sulfides (Nelson, 1995). There is significant variability in the thickness of the secondary blanket (3–111 m, averaging 35 m).

Cerro Colorado was discovered in 1932. Various feasibility studies involving government/industry partnerships with a number of companies, including Texasgulf, Inc., Canadian Javelin, Río Tinto Zinc, and most recently Teck Resources Limited, Vaaldiam (formerly Tiomin Resources, Inc.), and Aur Resources Inc., were undertaken to extend and develop the property. A feasibility study completed in 1997

Table D3. Identified porphyry copper resources in tract 003pCu4004 (CA_CARIB-T2), Cocos region—Chiapas and southern Oaxaca, Mexico; Guatemala; Honduras; El Salvador; Nicaragua; Costa Rica; and western Panama.

[Ma, millions of years before present; Mt, million metric tons; %, percent; t, metric ton; g/t, grams per metric ton; contained Cu in metric tons is computed as tonnage (Mt × 1,000,000) × Cu grade (percent) × 0.01]

Name	Latitude	Longitude	Country	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained Cu (t)	Reference
Cerro Colorado	8.510	-81.797	Panama	4.3	3,730	0.39	0.015	0.08	5.2	15,000,000	Anderson (2004), Clark and others (1977), Kents (1975), Kesler and others (1977), Nelson (1995), Raynolds (1983)
Cerro Chorcha	8.660	-82.102	Panama	3.6	201.9	0.49	0.01	0.07	1.8	990,000	Baughman (1995), Dominion Minerals Corp. (2010), Druecker and Sandefur (2008), Empire Minerals (2006), Kesler and others (1977), Nelson (1995), PRNewswire-FirstCall (2007)

suggested a 12-year mine life on a large-scale open pit mine with the intent of processing of the upper supergene cap for cathode copper by solvent extraction and electrowinning. Capital costs were estimated at $200 million (USD). The project was placed on hold in 1998. In 2003, Aur Resources Inc.'s exploration leases expired and in 2004 the property reverted to the government (Anderson, 2004).

Cerro Chorcha, Panama

Cerro Chorcha is located about 35 km west of Cerro Colorado, in western Panama (fig. D1, table D3). The deposit was discovered by regional stream-sediment sampling in 1969. The contained copper resource of approximately 990,000 t is associated with a magnetite-bearing quartz stockwork (Druecker and Sandefur, 2008). Host rocks at Cerro Chorcha include Miocene andesitic to basaltic flows, breccias, tuffs, plugs, and volcaniclastic rocks of the Cañazas Group that are intruded by Pliocene to Miocene granodioritic and monzonitic rocks of the Tabasara Group. In the area of the deposit, a structurally and compositionally complex granodiorite-tonalite intrusion cuts Miocene andesite lapilli tuffs and flow rocks. In addition, a series of northeast-striking quartz-feldspar porphyry dikes is mapped in the deposit area. Phyllic alteration is well developed and imparts a bluish-green tint to the feldspar. Neither secondary potassium feldspar nor biotite has been observed.

Prospects, Mineral Occurrences, and Related Deposit Types

Table D4 lists four significant prospects with characteristics of porphyry copper deposits in the tract.

Ixhuatán, Mexico

The Ixhuatán concession is currently owned by Cangold Ltd. (75 percent) and Brigus Gold Corp. (25 percent); Brigus Gold Corporation was formed by merging Linear Gold Corporation and Apollo Gold Corporation. Previous work, done mainly by Linear, included rock chip and soil sampling that identified six separate anomalous zones of greater than 100 ppb gold. Each of the six anomalies, named San Isidro, Central, Northern, Western, Cerro La Mina, and Campamento, has strong indications of porphyry and skarn alteration. Rock chip sample analyses ranged from 0.1 to 9.4 g/t gold and from 0.1 to 1.1 percent copper. In January 2004, Brigus Gold Corp. initiated a five-hole drilling program to test the San Isidro anomaly on the southeastern portion of the property. The holes targeted a 2.3-km soil anomaly with more than 100 ppb gold; results confirmed the existence of broad zones of low-grade disseminated gold mineralization which locally contained some higher grade zones.

The Campamento area is situated in a highly fractured, northeast-trending fault zone that dips subvertically (Brigus Gold Corp., 2010 a, b). Drilling indicates that this structure is up to 120 m wide and extends for about 200 m along strike. The highest-grade gold mineralization is associated with calcite, clay, and quartz fracture-filling veinlets, and with highly fractured zones. The mineralized fault structure is open to the northwest, southeast, and down dip. The zone of gold mineralization is associated with 1–2 mm wide stockwork veinlets and disseminations hosted in an andesite breccia. Strong clay alteration and pyrite are closely associated with the zone of mineralization. The mineralization is hosted in both the oxide and sulfide portions of the system and open in three directions (Linear Gold Corp., 2007a, b).

In the Cerro La Mina area, mineralization is defined by a 750 by 450 m zone with anomalous gold in soils on the western flank of the hillside facing Campamento. The area is marked by silicification, with local vuggy silica and strong clay alteration. Limited petrographic studies suggest that an intermediate-sulfidation porphyry-related gold-copper-molybdenum event has been overprinted by a later high-sulfidation gold-copper event in the area. The earlier mineralizing stage with local sulfide veins and disseminations of pyrite, chalcopyrite, and molybdenite, with minor bornite, was overprinted by a secondary hypogene event containing covellite, digenite, and minor enargite, with these well-formed secondary copper phases replacing the earlier chalcopyrite (Giroux, 2006).

Los Lirios (El Triunfo), Honduras

Los Lirios (El Triunfo), discovered by Maya Gold Corp. in 1998, is believed to be the first recognized Cu-Au porphyry located between Panama and Mexico. The porphyry prospect is underlain by late Tertiary rocks of the Padre Miguel Group. These rocks consist mainly of flows, agglomerates, dacites, and basalts that have been intruded by a complex tonalite and andesite porphyritic stock that may be part of a larger granodiorite intrusion at depth (Maya Gold Corp., 2001). The area is capped by Quaternary basalt flows.

A northeast-trending gold soil anomaly more than 1 km in length and more than 0.5 km wide defines the Los Lirios mineralized area. Anomalous molybdenum values (more than 90 ppm) occur at the southwest end of the gold-copper anomaly at Cone Hill, a strongly altered and brecciated dacite porphyry. Zones of brecciation and strongly developed stockworks are common within the dacite, mainly along a northwesterly fracture trend. Alteration consists of silica, kaolinite, sericite, and possibly alunite. To date, limited drilling has occurred on the Los Lirios prospect. Several drill holes returned assays including 213 m at 0.532 g/t gold and 0.252 percent copper, 218 m at 0.509 g/t gold and 0.317 percent copper, and 180 m at 0.624 g/t gold and 0.288 percent copper (Maya Gold Corp., 2001).

Sukut, Costa Rica

The Sukut prospect is a porphyry Cu-Au system hosted by intermediate volcanic and volcanogenic sedimentary rocks. Alteration is zoned from a core of advanced argillic alteration (pyrite-alunite-kaolinite) outward through phyllic and propylitic envelopes to unaltered rocks. Copper Range Exploration drilled four holes in 1975 (totaling 2,000 m) into the advanced argillic core of the system; drill intercepts averaged 0.2 percent copper. Gold occurs with a complex sulfide suite in the phyllic alteration zone surrounding the copper-rich core. No drill holes encountered gold. However, gold mineralization at Sukut has been known since 1898 (Nelson, 1995, citing a 1959 report by Henry Juchem). Fischer-Watt resampled many of Juchem's sites during the 1980s and obtained up to 7.7 ppm gold. Peripheral gold, copper, silver, and zinc mineralization is controlled by two northwest-striking fracture zones. These fractures contain anastomosing veins of quartz and barite up to 50 cm in diameter. Sulfide mineral contents are high and consist of sphalerite, galena, chalcocite, pyrite, chalcopyrite, and bornite.

Nari (Matama II), Costa Rica

Country rocks in the Nari (Matama II) 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 (Castro Muñoz and Vargas Ramírez, 1982). Based on an aeromagnetic survey, the plugs appear to be part of a larger buried stock. Nelson (1995) divided the intrusive rocks into four units: quartz-diorite and quartz-diorite porphyries are cut by dacite and andesite porphyries. Potassic alteration (potassium feldspar, biotite) covers an area of 0.7 km^2 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 km^2. This system contains at least 200 Mt of 0.25 percent copper (Nelson, 1995).

Exploration History

Areas within the tract range from thoroughly explored (Panama, Costa Rica, and southern Mexico) to poorly explored (Honduras, El Salvador, Guatemala, and Nicaragua). Of the poorly explored areas, only Honduras contains historical districts where gold and copper were once produced at significant levels. The current focus of exploration in the tract, as typified by exploration in Honduras, is toward precious metal and polymetallic vein deposits, including low-sulfidation epithermal veins and epigenetic skarn. Some scattered exploration for copper was initiated due to surging metal prices, but these efforts mainly centered on high-grade skarn systems from historical districts with gold and silver as by-product metals. Current exploration is primarily in Honduras, southern Mexico, and western Panama. However, land ownership and land-use policies, together with social and environmental concerns, continue to be barriers to exploration and resource development in the remaining countries of the region, including Guatemala, El Salvador, and Costa Rica.

Sources of Information

Principal sources of information used by the assessment team for delineation of tract 003pCu4004 are listed in table D5.

Grade and Tonnage Model Selection

The global porphyry Cu-Au-Mo model of Singer and others (2008) was selected for the assessment based on geologic characteristics of the two known deposits in the tract and the results of a *t*-test comparing tonnage, copper grade, and gold grade for those deposits against the global model (see table 2). Statistical tests showed that the deposits are not significantly different from the global model at the 1-percent level.

Table D4. Significant prospects and occurrences in tract 003pCu4004 (CA_CARIB-T2), Cocos region—Chiapas and southern Oaxaca, Mexico; Guatemala; Honduras; El Salvador; Nicaragua; Costa Rica; and western Panama.

[%, percent; ppm, parts per million; g/t, grams per metric ton; Mt, million metric tons; Ma, millions of years before present; n.d., no data]

Name	Latitude	Longitude	Country	Age (Ma)	Comments	Reference
Ixhuatán	17.247	-93.060	Mexico	3	Cu-Au porphyry and related styles of mineralization are exploration targets here: low and high-sulfidation, Cu-Au skarn overprinted by epithermal high sulfidation Cu-Au breccias and veins. Maya terrane, alkaline, extensional structures, strike-slip fault	Islas-TenoRío and others (2005), Linear Gold Corp. (2007a, b, 2008), Miranda-Gasca and others (2005)
Los Lirios (El Triunfo)	15.438	-91.775	Honduras	n.d.	Drilling (1999–2000) encountered up to 61 m of 0.452% Cu and 0.98 ppm gold in one of 20 holes completed (1735 m total depth). Hosted in dacite dome and pyroclastic blanket with quartz-sericite-pyrite alteration. To date, 15 diamond drill and 9 reverse circulation holes have been drilled on Los Lirios. Three diamond drill holes, and the extension of a fourth, returned assays including 213 m at 0.532 g/t Au and 0.252% Cu, 218 m at 0.509 g/t Au and 0.317% Cu, and 180 m at 0.624 g/t Au and 0.288% Cu	Nelson (1995), U.S. Geological Survey (1987), Maya Gold Corp. (2001)
Sukut	9.363	-82.976	Costa Rica	n.d.	Fischer-Watt reported potential for 63 million tons of gold ore. Drilling reported 0.2% Cu, with 10 m interval of 7.7 g/t Au	Nelson (1995), U.S. Geological Survey and others (1987)
Nari (Matama II)	9.680	-83.409	Costa Rica	n.d.	Resources of 200 Mt at 0.2 to 0.3% Cu and 100 ppm Mo. Ten holes drilled in 1974; open. Partners: Alcoa in the 1970s. Average values in a 600 m drill hole: 0.28% Cu, 15 ppm Mo, <2 ppm Au	Nelson (1995), U.S. Geological Survey and others (1987)

Table D5. Principal sources of information used for tract 0003pCu4004 (CA_CARIB-T2), Cocos region—Chiapas and southern Oaxaca, Mexico; Guatemala; Honduras; El Salvador; Nicaragua; Costa Rica; and western Panama.

[NA, not applicable]

Theme	Name or title	Scale	Citation
Geology	CBMap—Digital geologic map of the Caribbean Basin	1:500,000	Available for purchase at http://www.cbmap.net/
	Preliminary digital geologic map of the Republic of Mexico	1:500,000	Servicio Geologico Mexicano (written commun., 2007), Hammarstom and others, 2010
Mineral occurrences	Porphyry copper deposits of the world—Database, map, and grade and tonnage models	NA	Singer and others (2008)
	CBMap—Digital geologic map of the Caribbean Basin	1:500,000	Available for purchase at http://www.cbmap.net/
	U.S. Geological Survey Mineral Resources Data System	NA	U.S. Geological Survey (2005)
	Mineral resource assessment of Costa Rica	1:500,000	U.S. Geological Survey and others (1987)
	Metals Economic Group database	NA	http://www.metalseconomics.com/default.htm
Geochemistry	United Nations Development Program	NA	UNDP (1969a, b)
Exploration	Company Web sites, literature	NA	Dominion Minerals Corp. (2010), Brigus Gold Corp. (2010a, b), Linear Gold Corp. (2007a, b), Empire Minerals Corp. (2006), Maya Gold Corp. (2001), Nelson (1995)

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Active uplift and exhumation along the trench margin led to exposure of tops of Miocene to Pliocene intrusive rocks prospective for porphyry copper deposits. Numerous small intrusive rocks with surrounding coeval volcanic rocks indicate an appropriate level of exposure for porphyry copper deposits. The two known deposits and the four significant prospects led the team to estimate a 90-percent chance of 4 or more undiscovered deposits, a 50-percent chance of 14, and a 10-percent chance of 24 or more, for a mean of 14 undiscovered deposits (table D6). A mineral resource assessment of Costa Rica conducted in the 1980s delineated a permissive tract for porphyry copper deposits which is included within the area of tract 003pCu4004; the authors of that assessment estimated a 90-percent chance of one or more undiscovered deposits, a 50-percent chance of three, and a 10-percent chance of eight or more deposits in Costa Rica (U.S. Geological Survey and others, 1987; Schruben, 1996).

Table D6. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 003pCu4004 (CA_CARIB-T2), Cocos region—Chiapas and southern Oaxaca, Mexico; Guatemala; Honduras; El Salvador; Nicaragua; Costa Rica; and western Panama.

[N_{xx}, estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; s, standard deviation; C_v%, coefficient of variance; N_{known}, number of known deposits in the tract that are included in the grade and tonnage model; N_{total}, total of expected number of deposits plus known deposits; km², square kilometers; N_{total}/100k km², deposit density reported as the total number of deposits per 100,000 km². N_{und}, s, and C_v% are calculated using a regression equation (Singer and Menzie, 2005)]

Consensus undiscovered deposit estimates					Summary statistics					Tract area (km²)	Deposit density (N_{total}/100k km²)
N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	s	C_v%	N_{known}	N_{total}		
4	14	24	24	24	14	7	51	2	16	203,630	8

Table D7. Results of Monte Carlo simulations of undiscovered resources for tract 003pCu4004 (CA_CARIB-T2), Cocos region—Chiapas and southern Oaxaca, Mexico; Guatemala; Honduras; El Salvador; Nicaragua; Costa Rica; and western Panama.

[t, metric tons; Mt, million metric tons]

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	2,200,000	6,100,000	39,000,000	120,000,000	160,000,000	53,000,000	0.36	0.02
Mo (t)	5,700	67,000	830,000	3,500,000	5,100,000	1,400,000	0.31	0.04
Au (t)	20	110	970	2,900	3,800	1,300	0.37	0.03
Ag (t)	0	550	9,400	41,000	62,000	18,000	0.29	0.06
Rock (Mt)	480	1,300	8,400	24,000	30,000	11,000	0.39	0.02

The estimates reported here reflect the large tract area (about 200,000 km²), the number of current exploration targets, precious metal epithermal occurrences not associated with deposits, and the extent of geochemical anomalies and altered areas in the tract. The team observed that modern exploration has been restricted by land ownership and land-use conflicts.

Probabilistic Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered porphyry copper deposits with the general porphyry Cu-Au-Mo grade and tonnage model of Singer and others (2008) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, 2012; Duval, 2012). Selected simulation results are reported in table D7. Results of the Monte Carlo simulation are presented as a cumulative frequency plot (fig. D3). The cumulative frequency plot shows the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

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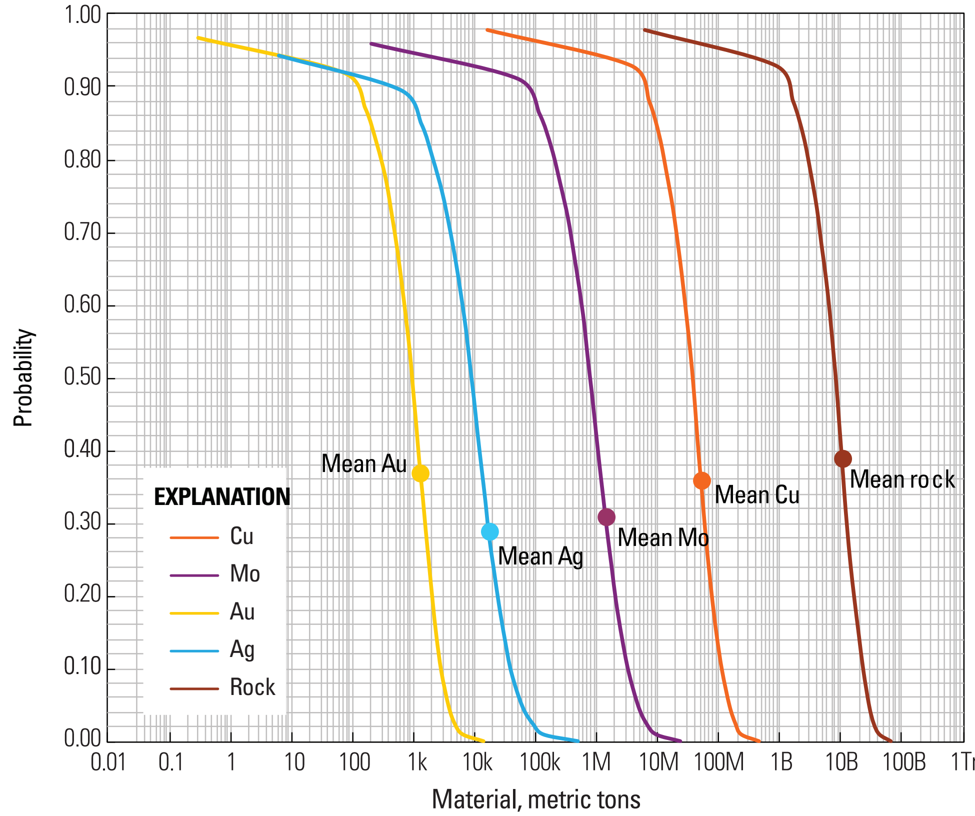

Figure D3. Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in 003pCu4004 (CA_CARIB-T2), Cocos region—Chiapas and southern Oaxaca, Mexico; Guatemala; Honduras; El Salvador; Nicaragua; Costa Rica; and western Panama. k, thousands; M, millions; B, billions; Tr, trillions.

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Appendix E. Porphyry Copper Assessment for Tract 003pCu4005 (CA_CARIB-T3), Lesser Antilles—Antigua and Barbuda, Dominica, Grenada, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, and Nonsovereign Territories[1]

By Floyd Gray[2], Lukas Zürcher[3], Steve Ludington[2], Gilpin R. Robinson, Jr.[2], Jane M. Hammarstrom[2], Carl E. Nelson[4], and Barry C. Moring[2]

Deposit Type Assessed: Porphyry Copper, Cu-Au Subtype

Descriptive model: Porphyry Cu-Au (Cox, 1986)
Grade and tonnage model: Porphyry copper, Cu-Au subtype (Singer and others, 2008).
Table E1 summarizes selected assessment results.

Table E1. Summary of selected resource assessment results for tract 003pCu4005 (CA_CARIB-T3), Lesser Antilles—Antigua and Barbuda, Dominica, Grenada, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, and nonsovereign territories.

[km, kilometers; km^2, square kilometers; t, metric tons]

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (t)	Mean estimate of undiscovered copper resources (t)	Median estimate of undiscovered copper resources (t)
April 2010	1	2,980	0	3,300,000	670,000

Location

Island chains that constitute the Lesser Antilles Arc (fig. E1).

Geologic Feature Assessed

Lesser Antilles Eocene through Holocene composite volcanic arc.

[1]Islands of Anguilla, Guadeloupe, Martinique, Montserrat, Saba, Saint Barthélemy, Saint Eustasius, Saint Martin.
[2]U.S. Geological Survey.
[3]Univesity of Arizona, now U.S. Geological Survey.
[4]Recursos del Caribe, S.A.

Delineation of the Permissive Tract

Tectonic Setting

The many islands of the Lesser Antilles define an 850-km-long curve from Grenada to Anguilla, linking the Venezuelan continental borderland to the south with the eastern tip of the extinct Greater Antilles Island Arc (fig. 3) in the north (for further details, see Bouysse, 1979; Bouysse and Guennoc, 1983; Bouysse, and others, 1985). The Lesser Antilles chain of volcanic islands represents a composite volcanic arc, comprised of an older (Eocene-Oligocene) and a recent (Miocene and younger) Lesser Antilles Arc. Remnants of an older protoarc or Mesozoic arc, the substratum of the modern Lesser Antilles Arc, are part of a wider Mesozoic Caribbean Arc. Arc-related volcanic rocks dated at 120–130 Ma crop out as Mesozoic basement (Bouysse and others, 1983, 1985, 1988; Westercamp and others, 1985) on La Desirade (fig. E2). The older Lesser Antilles Arc was active from the early Eocene (Andreieff and others, 1988) to the mid-Oligocene (30–28 Ma). The axis of the Eocene-Oligocene arc lies to the east of the recent arc (fig. E2). The older arc, also known as the Limestone Caribbees, includes Sombrero, Anguilla, Saint Martin, Saint Barthélemy, Antigua, and Grande Terre Island (fig. E2). These islands are comprised of Eocene to Oligocene igneous rocks capped by Miocene and younger limestones (Roobol and Smith, 2004).

The recent arc, also known as the Volcanic Caribbees (fig. E2), has been active since the early Miocene (22–19 Ma) (Andreieff and others, 1988) and includes Grenada, Saint

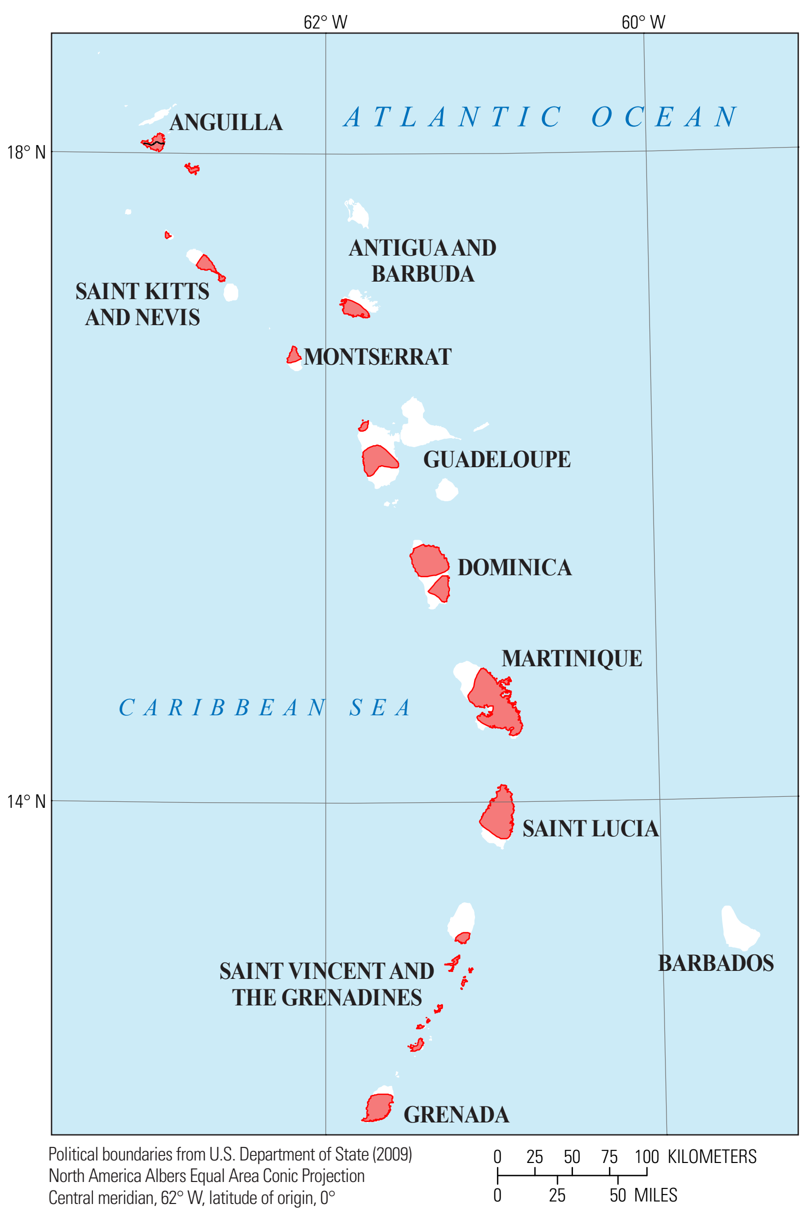

Figure E1. Map showing the location of tract 003pCu4005 (CA_CARIB-T3), Lesser Antilles—Antigua and Barbuda, Dominica, Grenada, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, and nonsovereign territories.

Table E2. Map units that define tract 003pCu4005 (CA_CARIB-T3), Lesser Antilles—Antigua and Barbuda, Dominica, Grenada, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, and nonsovereign territories.

[Map unit, age range, and principal lithologies are based on a 1:500,000 digital geologic map of the Caribbean Basin (available for purchase at http://www.cbmap.net/) and French and Shenk (2004)]

Map unit	Age range	Lithology
		Volcanic rocks
lTv	Eocene and Paleocene	Volcanic flows and associated pyroclastic and volcanogenic sedimentary rocks
QTv	Quaternary and Tertiary	Volcanic edifices, flows, tuff, silicic pyroclastic and volcanic epiclastic rocks
Tmov	Miocene and Oligocene	Volcanic rocks
Tplv	Pliocene	Calc-alkaline volcanic and plutonic rocks
Tv	Tertiary	Volcanic rocks

Vincent and the Grenadines, Saint Lucia, Martinique, Dominica, Basse Terre Island, Montserrat, Redonda Island, and Saint Kitts, and Nevis (fig. E2). Saba and Saint Eustatius (fig. E2) represent the northernmost subaerial part of the active Lesser Antilles Arc. North of Saba, a 110-km-long submarine ridge represents the northern termination of the recent arc, but has been extinct since the late Pliocene (Reynal de Saint-Michel, 1966; Westercamp and others, 1985; Bouysse and others, 1988). The active island arc of the Lesser Antilles (fig. 3) marks the eastern boundary of the Caribbean Plate, which is underthrust by the oceanic crust of the western central Atlantic Ocean along a westward-dipping subduction zone. To the north, the axis of the arc coincides with structures offshore north of Puerto Rico; on the southern extremity, the trench is infilled by large detrital deposits from the South American rivers.

Between Grenada and Venezuela, calc-alkaline metavolcanics yielded a K/Ar age of about 45 Ma (Santamaria and Schubert, 1974) which suggests that the southern tip of the older arc of the Lesser Antilles may have extended, in middle Eocene, about 150 km beyond Grenada (Bouysse and others, 1990). From Martinique northwards, the older eastern arc segment is separated from the recent arc segment by a 50-km-wide depression (Germa and others, 2011). The westward shift in the axis of arc volcanism from the older to recent arcs has been ascribed to initiation of new subducting slabs that developed as buoyant aseismic ridges on the North American Plate attempted to subduct beneath the Lesser Antilles Arc (Bousse and Westercamp, 1990). Alternatively, Roobol and Smith (2004) suggested that in the southern part of the Lesser Antilles Arc interaction with the continental margin of South America interfered with eastward movement of the Caribbean Plate and produced a change in the focus of arc volcanism. Recent studies on Martinique, which preserves the most complete record of Lesser Antilles Arc development, support an interpretation of westward migration of subduction away from the trench related to slab flattening that resulted from aseismic ridge subduction in the northern part of the arc (Germa and others, 2011). Three distinct (older to the east, intermediate, recent to the west) nonoverlapping stages of arc development are preserved on Martinique. South of Martinique, volcanic arc activity essentially has occurred along a single arc trajectory from the Oligocene onward, so younger arc rocks are superimposed on the older arc.

Geologic Criteria

The Lesser Antilles tract was constructed using the 1:500,000 digital geologic map of the Caribbean Basin (available for purchase at http://www.cbmap.net/), the geodatabase included in the energy assessment of the Caribbean Region (French and Schenk, 2004), and several island-specific maps in ArcGIS to identify areas of permissive rock types. Attribute tables associated with those maps provided information on lithologic assemblages containing rocks of the appropriate age and composition to be included in this permissive tract (fig. E2). Using GIS queries, appropriate map units were selected; lithologic assemblages not considered permissive by reason of age or composition were excluded. Cenozoic volcanic arc rocks include a dominantly low-K andesite suite, with minor dacite, on the northern islands (Saba to Montserrat) and a medium-K suite, with andesite, some basalt and dacite, and rare rhyolite on the central islands (Guadeloupe to Saint Lucia); Cenozoic volcanism in the southernmost islands of the arc is mainly basalt and basaltic andesite (Macdonald and others, 2000). The older arc rocks exposed on the northern islands of Saint Barthélemy and Saint Martin include intrusive stocks and dikes of quartz microdiorite porphyry as well as andesite and andesite porphyry (Christman, 1953).

Digital geologic map units that include polygons assigned to this permissive tract are listed in table E2. Areas of permissive rock where porphyry copper deposits could be present under shallow cover (less than 1 km thick) were defined by creating a 2-km buffer around appropriate volcanic rocks. Larger scale (1:250,000) geologic maps and literature were consulted and used to check map unit boundaries, ages, and structures (Bouysse and others, 1985; Westercamp and Tazieff, 1980; Westercamp and others, 1985). Tract boundaries were clipped along coastlines using the accepted international boundaries for the project (U.S. Department of State, 2009).

Known Deposits

No porphyry copper deposits are known within the tract.

Prospects, Mineral Occurrences, and Related Deposit Types

No significant porphyry copper prospects are found on the Lesser Antilles islands. However, several minor high-sulfidation prospects occur on Montserrat, Saint Kitts and Nevis, and Saint Lucia; Cu-Au skarn prospects occur on Grenada, Saint Barthélemy, and Saint Martin (Christman, 1953; Martin-Kaye, 1955; Solomiac, 1974; Hutton, 1978; Westercamp and Andreieff, 1983; Maassen and others, 1984; McKelvey, 1995). Unnamed Fe-Au skarn prospects occur on Guadeloupe Island where a reported porphyry prospect was explored by the government (McKelvey, 1995).

On Saint Barthélemy, carbonate-rich units are intruded by latite and rhyolite intrusions and domes with contact areas of hornfels and epidote-chlorite-biotite skarns ranging from several square meters to 2 km^2. Gold (up to 1 ppm), silver (3.5 ppm), copper (200 ppm), lead (5,030 ppm), and zinc (174 ppm) are reported from samples in highly fractured outcrops (McKelvey, 1995). On Saint Martin, roughly 20 km^2 of exposed quartz diorite is shown on geologic maps, and several studies focusing on fossil hydrothermal systems associated with magmatic activity on the island note the comparable size (several km^2) of these systems with porphyry copper deposits (Westercamp and Tazieff, 1980; Reynal de Saint-Michel, 1965). Beaufort and others (1990) noted that the mineralogy, chemistry, and spatial distribution of the hydrothermal assemblages observed in Saint Martin are comparable with porphyry systems. This fossil geothermal system contained disseminated chalcopyrite, pyrite, and magnetite associated with K-silicates—components of mineralization typical of porphyry copper systems.

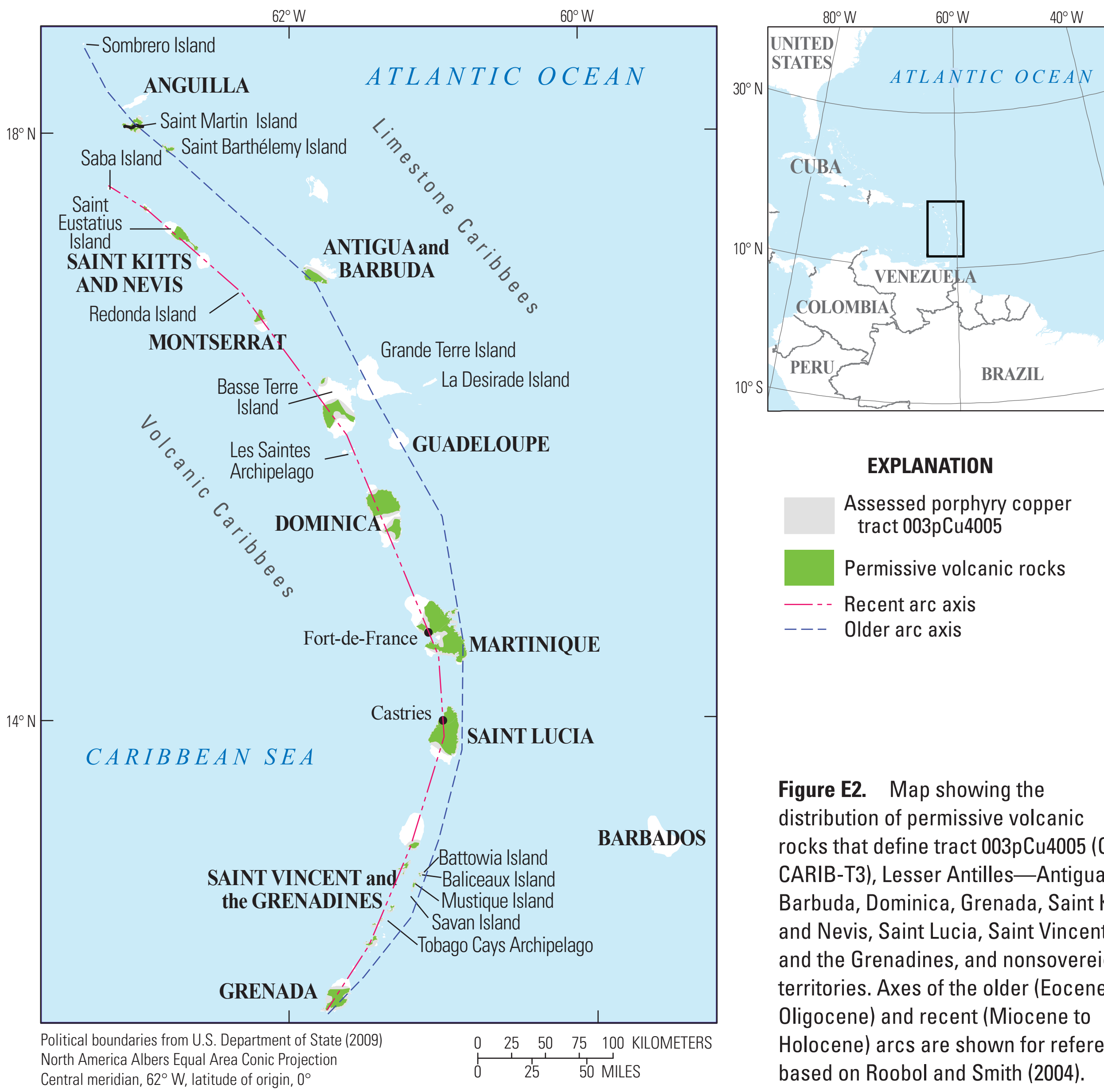

Figure E2. Map showing the distribution of permissive volcanic rocks that define tract 003pCu4005 (CA_CARIB-T3), Lesser Antilles—Antigua and Barbuda, Dominica, Grenada, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, and nonsovereign territories. Axes of the older (Eocene-Oligocene) and recent (Miocene to Holocene) arcs are shown for reference, based on Roobol and Smith (2004).

Table E3. Principal sources of information used for tract 003pCu4005 (CA_CARIB-T3), Lesser Antilles—Antigua and Barbuda, Dominica, Grenada, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, and nonsovereign territories.

[NA, not applicable]

Theme	Name or title	Scale	Citation
Geology	CBMap—Digital geologic map of the Caribbean Basin	1:500,000	Available for purchase at http://www.cbmap.net/
	Geological map of Saba Island	1:10,000	Roobol and Smith (2004)
	Geological map of Dominica	1:100,000	Roobol and Smith (2004)
	Geological map of Saint Eustatius	1:20,000	Roobol and Smith (2004)
	Geologic map of Saint Vincent	NA	Robertson (2003)
	Map showing geology, oil and gas fields, and geologic provinces of the Caribbean region	1:2,500,000	French and Schenk (2004)
Mineral occurrences	Porphyry copper deposits of the world—Database, map, and grade and tonnage models	NA	Singer and others (2008)
	CBMap—Digital geologic map of the Caribbean Basin	1:500,000	Available for purchase at http://www.cbmap.net/
	Map showing geology, oil and gas fields, and geologic provinces of the caribbean region	1:2,500,000	French and Schenk (2004)
	U.S. Geological Survey Mineral Resources Data System	NA	U.S. Geological Survey (2005)

Exploration History

Sparse exploration for porphyry copper deposits has occurred in the Lesser Antilles. Examination of the volcano-sedimentary environments of the islands shows that high-level epithermal hydrothermal systems are present on many of the islands. Active tectonism may have resulted in uplift to reveal deeper levels of exposure of subvolcanic rocks, especially in the uplifted northeastern parts of the Lesser Antilles Arc.

Sources of Information

Principal sources of information used by the assessment team are listed in table E3.

Grade and Tonnage Model Selection

The porphyry Cu-Au subtype model (Singer and others, 2008) was selected to assess the undiscovered resources associated with porphyry copper deposits in the Lesser Antilles tract based on the gold-rich nature of epithermal systems and geologic characteristics of the magmatic arc. The arc developed on oceanic crust in a subduction setting which largely lacked influence from continental crust or sediments derived from continental crust; these types of arc settings tend to produce gold-rich porphyry systems.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Parts of the Lesser Antilles arc should be favorable for the porphyry Cu-Au subtype model, where porphyry deposits may be present at shallow levels (1–3 km depth). A few high-sulfidation centers may have porphyry system roots. Uplift and erosion of volcanic centers on a few islands have exposed porphyry dikes, stocks, alteration, and geochemical anomalies that are prospective for porphyry mineralization—mainly in the northern part of the arc. With no known deposits or porphyry prospects, the team estimated a 50-percent chance of one, a 10-percent chance of two or more deposits, and a 5-percent chance of three or more deposits[5]. The expected number of deposits based on the estimates is one, with a high coefficient of variation (C_v%=91), reflecting the team's uncertainty about the area (table E4).

[5]The estimate was carried out to the 5-percent level to provide three non-zero numbers for simulation.

Table E4. Undiscovered deposit estimates and deposit numbers, for tract 003pCu4005 (CA_CARIB-T3), Lesser Antilles—Antigua and Barbuda, Barbados, Dominica, Grenada, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, and nonsovereign territories.

[N_{xx}, estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; *s*, standard deviation; C_v%, coefficient of variance; N_{known}, number of known deposits in the tract that are included in the grade and tonnage model; N_{total}, total of expected number of deposits plus known deposits; km², square kilometers; N_{total}/100k km², deposit density reported as the total number of deposits per 100,000 km². N_{und}, *s*, and C_v% are calculated using a regression equation (Singer and Menzie, 2005)]

Consensus undiscovered deposit estimates					Summary statistics					Tract are (km²)	Deposit density (N_{total}/100k km²)
N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	*s*	C_v%	N_{known}	N_{total}		
0	1	2	3	3	1.1	0.98	91	0	1.1	2,980	37

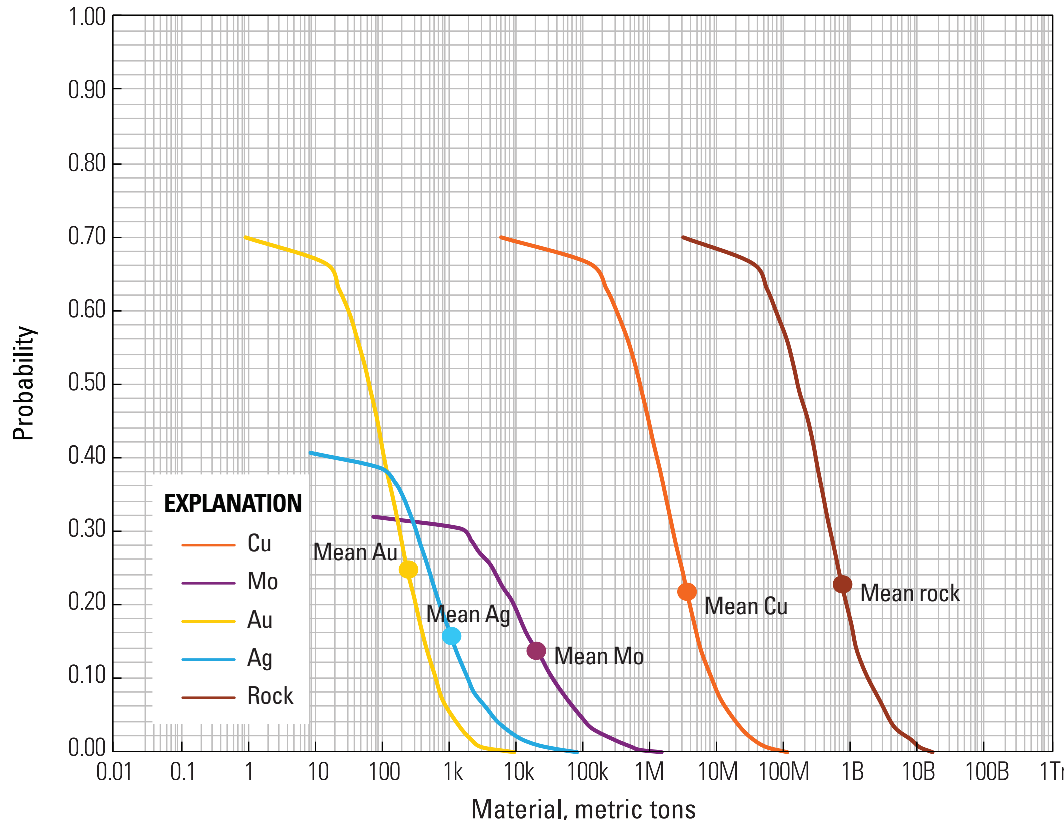

Figure E3. Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources for tract 003pCu4005 (CA_CARIB-T3), Lesser Antilles—Antigua and Barbuda, Dominica, Grenada, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, and nonsovereign territories. k, thousands; M, millions; B, billions; Tr, trillions.

Probabilistic Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered porphyry copper deposits with the porphyry Cu-Au model of Singer and others (2008) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, 2012; Duval, 2012). Selected simulation results are reported in table E5. Results of the Monte Carlo simulation are presented as a cumulative frequency plot (fig. E3). The cumulative frequency plot shows the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

Table E5. Results of Monte Carlo simulations of undiscovered resources for tract 003pCu4005 (CA_CARIB-T3), Lesser Antilles—Antigua and Barbuda, Dominica, Grenada, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, and nonsovereign territories.

[Cu, copper; Mo, molybdenum; Au, gold; and Ag, silver; t, metric tons; Mt, million metric tons]

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	0	0	670,000	7,900,000	15,000,000	3,300,000	0.22	0.3
Mo (t)	0	0	0	36,000	87,000	19,000	0.14	0.68
Au (t)	0	0	64	630	1,000	240	0.25	0.3
Ag (t)	0	0	0	1,900	4,500	1,100	0.16	0.59
Rock (Mt)	0	0	150	1,700	3,200	680	0.23	0.3

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Appendix F. Description of GIS Files

Three Esri shapefiles (.shp), a geodatabase (.gdb), and an Esri map document (.mxd) are included with this report. These may be downloaded from the USGS Web site as zipped file **GIS_SIR5090-I.zip**.

The shapefiles are as follows:

CentAm_Carib_pCu_Tracts.shp is a shapefile of the permissive tracts. Attributes include the tract identifiers, tract name, a brief description of the basis for tract delineation, and assessment results. Attributes are defined in the metadata that accompanies the shapefile.

CentAm_Carib_pCu_Deposits_prospects.shp is a shapefile of point locations for known deposits (identified resources that have well-defined tonnage and copper grade) and prospects. The deposits are listed in table 1 of this report. Shapefile attributes include the assigned tract, alternate site names, information on grades and tonnages, age, mineralogy, associated igneous rocks, site status, comments fields, data sources, and references. Attributes are defined in the metadata that accompanies the shapefile.

CentAm_Carib_political_boundaries.shp is a shapefile showing the outline of the study area and the countries within and adjacent to the study area. Tract boundaries were clipped to shorelines to eliminate undersea areas using small-scale digital international land boundary polygon files from the U.S. Department of State (2009), which incorporate high tide coastline data from the U.S. National Geospatial-Intelligence Agency's World Vector Shoreline[1] dataset.

These three shapefiles are included in an Esri map document (version 9.3): **CentAm_Carib_pCu.mxd**.

Probabilistic assessment results are included in two tables that can be related in the GIS project; an Excel version of these tables is provided as **CentAm_Carib_Results table.xlsx**. The **Mean** worksheet shows the mean amount for each commodity by tract. The **Quantiles** worksheet shows probabilistic assessment results as quantiles for commodity by tract.

An Excel file version of the deposits and prospects data is also included as **CentAm_Carib_Deposits_prospects.xlsx**.

The geodatabase **CentAm_Carib_pCu.gdb** contains the feature classes for the tracts, deposits and prospects, and political boundaries.

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[1]*http://shoreline.noaa.gov/data/datasheets/wvs.html*.

Appendix G. Assessment Team

Floyd Gray is a research geologist with the USGS in Tucson, Arizona. He received a B.A. in earth science and anthropology from the University of California, Santa Cruz (1976), and an M.S. in geology from the University of Massachusetts, Amherst (1982). Floyd has experience in economic geology, geoenvironmental characterization and analysis of watershed processes, mineral and interdisciplinary natural resource assessment, and modeling of geospatial data. He was Mission Chief for the USGS Venezuelan Cooperative project, an assessment study of the Precambrian Shield area of Venezuela. He has conducted metallic mineral resource assessments and wilderness studies (including gold, chromium, platinum group elements, and copper) in Oregon, California, and Arizona, and interdisciplinary natural resource assessments in the United States-Mexico borderlands.

Jane M. Hammarstrom is a research geologist with the USGS in Reston, Virginia. She received a B.S. in geology from George Washington University (1972) and an M.S. in geology from Virginia Polytechnic Institute and State University (1981). She is cochief of the USGS Global Mineral Resource Assessment project and the task leader for the porphyry copper assessment. Jane has more than 30 years of research experience in igneous petrology, mineralogy, geochemistry, economic geology, and mineral resource assessment.

Steve Ludington is a research geologist with the USGS in Menlo Park, California. He received a B.A. in geology from Stanford University (1967) and a Ph.D. in geology from the University of Colorado (1974). He worked as an exploration geologist in Colorado, New Mexico, and Arizona before joining the USGS in 1974. His work with the USGS has included regional geologic studies, metallogenic and geochemical studies, wilderness studies, and mineral-resource assessments. He has done mineral-resource assessment work in the United States, Costa Rica, Bolivia, Mongolia, Afghanistan, and Mexico and was a coordinator for the 1998 USGS National Mineral Resource Assessment.

Lukas Zürcher is a research geologist with the USGS in Tucson, Arizona. He received a B.S. in geological engineering from the Colorado School of Mines (1985) and an M.S. and a Ph.D. in geosciences from the University of Arizona (in 1994 and 2002, respectively). He worked as an exploration and consulting geologist for the mining industry in Mexico, Cote d'Ivoire, Bolivia, Argentina, and the United States (1985–2010), as a postdoctoral fellow in the Department of Lunar and Planetary Sciences (2002–2005) and as Manager of the Lowell Program in Economic Geology (2002–2011) at the University of Arizona before joining the USGS in 2011. He has 25 years of combined industry and academic experience in geologic, alteration, and mineralization mapping, structural geology, igneous and hydrothermal geochemistry, statistical methods, mineral economics, and GIS-based favorability mapping. His research has included local- to regional-scale geologic, geochemical, and metallogenic studies of intrusion-related, impact-generated, and IOCG hydrothermal systems, as well as comparative analyses of favorability mapping methods. With the USGS, he has contributed to the porphyry copper resource assessments of Mexico, Central America and the Caribbean, and the Central Tethys region.

Carl E. Nelson is a consulting geologist and president of Recursos del Caribe, S.A., a consulting firm focused on Central America and the Greater Antilles. He received a B.A. in geology from Amherst College (1973) and an M.A. in geology from Dartmouth College (1975). He did postgraduate studies in metamorphic petrology at University of California, Los Angeles, and, during 1987–1988, held a Fulbright Faculty Research Grant to the School of Geology, University of Costa Rica. He worked as an exploration geologist for Anaconda Copper Company and Homestake Mining Company (1975–1982) before launching his consulting career first in the Circum-Pacific region (1982–1986) and later in the Caribbean Basin (1987 to present).

Gilpin R. Robinson, Jr. is a research geologist with the USGS in Reston, Virginia. He received a B.S. in geology from Tufts University (1973) and a Ph.D. in geology from Harvard University (1979). He is a geologist, geochemist, and mineral resources specialist working on mineral-resource assessment and other projects, including geologic mapping, studies of the origin and genesis of metal and industrial mineral deposits, and geochemical modeling.

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